

The Analysis of the Impact of Urbanization on Urban Meteorology from Urban Growth Management Perspective

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Abstract—The amount of urban artificial heat which affects the urban temperature rise in urban meteorology was investigated in order to clarify the relationships between urbanization and urban meteorology in this study.

The results of calculation to identify how urban temperature was increased through the establishment of a model for measuring the amount of urban artificial heat and theoretical testing revealed that the amount of urban artificial heat increased urban temperature by plus or minus 0.23 °C in 2007 compared with 1996, statistical methods (correlation and regression analysis) to clarify the relationships between urbanization and urban weather were as follows.

New design techniques and urban growth management are necessary from urban growth management point of view suggested from this research at city design phase to decrease urban temperature rise and urban torrential rain which can produce urban disaster in terms of urban meteorology by urbanization.

Keywords—The amount of urban artificial heat, Urban growth management, Urbanization, Urban meteorology

I. INTRODUCTION

THE goal of this study is to understand the changes in urban meteorology resulted from the impact of urbanization on urban meteorology from urban growth management point of view. Urbanization not only results in a sense of incompatibility and growth gap between regions, which is both social and economic problem, shortage of houses and production of illegal houses by the urban poor, deterioration of downtown, traffic congestion and water shortage, waste disposal and environmental destruction, but also results in the changes in available land area according to the changes in land usage plan, the increase in the size and the number of floors of residential, commercial, education and research, public buildings or buildings for other purposes, affecting the changes in urban meteorology, which is a natural phenomenon caused by energy increase for each purpose [4, 5].

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Such changes in urban meteorology threatens the lives of city dwellers seeking a pleasant city life by producing adverse influence on urban meteorology by triggering heat island phenomenon derived from urban artificial heat, blocking natural air flow while increasing aerosol and CO₂ coming from driving transportation vehicles, etc. and the urban heat island phenomenon within downtown also affects the health of city dwellers.

Such urbanization also affects urban disasters: according to the studies of SDI (Seoul Development Institute), annual average damages that Seoul alone had for last 10 years (1988-2007) were 61,955 (170 people a day) casualties, property damage of 34.6 billion won, and 23 casualties and property damage of 10.3 billion won were caused by floods, and the characteristics of damages showed that large floods were decreased while damages caused by flooding in lowlands and riverside areas are occurring repeatedly, hence, the impact of urbanization is becoming an urban disaster beyond a natural disaster.

II. SCOPE OF STUDY

The scope of this study covers the performance of correlation analysis and regression analysis as analysis methods of statistics over the target areas after obtaining the amount of urban artificial heat by calculation with a model.

The spatial range of target areas are limited to 5 cities out of 9 points -Gangneung (105), Seoul (108), Seosan (129), Pohang (138), Gunsan (140), Jinju (192), Cheonan (232), Boryeong (235), Milyang (288)-while excluding Seosan (129) and Milyang (288) where missing values were found in the data of urban statistics.

Target areas should be limited to the points of the following conditions where observation equipments were installed on grass 30 m below sea level to simulate the conditions to avoid the possibility of occurring errors due to installed locations of observation equipments

- 1) Target observation points are restricted to the points 30 m below sea level, (the amount of precipitation may vary according to the height of an observation point; and, because of evaporation, the higher an observation point is, the more precipitation it gets, and vice versa)
- 2) Environmental condition of target observation points were restricted to the points on grass, (as environmental conditions of observation points affect the measurement of temperature, the points where such influence was

minimized were selected)

- 3) Due to the limitations of this study, amount of clouds will be excluded though it affects precipitation directly, and the analysis on aerosol out of urban factors will be also excluded as no such analysis will be performed.

The target of analysis in time range covers meteorological data2) such as daily precipitation, average daily temperature, the highest daily temperature from July to September (summer season) between 1971 and 2009 and urban statistical data from 1971 to 2007 [7].

This study cannot reflect the differences by latitude and the differences of oceanic and continental climate according to the position of each observation point.

In addition, the impact of urban planning facilities such as drainage facilities and water tank, etc. installed to reduce urban disasters derived from urban heavy rainfall were excluded.

