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A Study on Thermal Comfortable following the Thermal Environment Migration in Detached Housing Area in Korea

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1 ABSTRACT

The purpose of this study is to increase thermal comfort within a detached housing area by improving the thermal environment. Therefore, it suggests application of various greening methods, taking into account the materials and shape of the outdoor space, as a systematic approach to reducing sensible heat by lowering the surface temperature.

As to Case 1 and Case 2, there was no significant difference in the surface temperatures within the detached housing area, but Case 1 showed lower surface temperature distribution around the fence due to shade during the daytime. Case 3 showed the low surface temperature distribution of 10℃ around the planted trees during the daytime and temperature of 15℃ around the green roof. With respect to MRT the green roof showed a temperature difference of 3℃ or more and the vacant land covered by the grass also showed a difference of 2~3℃. In addition, Case 3 with increased green coverage showed the temperature 10℃ lower than Case 2.

Meanwhile, changes in the wind velocity may cause dispersion of sensible heat and thus affect the temperature. And higher trees are more effective in blocking solar radiation and lowering the temperatures.

2 INTRODUCTION

2.1 Backgrounds and Purpose

Temperature rises in detached housing area are caused by various climate factors including not only a temperature but also wind and humidity, which all affect human senses and behaviors. And creating a thermal comfort environment by considering such various climate factors is critical to designing detached housing area. In particular, the surface temperature of the components of an actual detached housing area such as a building or the ground is closely related with space design involving materials or the shape of outdoor space, indicating that outdoor space should be carefully designed by taking the thermal environment into account.

The purpose of this study is to examine how fence demolition affects the thermal environment of outdoor space in a detached housing area and to highlight the positive effects of greening, which is expected to improve the thermal environment. This can provide a basis for a continuous fence demolition campaign by assessing the thermal environment of outdoor space in a detached housing area.

In addition, this study suggests greening methods considering the materials or shape of outdoor space as a systematic approach to improving the surface temperature with the purpose of increasing thermal comfort within a detached housing area by controlling sensible heat. To that end, we have reproduced the materials or the shape of the outdoor area, which affects the surface temperature of a case study area, with 3D-CAD and applied relevant climate factors to a computer simulation.

3 METHODOLOGY

The simulation process is outlined in Fig. 1. The simulation is performed using 3D-CAD models (shown at the upper left in Fig. 1) for buildings, trees and other structures in the area being analyzed. As shown at the top right corner of Fig. 1, three-dimensional spatial forms of buildings, trees and other structures, and two-dimensional ground surfaces are divided into mesh grids. Thermophysical data of construction materials such as albedo, conductivity, and solar transmittance are assigned to the grids. An automatic mesh-dividing process with a spatial resolution of 0.05-5m(a practical size is 0.1-0.4m) has been designed and only uniform mesh can be used in the present version of the tool. A uniform mesh size of 0.4m was used in this study.

Three-dimensional radiation (solar radiation and longwave radiation) from surroundings (the sky, ground and surroundings) was considered in the heat balance calculation for each mesh. Conduction heat was assumed to be transferred in one direction which is normal to the mesh surface. The following assumptions were also used in the thermal simulation. Ambient air temperature and wind velocity are uniformly distributed in the outdoor spaces at an analysis time. Indoor air temperature is uniform in a room at an analysis time. The effect of heat bridges is not considered in the building heat load simulation.[1]

