An Empirical Study on the Impacts of Urban Form, Architectural Elements, Microclimate and Natural Environment On Microscopic Surface Temperature

Yunnam Jeong, Gunwon Lee

Abstract ***This study is an examination of the impacts of urban form, architectural elements, microclimate, and the surrounding natural environment on the microscopic surface temperature of buildings, a major cause of urban heat island effect in summer. It applies urban form and tissue, major elements of the built environment, and green areas, a key component of the natural environment, as basic factors and microclimate as an interest variable. For this purpose, the surrounding temperatures of selected buildings in Seoul within a 500m radius of the 23 Automated Weather Stations (AWS), measurement points selected by the Meteorological Office, in August of 2017 were analyzed. The study employed hierarchical regression analysis using ordinary least squares (OLS). The results show that urban form and tissue mostly demonstrate a relationship with the microscopic surface temperature of buildings, as opposed to building form variables. It is also found that microclimatic elements such as temperature, wind speed, and humidity are relevant to microscopic surface temperature. This study is meaningful in that it sheds new light on the role of urban planning in reducing the urban heat island effect.***

Keywords: *Urban design, Hierarchical regression analysis, Urban heat island, Microscopic surface temperature, Urban form and tissue, Building form and envelope*

1. INTRODUCTION

In the decades following the two world wars, rapid economic growth and soaring automobile use led to skyrocketing consumption of fossil fuels. Freon gas applied as a refrigerant also became commonplace, which resulted in a decline in ozone concentration within the atmospheric ozone layer. Aggravated global warming and changes in the overall climate are the result of the above problems. There is a near-consensus that cities, the primary habitat for most humans, are a major contributor to this phenomenon, and thus addressing urban issues must be a component of the fundamental solution.

Modern cities with inefficient structures have been generating environmental impacts, such as excessive energy consumption and emission of greenhouse gases and various other pollutants. A surge in horizontal movement driven by urban sprawl and leapfrog development, increased use of energy for vertical movement resulting from overcrowded cities and the development of high-rise buildings, and excessive energy use for the maintenance and development of commercial or industrial usages are some examples.

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In particular, overcrowded buildings in cities and artificial heat emitted by them have caused congestion of artificial heat. This brings about the urban heat island effect and elevated use of cooling energy, which in turn has been exacerbating environmental problems in cities.

2. Literature review

2.1. Literature review

This study focuses on the microscopic surface temperatures of buildings, which are impacted by the physical environment of cities and buildings, such as urban form and tissue and architectural elements. Since it affects overall urban temperature and the energy consumption of buildings by influencing indoor and outdoor environment in the form of radiant heat, the microscopic surface temperature of a building is a significant factor.

Elements affecting microscopic surface temperature can be grouped into three categories: urban form and tissue; building form and envelope; and natural factors. Studies concerning this issue are characterized as follows.

The study carried out by Julie Ann Futcher and Gerald Mills (2012) offers representative research focusing on urban forms and structures. They selected three different building types, created various block structures in different combinations, and used a simulation to calculate the cooling and heating time for the respective block structures and arrangements. Reid Ewing and Fang Rong (2013) analyzed the effect of elements of urban form such as density, accessibility, and centrality on microclimate and residential choice. They then examined the effect of these variables on the energy consumption of buildings.

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Table 1: Literature review

Type	Author	Dependent variables	Independent variables
Urban Elements	Julie Ann Futcher & Gerald Mills (2012)	Building types, urban form (block structures, block arrangements)	Cooling time, Heating time
	Reid Ewing & Fang Rong (2013)	Elements of urban form (density, accessibility, centrality)	Microclimate, Residential choice
	Iain Douglas Stewart (2000)	Urban forms, land use	Temperature of artificial heat
	Taha, H. (1997)	Temperature of artificial heat, land use	Microclimate (Urban Heat Island effect)
	Barry, R.G. & R.J. Chorley (1968)	Building material, building shapes	Thermal capacity
		Thermal capacity	Air flow
	Landsberg, H. (1981)	Vegetation density, scale of park	Cooling effect of areas (Local temperature)
	Meier, A.K. (1991)	Green area (vegetation)	Cooling effect of areas (Local temperature)
	Rosenfeld A.H. et al. (1998)	Shade of roadside tree	Urban Heat Island
Building form & Cover condition	Weng et al. (2004)	Land use, land cover	Microclimate
	Weng et al. (2011)	Land use, land cover, NDVI, type of vegetation	Microclimate
	Laurence Pattacini (2012)	Building form, building type	Microclimate
	Claire Smith & Geoff Levermore (2008)	Design of urban space, design of buildings	Microclimate
	Michele Lazzarini (2011)	Form elements of buildings	Surface temperature of buildings
	Haiyong Ding & Wenzhong Shi (2013)	Land use, land cover	Urban Heat Island, Surface temperature of buildings
	Weizhong Su et al. (2010)	Land use, land cover	Urban heat island
Vegetation & Shade	T.J. Chandler & S. Gregory (1976)	Type of parks	Urban heat island
	F.G Hannel (1976)	Time	Urban heat island
	Yunnam Jeong et al. (2015)	land cover, land use	Microclimate (Wind speed, Local temperature, Surface temperature)
	Gunwon Lee & Yunnam Jeong (2017)	Urban form, land use, building form, building use, vegetation	Microclimate
		Urban form, land use, building form, building use, vegetation, microclimate	Energy consumption of Building

