Determination of search radius for urban heat evaluation according to urban form

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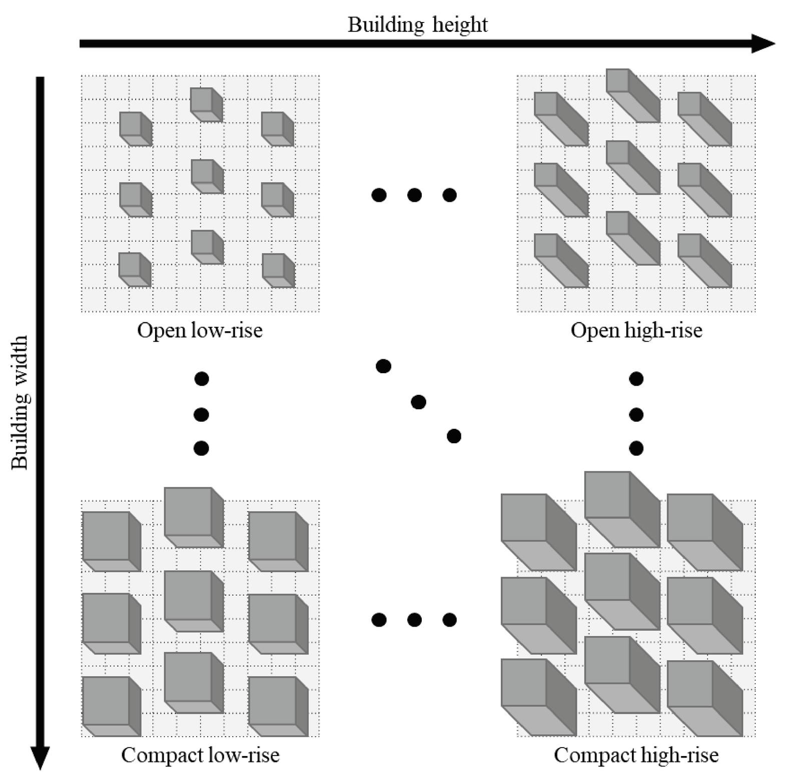
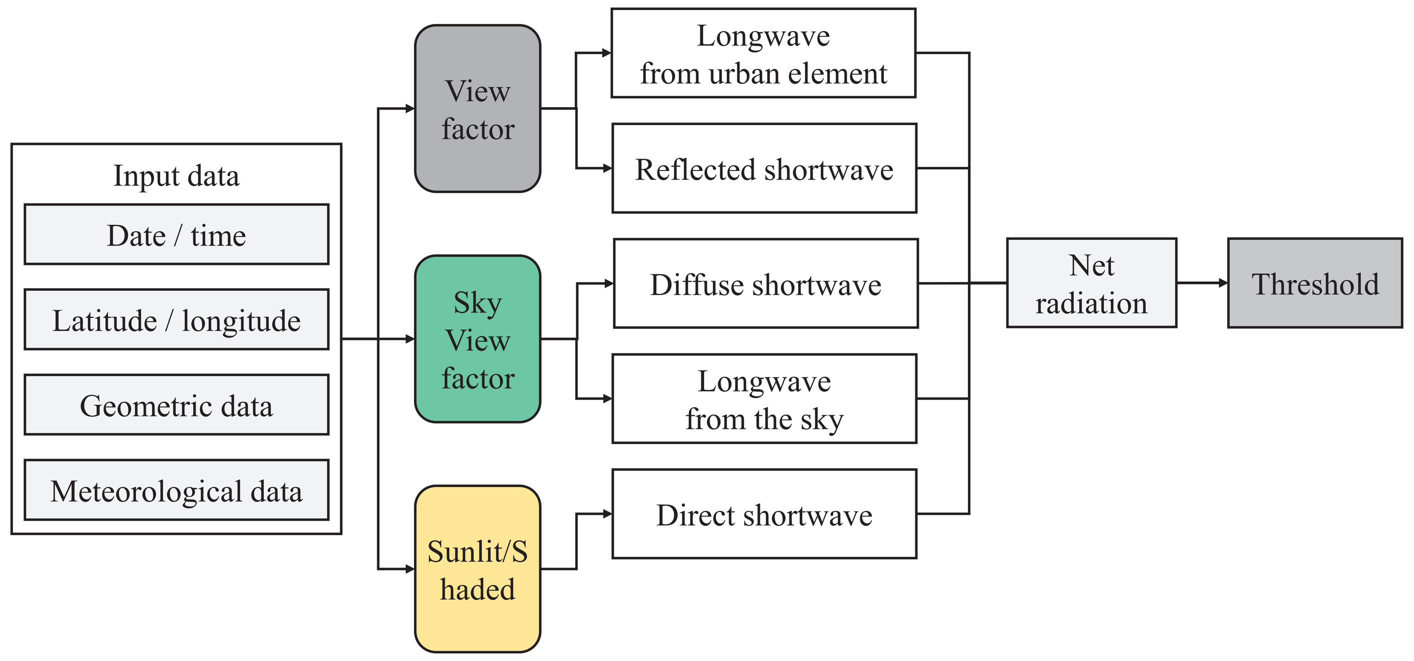
Background