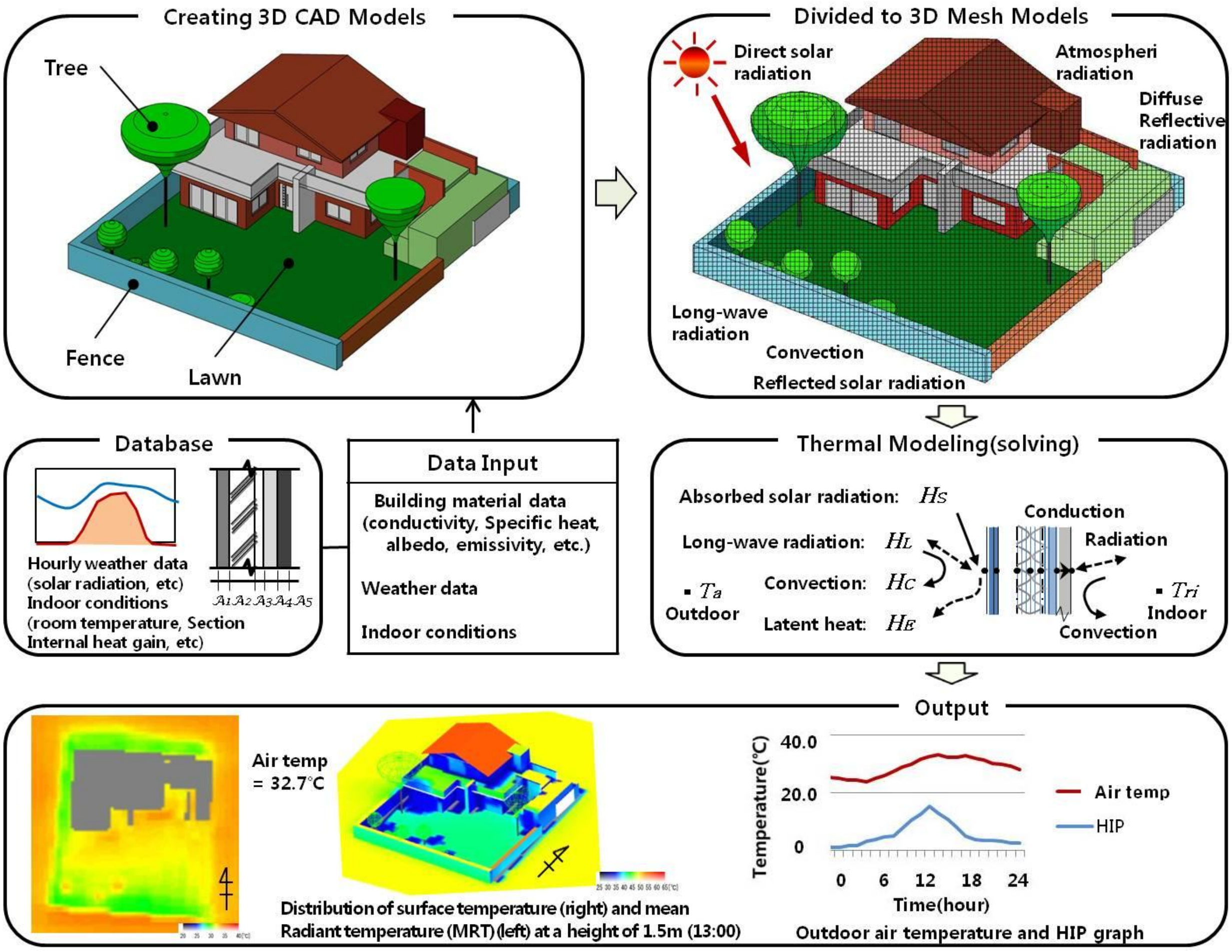

Fig. 1: Diagram of the simulation tool.

3.1 External surface temperature simulation

The energy balance equation at each mesh surface can be written as Eq. (1). The left term of Eq. (1) is the conductive heat at the mesh. The first right term is the absorbed shortwave (solar) radiation by the mesh. The second right term is the net longwave radiation. The third right term is the convective heat transfer from ambient air. The fourth right term is the latent heat from evaporation Eq. (1) accounts for three-dimensional radiation irradiated on the surface. Short-wavelength radiation on the surface includes direct solar insolation, sky solar radiation and reflected solar radiation. Reflected solar radiation includes both specular reflection and isotropic diffuse reflection. The first reflected solar radiation is considered in the calculation. Atmospheric radiation and longwave radiation from the surroundings are considered in the longwave radiation irradiated on the surface. Sky solar radiation and atmospheric radiation are calculated from the sky view factor for each mesh.

The sky view factor is calculated by the multi-tracing simulation from the mesh toward multiple hemispherical directions. The tracing direction is established so that the tracing density (interval) comes to have the same shape factor. The sky view factor is estimated by counting the number of tracers reaching the boundary surfaces. The shape factor for calculating the reflected solar radiation and long-wavelength

[1] He J, Hoyano A, Asawa T. A numerical simulation tool for predicting the impact of outdoor thermal environment on building energy performance. Applied Energy 2009; 86; 1597-1600.

radiation from the surroundings is determined by the same method used in the estimation of the sky view factor. A detail description of the calculation methodology can be found in Asawa et al.[2]

Convective heat transfer is calculated on the assumption that ambient air temperature and wind velocith are uniformly distributed in the outdoor spaces at the time of analysis. This assumption is valid under weather conditions with low wind velocity. The convection coefficient is considered as a function of wind velocity, and is given by Jurges' equation.[3]

The non-steady-state one-dimensional conduction equation inside each mesh is expressed by Eq. (2). The external and internal surface temperature for each mesh can be determined by solving Eq. (2), using Eqs. (1) and (3) as boundary conditions for external surfaces and internal surfaces, respectively. Boundary conditions for internal surfaces are indoor air temperature for buildings, and underground temperature for the ground, respectively. Rooms on the same floor of a building are assumed to be single rooms, as the influence of internal partitions is not taken into consideration. The indoor air temperature is assumed to be uniform at an analysis time, and its hourly data is given as follows. For the first calculation, the indoor air temperature is assumed to be equal to the ambient air temperature or setpoint temperature for the non-air-conditioned or air-conditioned period. Eq. (3) is a boundary condition for an internal surface. The energy exchange at the internal surfaces is considered to by radiative and convective exchanges with indoor air, where a combined heat transfer coefficient α_o is used and assumed to be constant at 9.3W/(m²K). In the second calculation, the indoor air temperature is given from the results of the building heat load calculation described below. The underground temperature at a depth of 0.6m is considered to be constant during the day, and is given from the input data.

The backward-difference method is used to solve the non-steady-state heat conduction equation (Eq. (2)). The calculation time-step used in this study is 5-min.