Iain Douglas Stewart (2000) investigated the effect of urban forms on microclimate and of microclimate on the urban heat island effect along an automobile route in Regina, the provincial capital of Saskatchewan, Canada. As for research on the effect on temperature of artificial heat resulting from land use, Taha, H. (1997) analyzed the increase in temperature due to artificial heat in the central area of major cities. Barry, R.G. and R.J. Chorley (1968) investigated various changes in temperature within a forested area in the temperate zone in order to examine the temperature-reduction effect of vegetation. Landsberg, H. (1981) also investigated the cooling effect of areas with large parks or high vegetation density. Meier, A.K. (1991) analyzed the cooling effect of green areas in hot climates, while Rosenfeld A.H. et al. (1998) examined the effects of roadside trees and other shade trees on urban heat island mitigation.

Second, research that focused on the effect of building form and cover condition on temperature, notably the study by Weng et al. (2004, 2011), has been reported. They analyzed the changes in microclimate in relation to land use and land cover, NDVI, and type of vegetation in the city of Indianapolis. Laurence Pattacini (2012) analyzed the effect of urban form, in particular the type of buildings, on microclimate through a CFD analysis case study by the URSULA project focusing on the Wicker Riverside area of Sheffield in the UK. Claire Smith and Geoff Levermore (2008) revealed a significant effect for urban space and the design of buildings on microclimate through a literature review. Michele Lazzarini (2011) analyzed the effect of various form elements of buildings on the surface temperature of buildings by converting satellite images of cities and buildings into a map of the surface temperature of buildings in Madrid, Spain. Haiyong Ding and Wenzhong Shi (2013) divided satellite images of Beijing into the

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categories of land use and land cover and analyzed the effect of these variables on urban heat island effect and land surface temperature. Weizhong Su et al. (2010) analyzed the effect of changes in land use and land cover on urban heat islands in Nanjing, China.
Lastly, research has been reported that focused on natural elements, including season, time of day, wind speed, altitude, and weather. T.J. Chandler and S. Gregory (1976) measured and compared temperatures of parks in London by time of day. F.G Hannel (1976) found that a heat island occurred only in the daytime in Quinto, Ecuador.
The above studies are meaningful in that they examined the relation between the physical conditions of cities and building temperatures, thereby presenting implications in terms of designing the temperature and environment of cities, despite having the following three limitations.
First, they failed to generalize any theories, since they mainly relied on observation or tests on a small number of sites.
Second, they did not generate an integrated model reflecting urban form and tissue, building form and envelope, microclimate and natural environment, and microscopic surface temperature, consequently not performing analysis with any variables controlled. They simply drew a vague relation between physical elements of cities and buildings and microscopic surface temperature.
Third, in the same context as the above two points, they show limitations in their research method. They are unable to compare the degree of the impact on microscopic surface temperature of the variables, such as urban form and tissue, building form and envelope, microclimate, and natural environment.
This study aims to establish a comprehensive model by complementing the limits found in the preceding research and applying a wide range of statistical data while utilizing a more accurate statistical method.

2.2. Hypotheses

Based on the literature review, this study suggests the following hypotheses:
First, some elements found to affect the surrounding temperatures of buildings in previous research are meaningless according to the statistical model applied in this study.
Second, building form elements found to affect the energy consumption of buildings in previous research have a relation to the microscopic surface temperature of buildings and to the surrounding areas as well.
Third, urban form and tissue, microclimate, and the surrounding natural environment, which have been neglected in previous research compared to other variables, have a huge impact on microscopic surface temperature.

3. Analysis structure

3.1. Analysis model

OLS (ordinary least squares), a method utilized in this research, is a traditional linear model. Hierarchical regression analysis, an analysis technique chosen for the study and based on OLS, groups or blocks various independent variables and applies them in multiple regression analysis in order to compare the degree of impact each independent variable has on the dependent variables. Each previous model should be nested in the next model. A comparison of adjusted R2 whenever each independent group or block is input can generate a model with more explanatory power and determine the effect of the input of each independent variable in explaining the condition.