As urban factors, in order to maintain the consistency in data collection for this paper, the number of households, demography, population growth, road growth, road pavement rate in 5 cities provided by Korea National Statistical Office, and from the number of households by the number of floor, area, use, and energy consumption of buildings in Seoul, power consumption was selected for analysis.

III. GOAL OF STUDY

The goal of this study is to provide city dwellers with pleasant and safe living conditions by suggesting solutions for 'abatement' or 'reduction' of the impact of urbanization on urban meteorology from urban growth management point of view while revealing the correlations between cities and urban factors focused on precipitation, average temperature, the highest temperature among urban meteorology in summer between June to September over the target areas after calculating urban artificial heat through a model so as to identify what affects urban meteorology [14, 16, 17]. In addition, how to manage a city is going to be suggested from urban growth management point of view through urban artificial heat generation model; and, factors correlated to urban meteorology, regression equation, and general correlations between city and urban meteorology are to be found out targeting 5 cities based on the analysis results of target areas by setting urban factors as dependant variables; particularly, the analysis on correlations between city and urban meteorology will be centered on Seoul where the most rapid urbanization, urban problems, and urban meteorology changes have been occurred, setting power consumption by use, area, number of buildings to independent variables [6, 11].

IV. HYPOTHESIS OF STUDY

The following hypotheses have been developed to find out which factors of urbanization are affecting the changes in urban meteorology:

Hypothesis 1: Urbanization has more impact on urban meteorology of urban areas than rural areas.

Hypothesis 1-1 Generation of urban artificial heat increases

urban temperature.

Hypothesis 1-1 can be expressed as the following research model.

Hourly artificial heat generation per each unit residential building

$HB_{yr} = D \times Z\gamma$ (monthly average of 4 months from July to September in base year, 1996)

Hourly artificial heat generation per each school building

$HB_{ys} = D \times Z\gamma$ (monthly average of 4 months from July to September in base year, 1996)

Total artificial heat generation is $TSHB = (HB_{r} 2,500unit) + HB_{s}$

TSHB is total artificial heat generation

HB_{s} is yearly artificial heat per each purpose of buildings (MJ/m/year)

D is floor area per each purpose of buildings

Z is yearly energy consumption unit per each purpose of buildings (MJ/m/year)

Hypothesis 1-2. The degree of increased urban temperature resulted from the generation of urban artificial heat is measurable.

Hypothesis 1-2 can be expressed as the following theoretical model.

"Heat radiated from human body

$He = keAC(Te - Ta)$

Heat generation by radiation

$H1 = krAres(Ts - Tr)$

Heat generation from oil products among fossil fuels + heat generation from gas products

Heat generation by power consumption"

Hypothesis 2: urban meteorology changes can be reduced or abated from urban growth management point of view.

Hypothesis 3: The correlations between urbanization and urban meteorology can be clarified using statistical methods.

Hypothesis 3-1 There are some correlations between urbanization factors and urban meteorology.

Hypothesis 3-2 The relationships between urbanization factors and urban meteorology can be clarified by regression equation.

V. PREVIOUS STUDIES

Jaesik Roh suggested a model which can calculate the amount of artificial heat in a city in his paper, and the model is as follows.

"Heat released from human body"(Giyong Nam et al. 1970; quoted. Jaesik Roh, 1973, 56-57)

" $He = keAC(Te - Ta)$ "

"Amount of heat by radiation"

" $H1 = krAres(Ts - Tr)$ "

"Amount of heat generated from oil-type fossil fuel + heat emission from anthracite"

"Amount of heat generated from electricity consumption"

In this paper, the amount of urban artificial heat is going to be obtained by establishing a model of urban artificial heat and testing of Jaesik Roh's theory and the data acquired from chapter 3 will be analyzed [1, 15, 18].

According to analysis results-the amount of precipitation for last 32 years, monthly rainfall frequency, rainfall frequency in summer-on occurrence of urban disasters caused by urbanization, which is one of the main factors affecting urban meteorology and natural factors influenced the flooding of urban areas the most; [16] however, the most influential factor except for natural factors was proved to be land utilization area due to urbanization, and it means that urban land utilization area is also playing important role in increasing flooding in urban areas as an element of urbanization; therefore, it suggests that the impact of urbanization is connected not only to natural disasters but also to urban disasters [2, 9, 12].