The tree shape is modeled as a 3D-CAD model and the crown is composed of meshes containing solar transmittance data. Solar transmission radiation decreases as it passes through the tree mesh model. As shown in Fig. 2, this mesh model makes it possible to quantify the influence of the position and distance of sunlight passage within the crown on solar transmission. The surface temperature of a tree's crown is calculated by empirical formulas derived from the experimental data, and can be expressed as a function of the solar radiation incident on the surface, ambient air temperature, and wind velocity.

$$H_G = H_S + H_L + H_C - H_E \quad (1)$$

$$H_G = -\lambda \left.\frac{\partial T}{\partial x}\right|_{x=0} \qquad H_S = a_{su}(\cos\theta \cdot I_{DR} + F_{sky} I_{SR} + I_{RR})$$

$$H_L = F_{sky} R_{La} + R_{LW} - \varepsilon_s \sigma T_s^4$$

$$R_{La} - \varepsilon_s \sigma T_s^4 = \varepsilon_s \sigma T_s^4 (a + b\sqrt{e}) - \varepsilon_s \sigma T_s^4 \text{ (clear sky)}$$

$$R_{La} - \varepsilon_s \sigma T_s^4 = \left(\varepsilon_s \sigma T_s^4 (a + b\sqrt{e}) - \varepsilon_s \sigma T_s^4\right) \times (1.0 - (1 - m_c)C/10))$$

(cloudy sky)

$$R_{LW} = \varepsilon_s \sum_{i=1}^{Nw} F_i \varepsilon_i \sigma T_{wi}^4$$

$$H_C = \alpha_c (T_a - T_s)$$

$$H_E = \iota\beta K(X_s - X_a)$$

$$pc_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) \quad (2)$$

[2] Asawa T, Hoyano A, Nakaohkubo K. Thermal design tool for outdoor spaces based on heat balance simulation using a 3D-CAD system. Build Environ2008; 43(12); 2112-23.

[3] Jurges W. Der Wameubergang an einer ebenen Wand. Beihefte Zum Gesundheits-Ineenieu 1924;19 (in German).

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$$-\lambda \frac{\partial T}{\partial x}\Big|_{x=L} = \alpha_o\left(T_{ri} - T_{al}(i,j)\right) \quad (3)$$

3.2 Simulation output

As outputs of the simulation, temperatures of all external surfaces can be predicted and visualized on the 3D models (see the lower left corner of Fig. 1). From the calculated results of surface temperatures, mean radiant temperature (MRT) at a point can be estimated. The mean radiant temperature at a point is defined as the uniform temperature of an imaginary enclosure in which radiant heat transter from the human body of object equals to the radiant heat transfer in the actual non-uniform enclosure. The MRT at a height of 1.5 m dbove the fround was used to evaluate thermal comfort in outdoor human activity spaces in the present study. In addition, diurnal variations of indoor air temperature, internal surface temperature and heating/cooling loads can also be obtained.[4]

4 ANALYSIS OF THERMAL ENVIRONMENT

4.1 Outline of study area

The exampled site is a fence demolition campaign district within Daegu Metropolitan City when has played a central role in the southeast areas, as one of 3 metropolitan cities in Korea. This site is limited to the first-type general residential areas where low-rise detached houses in good condition are concentrated. Preferably, the area should be the one intentionally formed for the purpose of providing additional houses to solve the housing shortage problem. Therefore, we have selected Daemyeong District, one of the land readjustment project districts formed between the 1960's and 1970's, after examining land readjustment project districts developed before the 1990's and land development project districts developed from the 1990's and up to now.

There was a clear street hierarchy in the area and a gridiron road pattern, directly connected with residence units, but street parking was threatening pedestrians' safety. In addition, there was a small number of a multiplex house but a large number of typical low-rise (two-story) detached houses with fences, which abutted on a road whose width is 10m or below.

Fig. 2: Case study area.

4.2 Outline of study assumes

As described in Table 1, a simulation was run on the three conditions.

[4] Jiwon R et al. Study on evaluation of thermal environment following alleviation of limit on number of floors of apartment complex. Real CORP2011;929.

Cases		Conditions
Before the fence demolition	Case1	- Surface: concrete - Road: asphalt - Vacant land and parking lot: vacant - Wall: cement bricks, R.C - Roof: concrete, slates - Green coverage: 5 %
After the fence demolition	Case2	– 8 houses removed walls - Green coverage: 7 % - Surface: grass and water retaining pavement - Tree planting
Greening after the fence demolition	Case3	- 16 houses removed walls - Green coverage: 25 % - Surface: grass and water retaining pavement - Tree planting and a green roof

Table 1: Simulation input conditions for the analysis of the thermal environment.

Based on these conditions, this study focused on reducing sensible heat generated by the surface and, especially, the effects of greening on the thermal environment of the outdoor space in the detached housing area. This study applied various greening methods such as vegetation, tree planting, improved artificial ground coverage, and a green roof in the detached housing area based on Figure 2, which shows thermal environment improvement methods by the scale.