Based on this, the following equation was devised.

$$T_k=f(UFT_k, M_k, E_k, MCN_k)$$

Here,
T_k = microscopic surface temperature of point k
UFT_k = surrounding urban form and tissue of point k
M_k = form and mass of buildings at point k
E_k = envelope and façade elements of buildings at point k
MCN_k = surrounding microclimate and natural environment at point k

According to the aforementioned operation of hierarchical regression analysis, group variables were input into the respective models to determine the effect and significance of each group variable.

Table 2: Composition of group variables by model

	Model 1	Model 2	Model 3	Model 4
(Surrounding)Urban form and tissue			○	○
Projected lifespan of buildings				
Gross area				
Distance between buildings				
Width of public space in front of buildings				
Presence of shade from roadside trees				
Distance between roadside trees				
Use				
Form and mass of building	○	○	○	○
Height				
Façade area				
Existence of diagonal shapes				
Existence of square shapes				
Width of buildings				
Depth of buildings				
Existence of flat roof				
Height of ground floor				
Setback distance of ground floor				
Existence of pilotis				
Envelope and façade of building		○	○	○
Color of roof				
% of window area (main)				
% of window area (side)				
Color of facade				
Façade material				
(Surrounding)Microclimate and natural environment				○
Wind speed				
Temperature				
Humidity				
Gradient				

	Amount of solar radiation

3.2. Variables analyzed

The following variables were applied to verify the above hypotheses.

First, variables related to urban form that have been established in existing research as influencing microscopic surface temperature were employed. The age and density of buildings, distance between buildings, width of public space in front of buildings, presence of shade from roadside trees, distance between roadside trees, and the usages of buildings are some examples.

Second, variables related to building form, particularly those in close relation with the mass and façades of buildings, which have been identified in previous research as affecting the energy consumption of buildings were applied. The height and façade area of buildings, existence of diagonal surfaces in buildings, existence of a four-sided shape for the building plan, width and depth of buildings, flat roofs, and shape of lower levels (height of ground floor, setback distance of ground floor, and presence of pilotis) are examples. As for the elements related to façade, color of the façade, proportion of window area (major orientation and side orientation), color of roofs, and façade materials were chosen.

Lastly, for variables related to microclimate and ambient natural environment, wind speed, temperature, humidity, gradient, and amount of radiation were employed.

3.3. Analysis target and data

This study utilized data on the buildings and 7,560 surrounding points within a 500m radius of the 23 AWS measurement points selected by the Korean Meteorological Administration. It applied this 500m radius because studies by Wilmers (1991) and Yunnam et al. (2015) have demonstrated that temperatures are maintained at a similar level within such a boundary. The target areas are shown in Figure 1 below.

Fig. 1: Target areas within a 500m radius of the 23 AWS

Official data regarding the variables of the target areas was provided by the Seoul Government. Building information taken from Architectural administration information system managed by the Ministry of Land, Infrastructure and Transport and microclimate data from AWS provided by the Korean Meteorological Administration were utilized.

For the microscopic surface temperature of buildings, a dependent variable, Landsat 8 satellite image data for the central portion of the Korean Peninsula obtained from the United States Geological Survey (USGC) were converted into thermal imagery.

Thermal images generated by combining the No. 10 and No. 11 bands has a spatial resolution of 100 m×100 m, and, according to the operational definition, microscopic surface temperature, a dependent variable in this study, is the temperature of target points within this area. The process in which information on buildings is combined with thermal imagery is shown Figure 2.