Urbanization increases the absorption of solar radiation by increasing impervious surfaces, reduces evapotranspiration, and increases artificial heat, causing many problems. Evaluating the thermal environment of the city is becoming important. However, there is no generalized criterion for an appropriate search radius for evaluating thermal environment. This study aims to determine search radius for precise evaluation of urban heat. As the radius which is the range of the surrounding search increases, we studied the extent to which the error of net radiation decreases and proposed an appropriate search radius according to various urban form. For analysis, we developed three dimensional urban surface model simulating radiation transfer. In addition, we compared net radiation between various urban form using the aforementioned results and this also could be used for urban planning.

Reseach flow



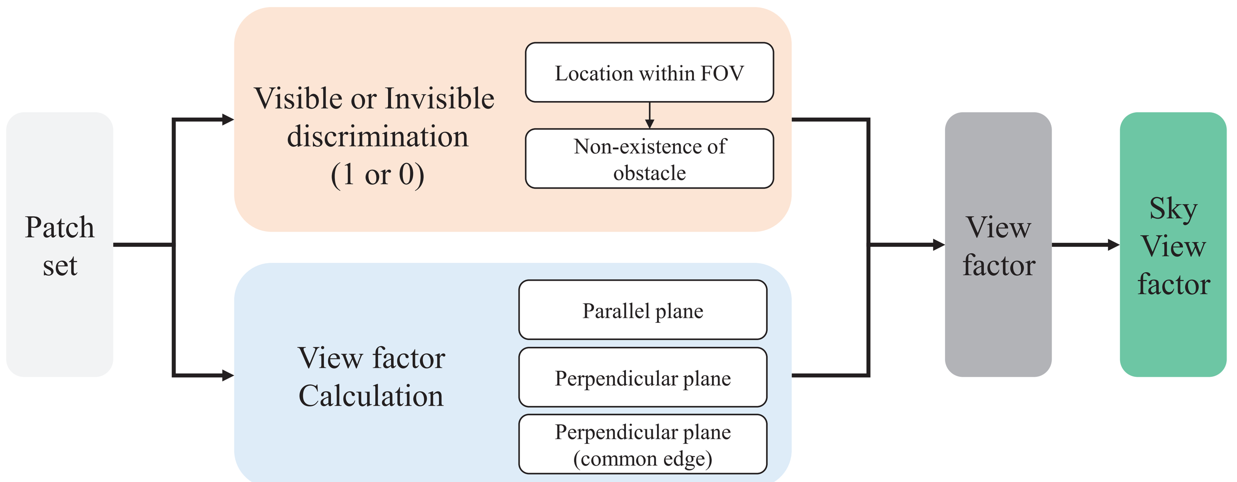
To reflect various urban form, the ratio of the height of the building, the width of the building, and the width of the road in the model domain were adjusted based on LCZ(local climate zone). If the buildings were listed in a row, the error of SVF is not large and it would not embrace most of the urban space type, so buildings are placed in a unevenly constant pattern.