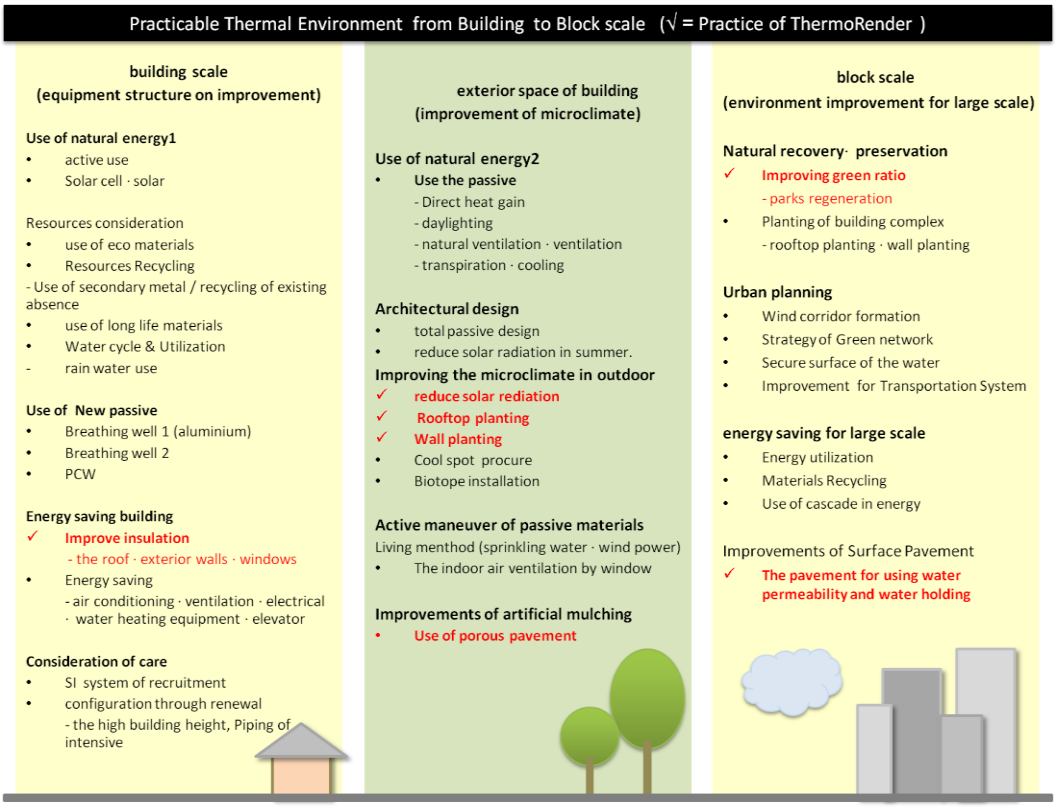

Fig. 3: Thermal environment measures of according to the scale.

4.3 Analysis of Thermal Environment

4.3.1 3D Surface Temperature Distribution

According to the 3D surface temperature distribution simulation for Case 1 and Case 2 (Figure 4), Case 1 showed the low surface temperature distribution during the daytime (15:00) because of the shade around the fence. Meanwhile, Case 3 showed the low surface temperature distribution of 10°C around the planted grass/trees during the daytime and temperature of 15°C around the green roof.

This result shows that the shading effects and evapotranspiration of planted vegetation/trees can lower sensible heat in the area and that use of ground coverage with bright colors and high reflectivity as well as increased greening with tree planting can reduce air/surface temperatures, eventually improving the thermal environment within the detached housing area. In addition, Case 3 shows that the green roof can also maintain the low surface temperature distribution of 15℃, which should be considered in order to improve the thermal environment and increase thermal comfort within a detached house as well as to save energy through enhanced insulation.