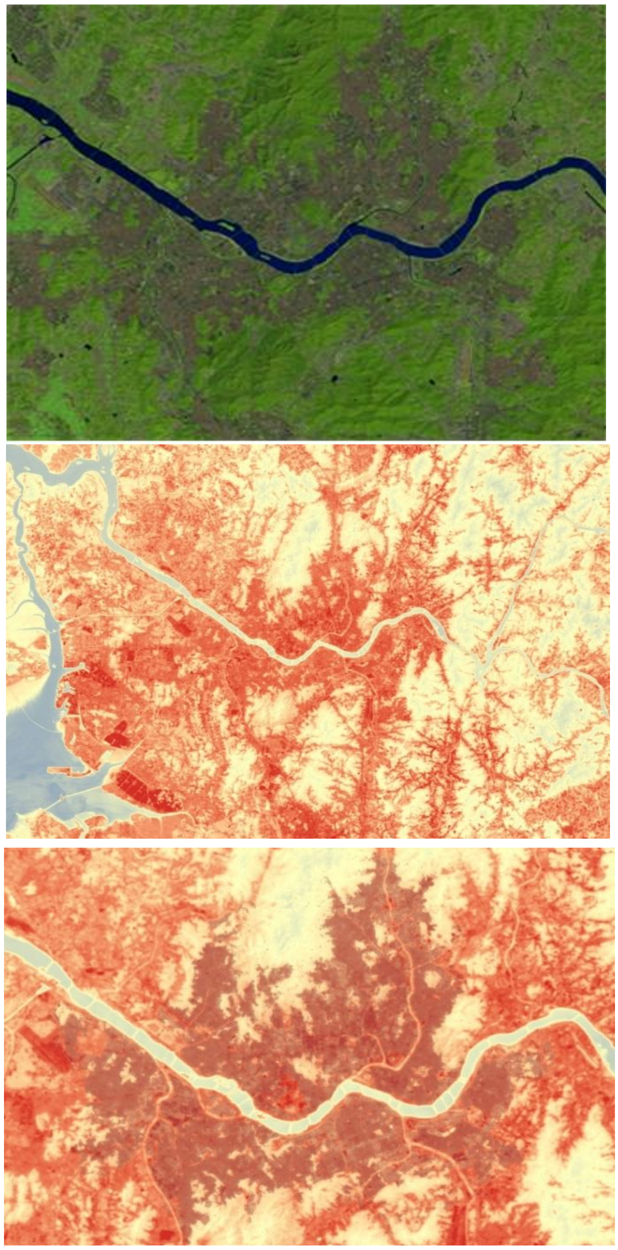

Fig. 2: Procedure for combining the surface temperature values extracted from Landsat 8 satellite image data with building location data

The data for the descriptive statistics of variables are shown in Tables 3 and 4.

Table 3: Descriptive statistics for continuous variable

Variables	Ave.	S.D.	Min.	Max.
Distance between Buildings (Side)	2.2	2.9	0.0	148.0
Width of Public Space in front of Buildings	18.2	44.6	0.0	120.0
Distance between Roadside Trees	0.2	1.2	1.0	16.0
Width of Buildings	11.6	5.1	1.0	114.0
Depth of Buildings	12.1	4.5	1.0	87.0
Height of Ground Floor	3.7	0.6	2.0	8.0
Setback Distance of Ground Floor	0.7	2.1	0.0	55.0
% of Window Areas (Main Direction)	0.4	0.2	0.0	1.0
% of Window Areas (Side Direction)	0.1	0.2	0.0	1.0
Wind Speed	2.2	0.4	0.8	3.4
Temperature	29.8	0.4	29.0	30.7
Humidity	67.7	2.8	61.4	73.2
Gradient	2.1	2.1	0.1	19.8
Amount of Solar Radiation	498,235.2	2,690.9	480,005.8	508,337.8
Projected Lifespan of Buildings	85.0	10.4	0.0	110.0
Gross Area	503.5	2,377.2	10.0	180,449.0
Height	10.2	5.2	1.5	97.8
Façade Area	503.4	455.1	55.0	12,525.7
Microscopic surface temperature	28.2	0.8	23.6	31.8

Table 4: Descriptive statistics for dummy variable

Variables	Proportion (%)
Presence of Shade by Roadside Trees	No: 96.7, Yes: 3.3
Existence of Diagonal Shape	Yes: 98.1, No: 1.9
Existence of Square Shape	Non-square (Triangle Circle: 1.2), Square: 98.8
Shape of Roofs	Gable: 19.0, Flat: 81.0
Color of Roofs	Achromatic Color: 39.6, Green: 45.2, Blue: 4.8, Red: 10.5
Existence of Pilotis	No: 96.1, Yes: 3.9
Façade Materials	Concrete: 8.2, Rock: 19.9, Brick: 62.3, Tile: 6.6, Steel: 0.6, Wood: 0.8, Glass: 1.7
Color of Facade	Achromatic Color: 29.8, Green: 6.3, Blue: 0.7, Red: 63.2
Building Use	Single Family Home: 44.7, Apartment Building: 20.6, Neighborhood Commercial: 29.3, Cultural and Religious: 0.2, Retail and Entertainment: 1.4, Welfare: 1.0, Office: 2.2, Factory etc.: 0.6

4. Analysis results

4.1. Comparison of models

A test to review the suitability of OLS as a research method was carried out prior to examining the explanatory power of models. Three hypotheses were examined: normality, independency among independent variables, and homoscedasticity of error.

First, normal distribution of dependent variables was examined. The histogram of microscopic surface temperature shows a bell shape focused on the average value in Figure3.