In addition, he empirically demonstrated that concentrated development on central area was more useful for the reduction of flooding than scattered development over broader areas while using the other areas as open spaces; and he also argued that turning the other areas into permeable layers was more important than increasing impermeable layers for the construction of buildings and road pavement; [13] and, to reduce the impact of urbanization on urban meteorology from urban growth management point of view, which is what the research methods in chapter 3 and the analysis results in chapter 4 of this paper are trying to reveal, the concept of compact city, which is a urban development method of reducing the building-to-land ratio while increasing floor area ratio, could be connected with; moreover, as a high density development may not always increase the danger of flooding, it is suggested that urban disasters can be rather reduced if the city is growing smart.

VI. ESTABLISHMENT OF URBAN ARTIFICIAL HEAT GENERATION MODEL

To find out the impact of urbanization on urban meteorology from urban growth management point of view, the difference in the generated amount of artificial heat according to the conditions of city planning (the building-to-land ratio, floor area ratio, the number of floor, the number of buildings) is going to be calculated, and prerequisites and the equation are as follows (Eunha Son, 2003, 37-47).

Designing a city on the virtual construction site with the size of community residential unit of 1km * 1km area and of the height of 1km under the assumption that the number of households is 2,500 and total building area of 250,000m² is required, the amount of artificial heat is going to be obtained through the studies of the following two cases.

A. Case 1) Housing type is detached house - Sblld Case.

Prerequisites : Required residential area by each household 100m²,

Site area per parcel 250m², Number of parcels 2,500, The building-to-land ratio 20%, Floor area 40%, Limits on the number of floors: below 2nd floor, The percentage of paved roads 10%,

Construction of an elementary school by the size of 24 classes (plottage 15,000m², building area 10,000m²),

The ratio of parks and green belts 26.0%

Classification of areas accorRoad 100,000 m², Site for elementary school 15,000m²

Parks and green ding to land utilization plan

- belts 260,000m², plot 625,000m²

Calculation of the building size by each household

- Construction area 50m²,

Gross area (6.2m × 8.0m × 2 floors + Porch 0.8 = 100m²), The height of each floor 3m.

Hourly artificial heat generation of unit residential buildings

$HB_{yr} = D \times Z\gamma$ (monthly average of 4 base years from July, 1996 to September)

Hourly artificial heat generation of school buildings

$HB_{ys} = D \times Z\gamma$ (monthly average of 4 base years from July, 1996 to September)

Total amount of artificial heat is $TSHB\gamma = (HB_{yr} \times 2,500\text{unit}) + HB_{ys}$

THBy is total amount of artificial heat.

HB_y is yearly amount of artificial heat by the purpose of each building (MJ/m²/year),

D is the floor area by the purpose of each building,

Zγ is yearly energy consumption unit of buildings per each purpose (MJ/m²/year)



Fig. 1 A diagram of model case 1 land utilization plan.

B. Case 2) Housing type is complex house-Mbld Case.

Prerequisites: Required residential area per each household 100m²,

Site area per each parcel 1,000m², The number of parcels 32,
The building-to-land ratio 60%,

Floor area ratio 1,200%, Limitation on the number of floors:
below 20th floor, Paved road rate 10%,

Construction of an elementary school by the size of 24
classes (site area 15,000m², gross area 10,000m²),

Percentage of parks and green belts 85.3%

Classification of areas according to land utilization plan:

Road 100,000 m², Site for the elementary school 15,000m²,

Parks and green belts 853,000m², Site 32,000m²,

Calculation of the size of each building:

construction area 400m², Gross area (10.0m × 40.0m × 20
floors = 8,000m²), Floor height 3m.

In other words, 80 households are living in a building and the
area allocated to each household is 100m²; and, as there are
31.25 such buildings, it means living in high density.