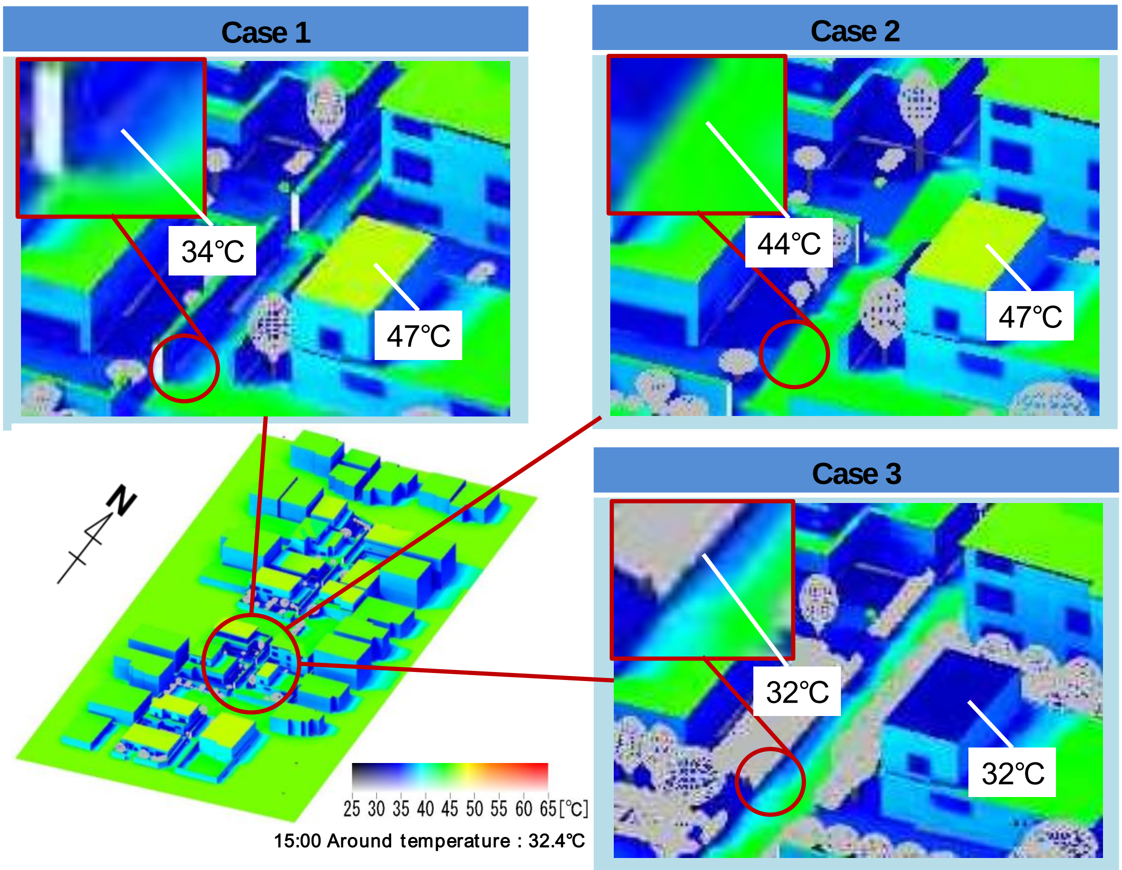

Fig. 4: Surface temperature distribution.

4.3.2 MRT Distribution

Mean Radiant Temperature (MRT) is the omnidirectional effect of radiant heat (which humans feel) converted into a mean temperature. According to Figure 5, Case 3 showed the low temperature distribution because of green coverage increased by tree planting and improved artificial ground coverage. In particular, the green roof showed a temperature difference of 3℃ or more and the vacant land covered by the grass also showed a difference of 2~3℃.

Higher MRT indicates a greater amount of radiant heat, which allows humans to feel higher temperatures than actual temperatures. In order to increase thermal comfort within a detached housing area, therefore, various methods to lower the surface temperature of a built-environment should be applied such as solar radiation blocking by trees, improved artificial coverage, a green roof, and so forth.

In particular, the radiant heat of the wall surface facing the west is enormous, which requires active efforts to find solutions. For example, high trees can be planted around the walls to block sunlight and radiation heat, and the greening of the wall facing the west with a green roof can produce similar effects as well.

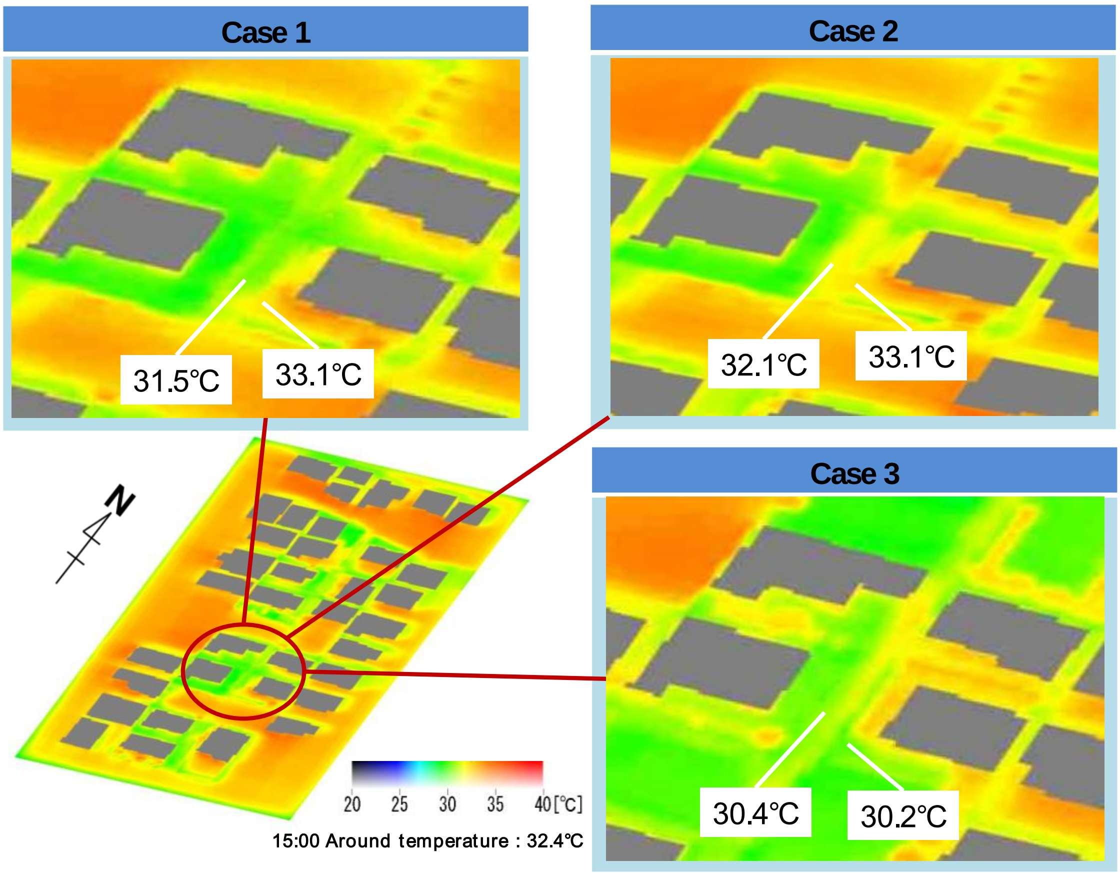

Fig. 5: MRT Distribution.

4.3.3 HIP Distribution

Figure 6 shows the HIP distribution of Case 3, in which the entire asphalt surface was compared with the grass/permeable pavement and green coverage was increased with vegetation, tree planting, improved artificial coverage, and a green roof. As a result, Case 3 with increased green coverage showed the temperature 10℃ lower than Case 2, and 5℃ lower than the grass pavers.