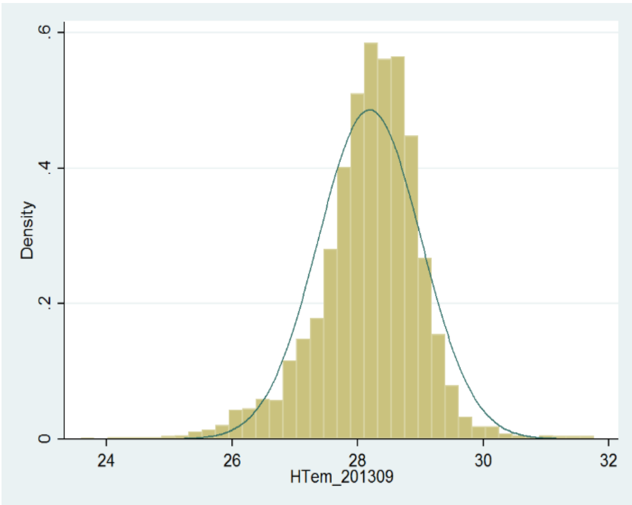

Fig. 3: Histogram of the buildings surface temperature

In addition. skewness and kurtosis tests were also implemented, with respective result of 1.1 and 1.4 (< 2.0), which indicates it is a normal distribution. To allow stricter analysis, a Shapiro-Wilk test was carried out as well. The p-value of the result was 0.2 (> 0.05), which could not dismiss the null hypothesis. Therefore, it was seen to present a normal distribution. As a result of these tests, it was confirmed that the dependent variables for the study show a normal distribution.

Table 5: Result of VIF test

Variable		VIF
Basic condition of buildings	Projected lifespan of buildings	1.89
	Gross area	2.08
Public space	Distance between buildings	1.08
	Width of public space in front of buildings	1.07
Vegetation and shade	Presence of shade from roadside trees	3.70
	Distance between roadside trees	3.67
Building use (standard: single family home)	Apartment building	1.02
	Neighborhood commercial	1.86
	Cultural and religious	1.05
	Retail and entertainment	1.22
	Public welfare	1.10
	Office	1.65

	Factory, etc.	1.14
Building form	Height	2.6
	Façade area	1.11
	Existence of diagonal shapes	1.06
Shape of plan	Existence of square shapes	1.04
	Width of buildings	2.16
	Depth of buildings	1.81
Shape of roof	Existence of flat roof	2.00
Shape of lower level	Height of ground floor	1.19
	Setback distance of ground floor	1.17
	Existence of pilotis	1.11
Color of roof (standard: grey)	Green	1.22
	Blue	1.21
	Red	1.71
Area of windows	% of window area (main)	1.32
	% of window area (side)	1.09
Color of facade (standard: achromatic color)	Green	1.33
	Blue	1.30
	Red	3.75
Façade material (standard: concrete)	Rock	3.56
	Brick	5.95
	Tile	1.88
	Steel	1.12
	Wood	1.15
	Glass	1.17
Wind speed		1.14
Temperature		1.19
Humidity		1.36
Gradient		1.19
Amount of solar radiation		1.13
Average of VIF		1.74

Second, independency among the independent variables was examined. To this end, a variance inflation factor (VIF) test was performed to review the multicollinearity of independent variables. The test was carried out using model 4, which applied the largest number of independent variables. The result shows that the average VIF is 1.74, and the variable with the greatest VIF (6.0 < 10) is the façade material bricks. The VIFs of most variables range from 1 to 2, which means a multicollinearity problem does not exist. In other words, independency among independent variables is confirmed.

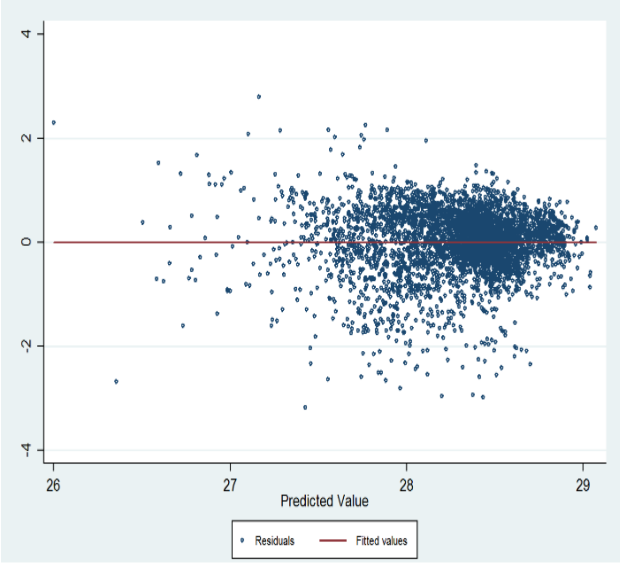

Fig. 4: Scatter plot of residuals

Third, homoscedasticity of error was examined. For this, the independency of residuals resulting from OLS analysis was reviewed. A scatter diagram reflecting the predictive value and residual value of y was drawn, which is shown Figure4. The diagram, a circular form, does not demonstrate any unusual patterns or patterns with a particular direction. The relevance predictive line of the residuals is '0', which means it has no relevance. These results indicate that the error of the model has independency, thereby showing homoscedasticity. The three analysis results above indicate that OLS is a suitable method for this study.

Lastly, the R^2s of the four models, which applied independent variables for the study, were compared. Degree of freedom was also compared to increase the explanatory power of each model. The model with the best explanatory power was chosen through this process. As shown in the table below, Model 4 is the most suitable for the analysis of the data in the study.

Table 6: Comparison of models.