" Hourly artificial heat generation from 1 building

$HB_{yr} = D \times Z\gamma$ (monthly average of 4 base years from July,
1996 to September)

Hourly artificial heat generation of a school building

$HB_{ys} = D \times Z\gamma$ (monthly average of 4 base years from July,
1996 to September)

Total amount of generated artificial heat is $TMHB_{\gamma} =$

$(HB_{yr} \times 2,500\text{unit}) + HB_{ys}$

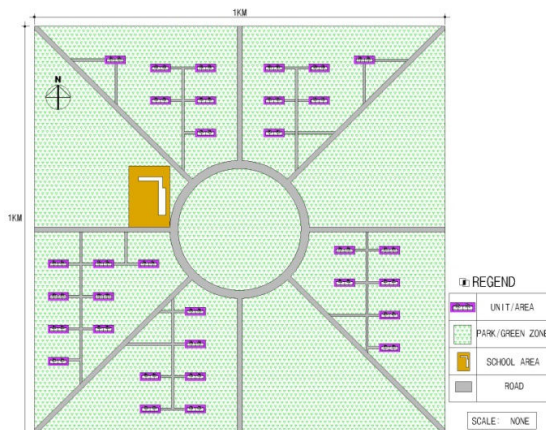


Fig. 2 A diagram of model case 2 land utilization plan

VII. THEORETICAL TESTING METHOD

Theoretical testing through calculation of artificial heat
generation model is going to be performed on the theoretical
basis with a series of equations which were originally suggested
by Jaesik Roh in his paper and partially modified and
supplemented for the purpose of this study, and the equations
for the calculation of artificial heat generation are as follows:

A. Heat radiated from human body

1. Heat generation by convection

$$H_e = kcAC(T_s - T_a)$$

H_e (kcal m² hr⁻¹ C⁻¹) : heat generation ratio from human body
by convection

kc : convection coefficient (If average wind speed is 9cm
sec⁻¹, kc is assumed to be 6 kcal m² hr⁻¹)

T_s : skin temperature (exposed skin temperature : 32°C)

T_a : temperature of ambient air

AC : exposed skin area (normally 1.4m²)

2. Heat generation by radiation"

$$H_r = krA_{ces}(T_s - T_r)$$

H_r : heat generation ratio by radiation

kr : radiation coefficient (relatively constant value 7.0 kcal
m² hr⁻¹ C⁻¹)

AC : Surface area of radiation, that is, exposed skin area
(usually 1.4m²)

e_s : emission rate from surface, in case of human body,
approximately 0.98

T_s : skin temperature (exposed skin temperature: 32°C)

T_r : temperature of nearby objects to which heat is radiated

B. Heat generation of oil-type fossil fuels

Oil consumption in Seoul for the year

$$= [(oil\ consumption\ of\ the\ year \div 1,000) * 158.9\ k\ell] * 0.87 * 10\ kcal$$

Average calories per hour =

$$oil\ consumption\ in\ Seoul\ for\ the\ year \div (365 * 24hr)$$

* Average percentage of fuel 0.87, Average calories per g
are 10.0 kcal *

C. Heat generation by natural gas

Natural gas consumption in Seoul for the year

= once gas consumption of the year * 10³ is translated into
hourly consumption,

$$= gas\ consumption\ of\ the\ year \div (365 * 24hr)$$

As the amount of generated heat per LNG 1Nm³ is 10,500
kcal,

Hourly heat generation = Hourly consumption for the year *
10,500 kcal /Nm³

D. Heat generation by electricity consumption

Average hourly electricity consumption in Seoul for the year
is

$$= electricity\ consumption\ in\ Seoul\ of\ the\ year \div (365 * 24hr)$$

Hourly heat generation

= Average electricity consumption per hour * 0.86kcal /kWh

Heat generation per kWh is 0.86 kcal /kWh

Total amount of generated artificial heat in Seoul for the year is

$$HTOTAL_{96} = H\sum_{96} + HLNG$$

Heat capacity of air 1m³ is 3.1 * 10² cal m⁻³ C⁻¹; however, if one considers urban plan area of Seoul (605.95km²) is located at the height of 37m, which was obtained by subtracting downtown (average altitude 50m) from observation point (altitude 87m), total heat capacity of significance equals 605.95 km² * 37M * 3.1 * 10² cal m⁻³ C⁻¹ = 6.95 * 10⁹ kcal C⁻¹.

VIII. METHODS OF ANALYSIS

In this section, city and urban meteorological data of 5 cities, the time and spatial target range of this study for last 39 years from 1971 to 2009, are going to be analyzed in order to analyze the relations between city and urban meteorology; moreover, 1971 was set as the base year for the targets of the analysis; and, setting the data of year 1971 is to base '1', variations on the data of compared years were translated into variations in time series and the variations were used as the target data of the analysis; therefore, correlation and regression analysis on that data will be conducted using a statistics program, SPSS17.