That is, higher HIP means a greater difference between the surface temperature and air temperature and also a greater amount of sensible heat emitted into the air, which is a major cause of a heat island. Such a situation may occur due to artificial coverage, the shape of the surface, a heat source, a water source, and so on. In particular, Figure 6 shows that artificial materials such as concrete and asphalt greatly contributed to heat accumulation and emission. The shape of the surface is closely related with radiant heat and cooling effects of wind may affect the temperature as well. In conclusion, increasing green coverage within the entire built environment is effective in improving the thermal environment than partial greening in the area.

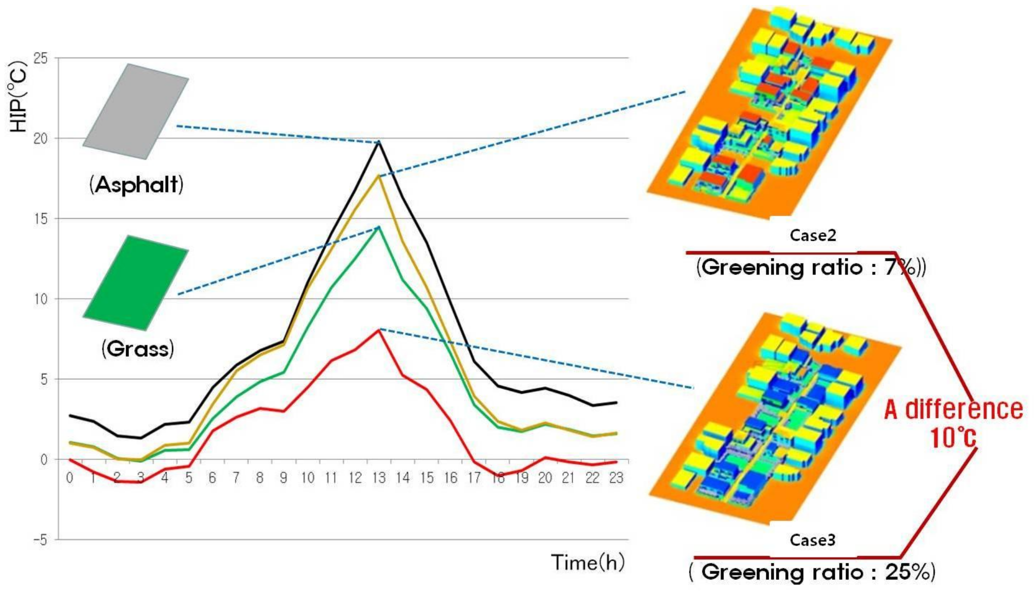

Fig. 6: HIP Distribution.

4.3.4 Wind velocity

Not only the air temperature but also wind velocity affects the human senses and behaviors, and wind is an important factor in creating a thermal comfort environment especially within a detached housing area. Figure 7 shows how the wind velocity affects the surface temperature during the daytime. It was observed that the surface temperature of the built environment went down when the wind velocity increases.