	Model			
	1	2	3	4
Adj. R^2	0.034	0.046	0.278	0.700
Number of Input Independent Variables	10	24	37	42
1Degree of Freedom		14	5	2
2Degree of Freedom		430	419	417
ΔAdj. R^2		0.012	0.232	0.422
F	27.86**	16.33**	16.77**	26.71**

< 0.1: †, < 0.05: *, < 0.01: **

4.2. Analysis of results

The results of the analysis of Model 4, which was proved to be the best method through the comparison of the models, are as follows.

First, the relations of the urban form variables and the microscopic surface temperature of buildings were examined. The results demonstrate that the age and total floor area of buildings are not meaningful when microclimate and ambient natural environment variables are controlled, which reveals the significance of the control of these variables. For the aspect of the distance between buildings and the width of public space in front of buildings, it is determined that greater width and distance result in a higher surrounding temperature for buildings. This can be explained by the fact that wider space leads to a greater amount of radiation, which is offset by an increase in ventilation. The degree of impact of these two variables on the surrounding temperature of buildings increases when microclimate and natural environment variables are controlled, which indicates that these variables are pertinent to microclimate and natural environment variables. However, further study is needed in this regard. Meanwhile, both vegetation and shade show a meaningful relation with microscopic surface temperature. The presence of shade from roadside trees considerably reduces the ambient temperature of buildings. In the same context, an increase in the distance between roadside trees leads to higher surrounding temperatures. As for the use of buildings, it is found that retail and entertainment buildings considerably increase the surrounding temperatures compared to single-family houses. In particular, the increase in temperature around factories is remarkable, which can be explained by artificial heat, a similar result to the findings of previous research.

Table 7: Result of Regression

Section	Variable		Model1	Model2	Model3	Model4
			Coefficient (standard error)	Coefficient (standard error)	Coefficient (standard error)	Coefficient (standard error)
Urban form and tissue	Basic condition of buildings	Projected lifespan of buildings			-0.007** (0.001)	-0.001 (0.001)
		Gross area			-0.067** (0.011)	0.004 (0.013)
	Public space	Distance between buildings			-0.010** (0.003)	-0.018** (0.005)
		Width of public space in front of buildings			-0.001** (< 0.001)	-0.003** (< 0.001)
	Vegetation and shade	Presence of shade from roadside trees			-0.095 (0.100)	-0.319** (0.095)
		Distance between roadside trees			0.019 (0.016)	0.061** (0.017)
	Use (standard: single family home)	Apartment building			-0.183† (0.114)	0.115 (0.140)
		Neighborhood commercial			0.100** (0.025)	0.015 (0.026)
		Cultural and religious			0.499** (0.199)	0.271 (0.206)
		Retail and entertainment			0.286** (0.085)	0.260** (0.108)
		Public welfare			0.035 (0.093)	0.112 (0.110)
		Office			0.073 (0.078)	0.056 (0.101)
		Factory, etc.			0.167 (0.128)	0.485** (0.185)
Form and mass of building	Building form	Height	-0.021** (0.002)	-0.020** (0.002)	-0.012** (0.003)	-0.013* (0.003)
		Façade area	< -0.001 (< 0.001)	< -0.001† (< 0.001)	< 0.000 (< 0.001)	< -0.001 (< 0.001)
		Existence of diagonal shapes	0.003 (0.070)	0.005 (0.069)	0.008 (0.067)	0.282** (0.114)
	Shape of plan	Existence of square shapes	-0.085 (0.085)	-0.050 (0.085)	0.014 (0.086)	0.151 (0.102)
		Width of buildings	-0.005* (0.002)	-0.006** (0.002)	0.001 (0.003)	-0.006* (0.003)
		Depth of buildings	-0.007** (0.002)	-0.006** (0.002)	0.004 (0.003)	-0.002 (0.003)
	Shape of roof	Existence of flat roof	0.122** (0.024)	0.163** (0.031)	0.170** (0.032)	0.073* (0.034)