In particular, regression equations are going to be obtained by regression analysis independent variables of which are the data of Seoul and the data collected additionally as the number of the buildings per area, use, the number of floor and dependant variables of which are energy consumption and the increase rate of precipitation and the increase rate of average temperate.

As explained in the previous section, the amount of generated artificial heat was calculated by analyzing the case studies composed of two virtual sites of the size of community residential unit (1km * 1km and 1km in height) so as to reveal which urban planning condition (the building-to-land ratio, floor area ratio, the number of floor, the number buildings) is affecting urban meteorology in order to create a urban artificial heat generation model in chapter 4; and, urban temperature rise will be actually calculated by centigrade degree using the city and urban meteorological data of 1996 and 2007 (when city statistics data of Seoul was available) to theoretically test the increase rate of urban temperature caused by artificial heat generation based on the theory presented in the paper of Jaesik Roh [1].

IX. RESULTS OF URBAN ARTIFICIAL HEAT RELEASE ANALYSES

As a result of urban artificial heat generation analyses using models, it was found that multi-storied and high-density TMHB γ was bigger than TSHBY and the difference was 0.037 °C - 0.035 °C = 0.002 °C, which is small enough to be neglected, when calculating the artificial heat generation amounts simply

considering building floor area sizes in the two cases. However, if the numbers are converted to reflect the administrative area size in Seoul, the temperature difference will be 0.002 °C * 605.95km² = 1.2 °C.

If the latent heat held by buildings is released from the outside of the buildings, more artificial heat is released toward the atmosphere in the Case 1 because the total outside area size in the Case (551,000m²) is twice bigger than that in the Case2(204,800m²). From an energy-saving perspective as well, the thermal energy loss in the Case 1 is bigger due to the total area facing the outside atmosphere is more than twice bigger in the Case 1.

Also, the park and green area ratio in the Case 1 is 26.0% while that in the Case 2 is 85.3%, which means in the Case 2 land use plans to ensure a more than three times bigger green area is allowed.

Even though the road coverage ratio is equally 10% in both cases, in the Case 2 urban temperature increases due to paved roads can be reduced because in the Case 1 each single-family house should face a road separately while in the Case 2 only the main exit connected to building on the land can face a road and therefore less roads are needed in the Case 2.

Hence, it is found that design techniques to reduce building coverage ratios and increase floor area ratios are needed to diminish the influence of urban growth management on urban meteorology.

In the theoretical validation part of the present study, the present study partially modified and adjusted a series of formulas suggested by Jaesik Roh in his paper, in accordance with the research objectives of the present study, and then analyzed the correlation between urban artificial heat generations and temperature rises. The year 1996 and the year 2007 were compared in terms of artificial heat generation in a city, namely heat releases from human bodies, petroleum-related heat releases among fossil fuel-related heat releases, heat releases caused by LNG consumption and heat releases caused by electricity consumption, by measuring the actual temperature rises.

Among research analysis target factors, the urban factor that contributes to the urban temperature rises the most was human body heat releases, and they were followed by heat releases caused by LNG consumption.

As a result, the summer temperature in 2007 was raised by around 3.0-2.77 = 0.23°C from that in 1996. In the present study, the difference between the summer 6 ~ 9AVTA of the two periods, 23.675°C(1996) - 23.85 (2007) = 0.175 °C, and the above-mentioned summer temperature increase was only 0.23 °C - 0.175 °C = 0.05 °C.

X. CORRELATION AND REGRESSION ANALYSIS RESULTS

In the analysis of the correlation between urbanization factors and urban meteorology factors in 5 cities, it was found

that urban factors PINS, RINS and RPINS were positively and significantly correlated to 20mm RNINS in Gangneung.

In Seoul, urban factors RINS, RPINS and WINS were found to be significantly correlated to climate factors 50mm and 100mmRNINS, 6AVTAINS and 8AVTAINS.

In Pohang, urban factors PINS and WINS were significantly correlated to climate factors 30mm and 50mmRNINS, 6, 9AVTAINS, and 8MAXTAINS.