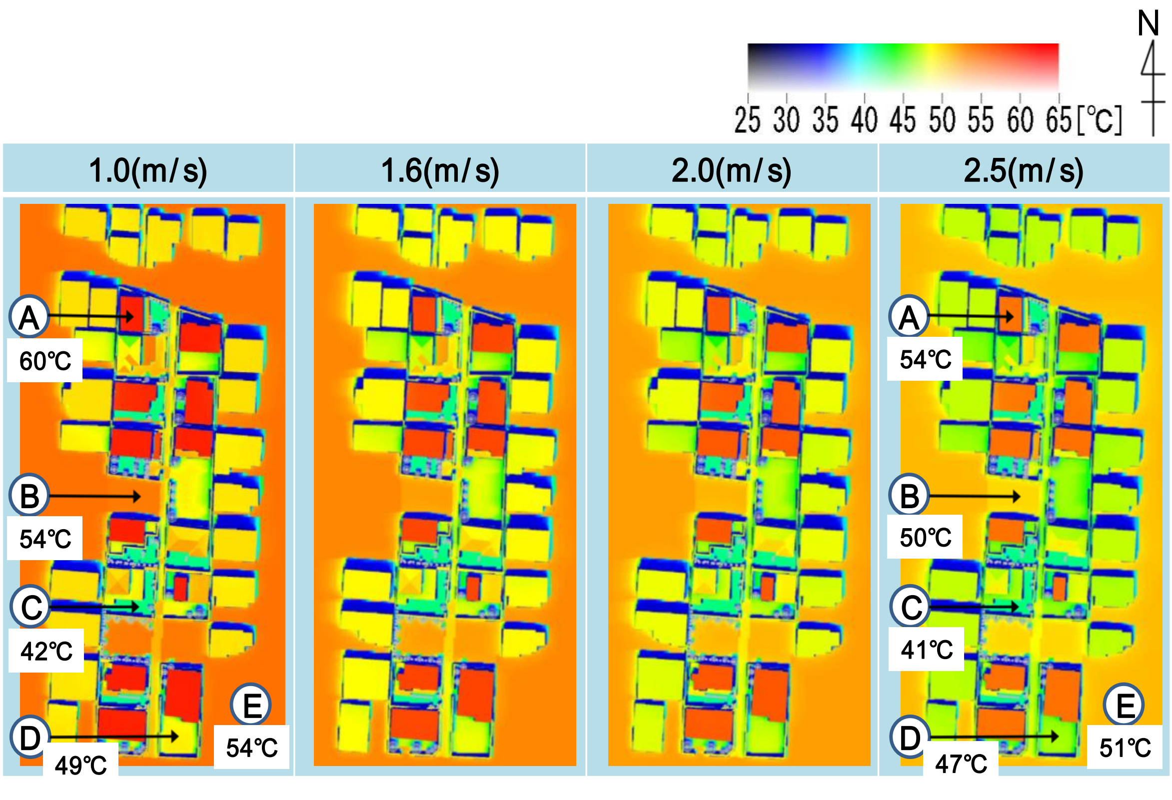

Fig. 7: Surface temperature distribution according to the wind velocity

The HIP values in Table 2 indicate the same results. Table 2 shows changes in the HIP values as the amount of sensible heat, emitted from the surface of the outdoor space, is high in the air due to direct solar radiation from sunrise to sunset. The direct solar radiation increased the surface temperature of the outdoor space during the daytime, which led to a rise in sensible heat in the air, and the changes in the wind velocity may cause dispersion of sensible heat and thus affect the temperature.

Time (h)	Wind velocity(m/s)				Time (h)	Wind velocity(m/s)			
	1.0	1.6	2.0	2.5		1.0	1.6	2.0	2.5
0	2.15	2.10	2.09	2.05	12	15.89	15.45	14.96	14.21
1	1.84	1.79	1.76	1.74	13	19.45	18.14	17.36	16.35
2	1.14	1.08	1.06	1.02	14	15.88	14.73	14.49	13.53
3	1.00	0.94	0.93	0.91	15	12.26	11.91	11.81	11.49
4	1.70	1.67	1.66	1.61	16	8.69	8.51	8.43	8.26
5	1.78	1.76	1.75	1.70	17	5.45	5.30	5.26	5.11
6	3.62	3.57	3.56	3.54	18	3.93	3.83	3.78	3.67
7	5.02	5.00	4.99	4.95	19	3.44	3.35	3.30	3.21
8	5.94	5.90	5.90	5.88	20	3.62	3.53	3.51	3.44
9	6.63	6.59	6.58	6.57	21	3.20	3.12	3.10	3.03
10	10.11	10.08	10.07	10.06	22	2.68	2.62	2.60	2.54
11	12.88	12.83	12.79	12.70	23	2.82	2.74	2.73	2.66

Table 2: HIP by changes in wind velocity. Unit : HIP(°C)

However, it was observed that existence of a fence did not significantly affect the temperature. Figure 8 shows that with the same wind velocity (2m/s) the surface temperature distribution was not significantly affected by the existence of fence but by materials of the ground, vegetation, trees, and so forth.

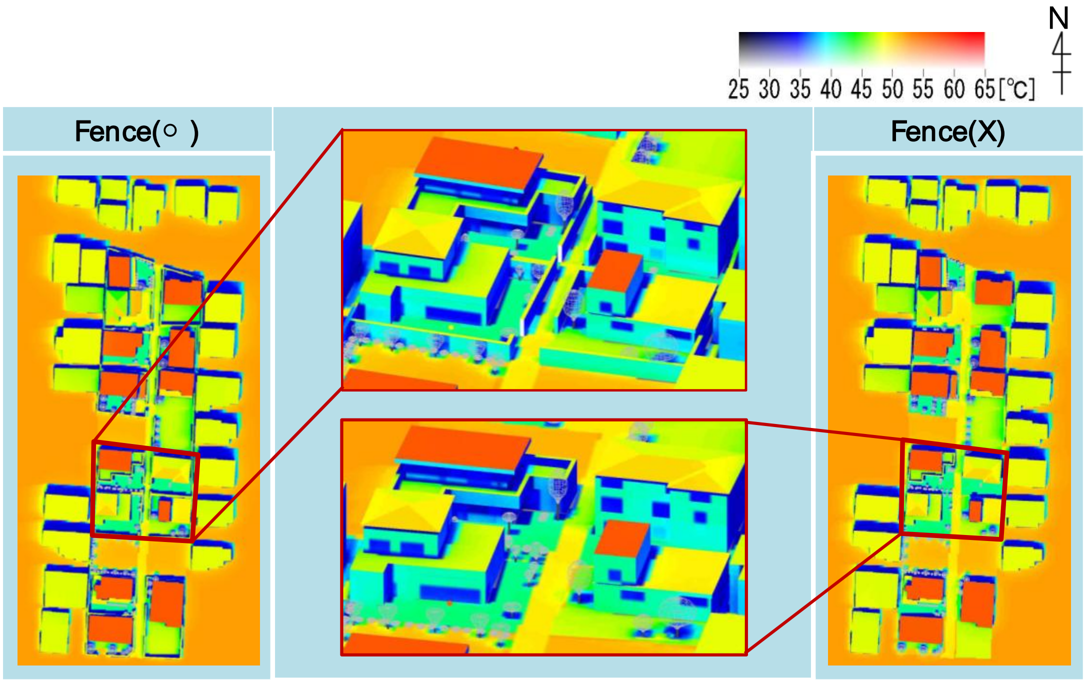

Fig. 8: Surface temperature distribution due to the presence of the fence.(wind velocity: 2m/s)

4.3.5 Tree planting

Various circumstances and methods should be taken into account in order to improve the thermal environment. Particularly, a site facing the west, which has the highest reflected heat from the ground or built structures around 15:00 should be considered sufficiently when greening methods are used to lower the surface temperature. Hence, this study also examined the temperature distribution according to the height of trees. Figure 9 shows that higher trees are more effective in blocking solar radiation and thus lowering the temperatures.