	Shape of lower level	Height of ground floor	-0.045** (0.016)	-0.061** (0.016)	-0.059** (0.016)	-0.087** (0.019)
		Setback distance of ground floor	-0.016** (0.005)	-0.019** (0.005)	-0.014** (0.005)	-0.014* (0.007)
		Existence of pilotis	-0.123** (0.049)	-0.100* (0.049)	-0.044** (0.018)	0.019** (0.006)
Envelope and façade of building	Color of roof (standard: grey)	Green		-0.020 (0.043)	-0.030 (0.043)	0.031 (0.048)
		Blue		-0.129 (0.128)	-0.145 (0.126)	-0.151 (0.168)
		Red		-0.098** (0.037)	-0.080* (0.037)	-0.040 (0.040)
	Area of windows	% of window area (main)		0.114* (0.052)	-0.033 (0.053)	0.125* (0.056)
		% of window area (side)		-0.220** (0.049)	-0.226** (0.048)	0.255** (0.055)
	Color of facade (standard: achromatic)	Green		-0.124** (0.020)	0.473** (0.003)	-0.050* (0.021)
		Blue		-0.082† (0.047)	-0.200** (0.004)	0.001 (0.052)
		Red		-0.014 (0.039)	-0.200** (0.004)	0.005 (0.040)
	Façade material (standard: concrete)	Rock		0.009 (0.041)	0.032 (0.043)	0.080† (0.047)
		Brick		0.152** (0.044)	0.133** (0.046)	0.159** (0.050)
		Tile		0.144** (0.049)	0.053 (0.050)	0.202** (0.061)
		Steel		0.312* (0.130)	0.284* (0.134)	-0.092 (0.182)
		Wood		-0.001 (0.110)	-0.159 (0.110)	0.211† (0.122)
		Glass		0.234** (0.088)	0.246** (0.093)	0.010 (0.119)
Surrounding microclimate and natural environment	Wind speed					-0.284** (0.034)
	Temperature					0.399** (0.048)
	Humidity					0.041** (0.004)
	Gradient					-0.107** (0.007)
	Amount of solar radiation					< 0.001** (< 0.001)
Constant			28.709** (0.111)	28.681** (0.117)	43.419** (2.212)	5.140 (4.234)

< 0.1: †, < 0.05: *, < 0.01: **

Second, the effects of building form variables on the microscopic surface temperature of buildings were analyzed. Height, which bears a considerable relation with the overall shape of buildings, contributes to an increase in microscopic surface temperature, while façade area, unlike in the case of the energy consumption of buildings, does not indicate any relevance to their microscopic surface temperature. This can be explained by a diagonal shape in buildings increasing the amount of radiation. It was also determined that the width of buildings is a more meaningful variable than the shape of the building plan, with greater width resulting in higher surrounding temperature. Variables related to lower levels show interesting results. All variables indicate a significant relation with microscopic surface temperature. Greater height and setback distance of the ground floor lead to lower microscopic surface temperature. The existence of pilotis diminished the microscopic surface temperature of buildings. Variables related to the lower levels of buildings show great significance with the ventilation performance of urban space. As for façade, contrary to common belief, buildings with a façade or roof in chromatic colors have only a slight impact on temperature compared to those with achromatic colors. This is the opposite result compared to their effect on the energy consumption of buildings. These variables are meaningful when microclimate and surrounding natural environment variables are not controlled. Albedo as influenced by façade and the color of the roof do have an impact on the microscopic surface temperature of buildings, while the variables of microclimate and the surrounding natural environment also play an important role in this regard. Further study on the interrelation between these two elements or their mediation effect is needed. It was also determined that a greater area of windows facing in both a main and side orientation lead to a higher microscopic surface temperature, while façade materials such as rock, brick, steel, and wood contribute to an increase in microscopic surface temperature compared to concrete.

Lastly, the relations of microclimate and variables in the surrounding natural environment with the microscopic surface temperature of buildings were examined. Higher wind speeds and gradients resulted in lower microscopic surface temperature, while higher temperature, humidity, and amount of radiation led to higher microscopic surface temperature for buildings.

4.3. Verification of hypotheses

According to the results of the analysis, the hypotheses established in Section 2 were verified as follows.

First, some elements that were found to influence microscopic surface temperature in previous research turned out to be meaningless in this statistical model. Particularly, façade variables such as the color of the façade or roof showed similar results to previous research when variables of microclimate and the surrounding environment were not controlled. However, with these elements controlled, the results changed.

Second, some elements found to influence the energy consumption of buildings in previous research do not have an impact on microscopic surface temperature. Buildings' age, total floor area, and shape of building plan, all meaningful variables in the energy consumption of buildings, do not have any relevance for microscopic surface temperature. These variables have a meaningful relation with surrounding temperature before microclimate and surrounding environment are controlled. However, with these elements controlled, the results change. This finding indicates that further investigation on the intricate relation between these variables and microclimate and the surrounding environment variables is needed.

Third, urban form and tissue, natural elements which have been relatively neglected in previous research, have the greatest effect on microscopic surface temperature. The increment of R2 when urban form and tissue variables are applied (Model 3), and microclimate and the surrounding environment variables (Model 4) are 23.2% and 42.2%, respectively. This figure is far higher than the 3.4% and 1.2% found when the building plan (Model 1) and façade elements of buildings (Model 2) are applied. This result shows that microclimate and the surrounding environment are the most important variables, followed by urban form and tissue variables. These variables should not be neglected in the research on surrounding temperature.