In Gunsan, unlike Pohang and Gangneung that had the same kind of marine climates, less significant urban-climate correlation factors were examined.

In Jinju, an inland city, in terms of the correlation between urban factors and climate factors, S was positively correlated to 8RNINS by .495* and to 6-9RNINS by .472*.. Other than that, there was no significant correlation found.

The present study performed regression analyses between urban factors and climate factors of each of the five city during the target research period. However, there was no noticeably statistically significant regression analysis result found.

Nevertheless, in summer in Seoul, 7MAXTAINS and CBLD, and 9AVTA and CBLD were explained to be significantly related to each other by regression equations. It provides a theoretical basis that increases in the number of commercial buildings in a city contributes to increases in the highest temperature on July in summer and the average temperature on September.

In addition, it was found that 50mmRN, which indicates the precipitation intensity as a measure of urban rainfalls, and urban factors R and RP were significantly correlated as well, which shows that road coverage ratios and road pavement ratios are related to urban rainfalls of more than 50mm.

Hence, it can be said that in Seoul the summer temperature and precipitation are statistically proven to be affected by the road coverage ratio, the road pavement ratio, and increases in the number of commercial buildings.

As a result of analyses of the correlation between urban factors and climate factors, it has been found that increases in urban factors are correlated with increases in climate factors such as temperature and precipitation.

XI. CONCLUSION

The goal of this study was to identify the relations between urbanization and urban meteorology by investigating urban artificial heat generation which affects urban temperature increase among urban meteorologies in order to figure out the impact of urbanization on urban meteorology from urban growth management point of view.

urban artificial heat generation, one of the representative features of the changes in urban meteorology caused by urbanization, clearly shows the development process of urbanization and the drastic increase of urban temperature.

In methods of study of chapter 3, the analysis results derived from analyzing artificial heat generation model and theoretical testing in chapter 4 and the analysis results of urban artificial heat generation according to model, show if the amount of artificial heat was calculated simply by floor area of buildings

in two cases, $TMHBy > TSHBy$ composed of high floor and high density, and $0.037\text{ }^{\circ}\text{C} - 0.035\text{ }^{\circ}\text{C} = 0.002\text{ }^{\circ}\text{C}$ is very small difference which can be ignored; however, once it is applied to the entire area of administrative district of Seoul, the difference in temperature becomes $0.002\text{ }^{\circ}\text{C} \times 605.95\text{ km}^2 = 1.2\text{ }^{\circ}\text{C}$.

If latent heat inside a building is emitted through external cover, the more artificial heat is released into the air than Case 1, and, in terms of energy conservation, as area adjacent to outside air is twice bigger, energy loss also gets bigger.

In addition, if parks and green zone ratio are compared with each other, Case 2 can have land utilization plan which enables three times more green zones than Case 1; and, in terms of road ratio can also be reduced in Case 2, and urban temperature rise caused by road pavement can be reduced.

Therefore, it is suggested that a new design technique that enables increasing floor area while reducing the building-to-land ratio by increasing the development density in central area and utilizing other areas as parks and green zones rather than flat urban expansion through regulations which lowers overall development density by increasing development density and utilizing other areas as open space when developing a city in order to reduce the impact of urban meteorology by urban growth management.

In theoretical testing, the differences in actual temperature increase by comparing 1996 with 2007 on the amount of heat generation by heat emitted from human body, oil-type fossil fuel, natural gas, electricity consumption were measured after analyzing the relations between urban artificial heat generation and temperature rise through partial modification of a series of equations presented in the paper of Jaesik Roh for the purpose of this study.

The most influential factor in the increase of urban temperature was heat emitted from human body, and the next most influential factor was the heat generated by natural gas.

This means that though one urban factor can produce impact, more complicated and organic relations produced from the interactions between urban factors and meteorological factors are contributing to the causes that affect on urban meteorology.

New design techniques and growth management considering urban meteorology are necessary at urban design phase to reduce or abate torrential rains and urban temperature rise which may produce urban disasters among urban meteorologies by urbanization; hence, the reduction or abatement of artificial heat generation through low energy consumption urban design, expansion of green zone, realization of compact city, and smart growth are to be expected in the future from urban growth management point of view through this study.

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