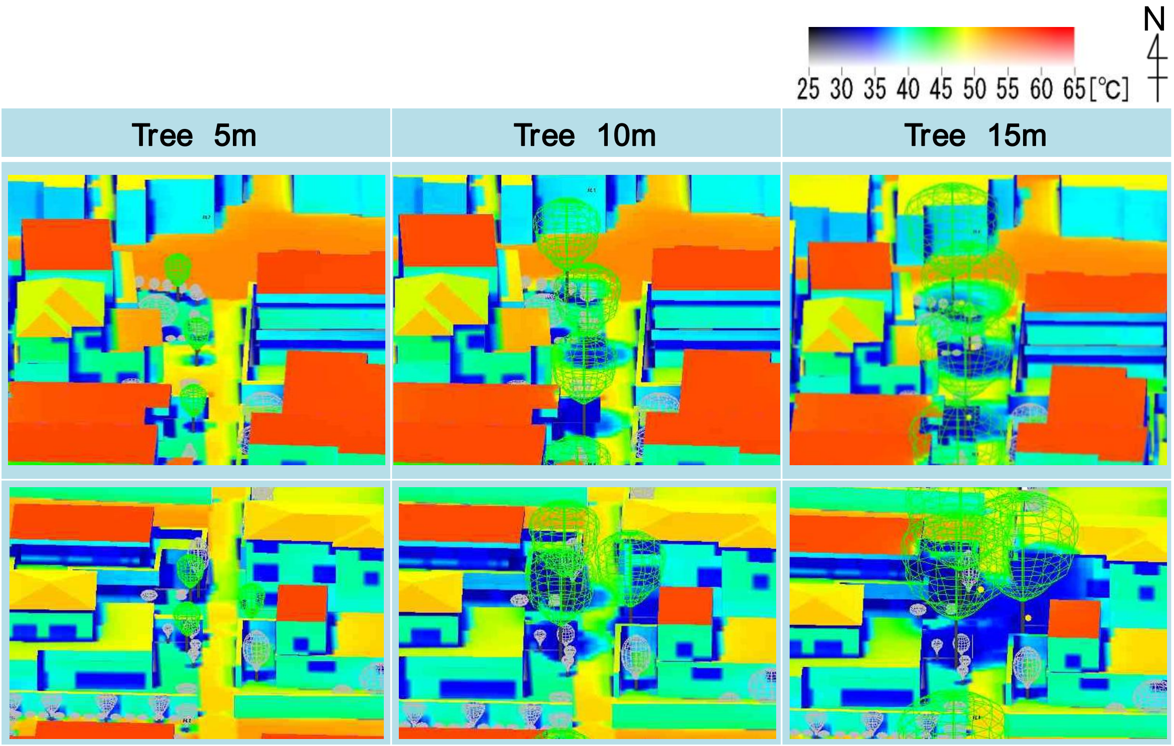

Fig. 9: Surface temperature distribution according to the height of trees

5 CONCLUSION

The purpose of this study is to increase thermal comfort within a detached housing area by improving the thermal environment. Therefore, it suggests application of various greening methods, taking into account the materials and shape of the outdoor space, as a systematic approach to reducing sensible heat by lowering the surface temperature.

As to Case 1 and Case 2, there was no significant difference in the surface temperatures within the detached housing area, but Case 1 showed lower surface temperature distribution around the fence due to shade during the daytime. Case 3 showed the low surface temperature distribution of 10℃ around the planted trees during the daytime and temperature of 15℃ around the green roof. With respect to MRT the green roof showed a temperature difference of 3℃ or more and the vacant land covered by the grass also showed a difference of 2~3℃. In addition, Case 3 with increased green coverage showed the temperature 10℃ lower than Case 2.

Meanwhile, changes in the wind velocity may cause dispersion of sensible heat and thus affect the temperature. And higher trees are more effective in blocking solar radiation and lowering the temperatures.

The study results indicate that controlling the surface temperature of the built environment is critical to improving the thermal environment and increasing thermal comfort within the detached housing area. Because wind and humidity as well as temperatures affect human senses and behaviors, the shape and layout of space should allow a constant and effective flow of wind within a detached housing area.

Therefore, it is important to predict and assess the thermal environment at an early stage, using computer simulations, to design pleasant space in terms of the thermal environment. However, it may not be practical to identify thermal characteristics of a detached housing area within limited time. Hence, we can analyze thermal characteristics identified from simulations in order to provide effective feedback for space design.

It is possible to identify and analyze thermal characteristics, using the data of HIP or the surface temperature distribution provided by simulations, and to utilize the results for another space design. Therefore, it is significant that this study has identified the thermal characteristics of an actual detached housing area and explored the possibility that the results can be used as effective indicators for designing general residential space and for determining when to carry out thermal environment analysis.

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