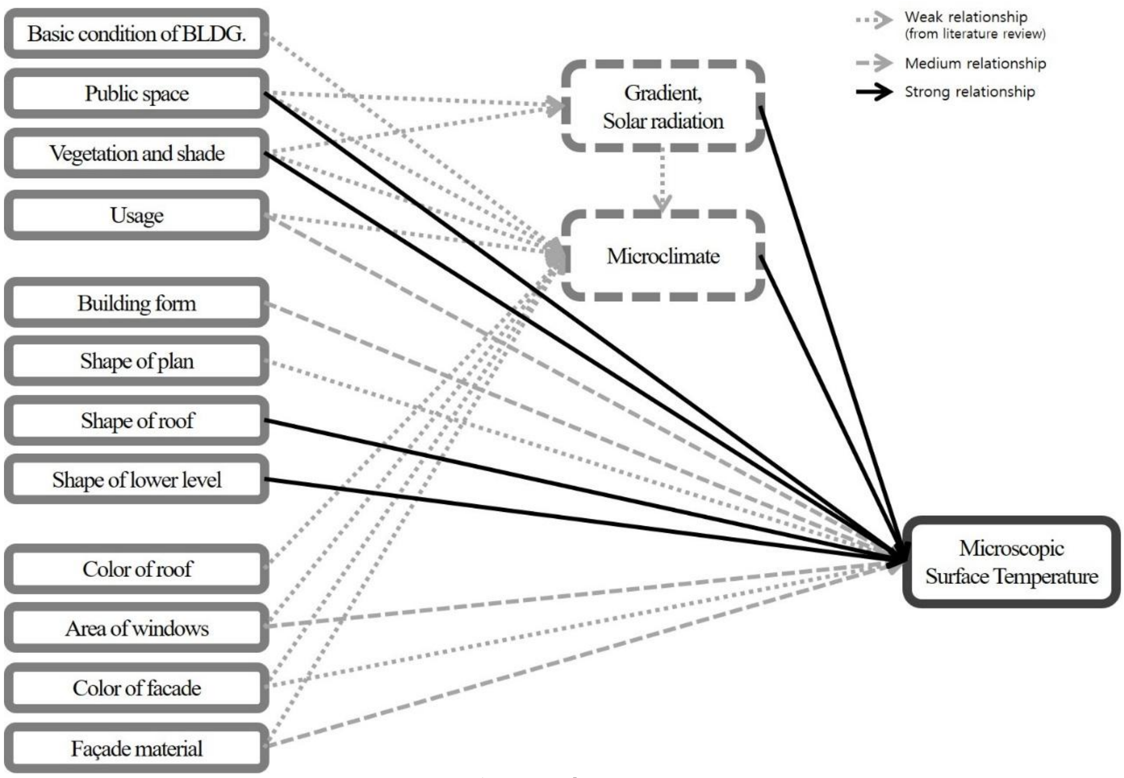

Fig. 5: Result summary

5. Conclusion

As a result of this study, the following implications can be drawn. First, variables of microclimate and the surrounding environment should be considered in research on the microscopic surface temperature of buildings. In particular, the impact of façade elements, such as the color of the façade or roof, on surrounding temperatures decreases when elements of microclimate and the surrounding environment are controlled. This result indicates that a reexamination of previous research in which microclimate and surrounding environment variables are not controlled is warranted, and these variables should be taken into consideration in future research.

Second, the energy consumption of buildings and their microscopic surface temperature show a different relation with certain variables.

Given the fact that microscopic surface temperature affects the energy consumption of buildings, it can be concluded that these two variables have an intricate relationship. As a result, the effects of urban form and tissue, microclimate and surrounding environment variables should be considered in research on microscopic surface temperature. It also appears that the significance of building form and façade elements changes significantly when urban form and tissue, microclimate, and the surrounding environment are controlled. This result indicates that building form and façade elements, which are expected to influence microscopic surface temperature, are also affected by urban form, microclimate, and the surrounding environment, consequently creating an interaction effect. It could be that these variables play the role of mediator in the process of a building's elements affecting microscopic surface temperature. In this regard, further research on these variables should be pursued, and there is a need to develop a research model on the interaction effect or mediator effect of these variables.

Finally, the significance of ventilation performance in urban areas should be recognized. The results of this research indicate that the building form variables that have a close relation with microscopic surface temperature when variables of urban form and tissue, microclimate, and surrounding environment are controlled are those related to the form of the lower levels. Given the fact that these variables are closely related to ventilation performance in urban areas, it can be suggested that ventilation performance is significantly relevant to surrounding temperature. Among urban form and tissue variables, width of urban space and wind speed also reduce microscopic surface temperature, supporting a similar result. In this light, further research on ways to enhance ventilation is needed.

This study has implications in that it used official data in a comprehensive manner despite dealing with simple and direct relations among the variables, which creates a need for further research.

In addition, this study is meaningful in that it provides a basis for the management of climatic environment in urban area, including the urban heat island effect. Considering the fact that urban climatic environment has a fundamental impact on human activities within cities, it is expected that an expansion of the research initiated in this study will contribute to the development of a sustainable city model.

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