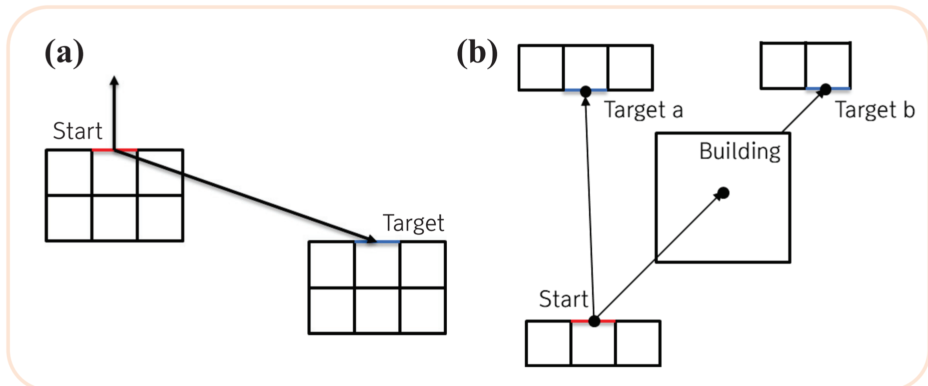
The main parameter were calculated using input data, then radiation transfer process were simulated. And finally, change pattern of the appropriate search radius according to the urban form was analyzed using net radiation.

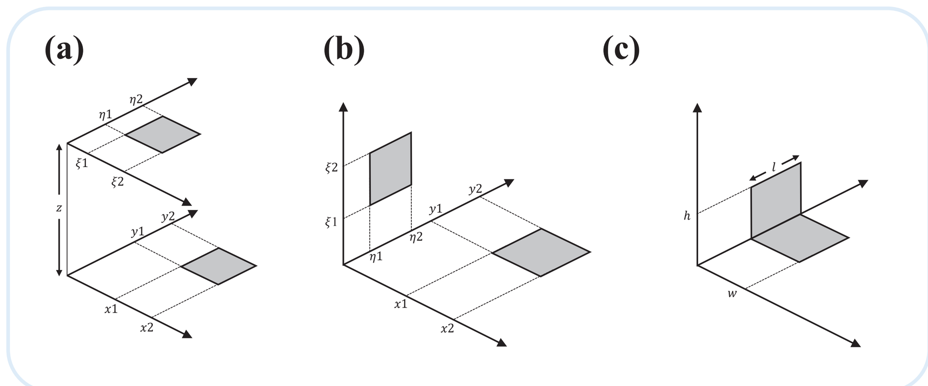
Methodology

Data processing

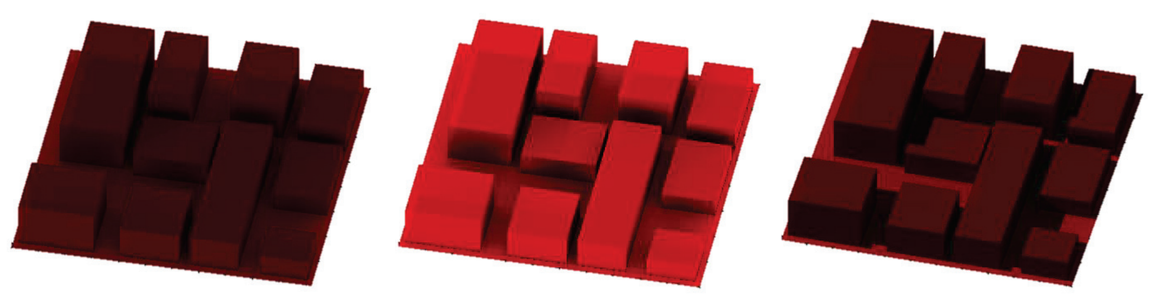


A key part of the 3-dimentional simulation model is the calculation of the (sky) view factors. First, patch set (start patch and target patch) was selected. Next the target patch was identified visible or invisible patch. And view factor was calculated by three formulas for each surface relationship. Finally, sky view factor was calculated using view factor.





We determine which patch was in a FOV(field of view) using dot product, then it was checked whether there are other patch(building) in a way between two patches. And view factor of 'seen' patches were calculated using analytic calculation Howell, 1982). The calculations were divided into three cases for each surface relationship; in a parallel plane, perpendicular plane, and perpendicular plane having common edge.



Example of results (09:00, 12:00, and 15:00)

The radiation transfer process were calculated method developed from MMRT(multilayer mean radiant temperature) model (Park et al., 2018). This process included direct shortwave, diffuse shortwave, reflected shortwave, longwave from the sky, and longwave from urban elements(patches). For the analysis of net radiation, we selected a day (9th July, 2020 1400 LST, Air temperature: 34.3°C, wind velocity: 2.9m/s, relative humidity: 52%).

Results & Discussions

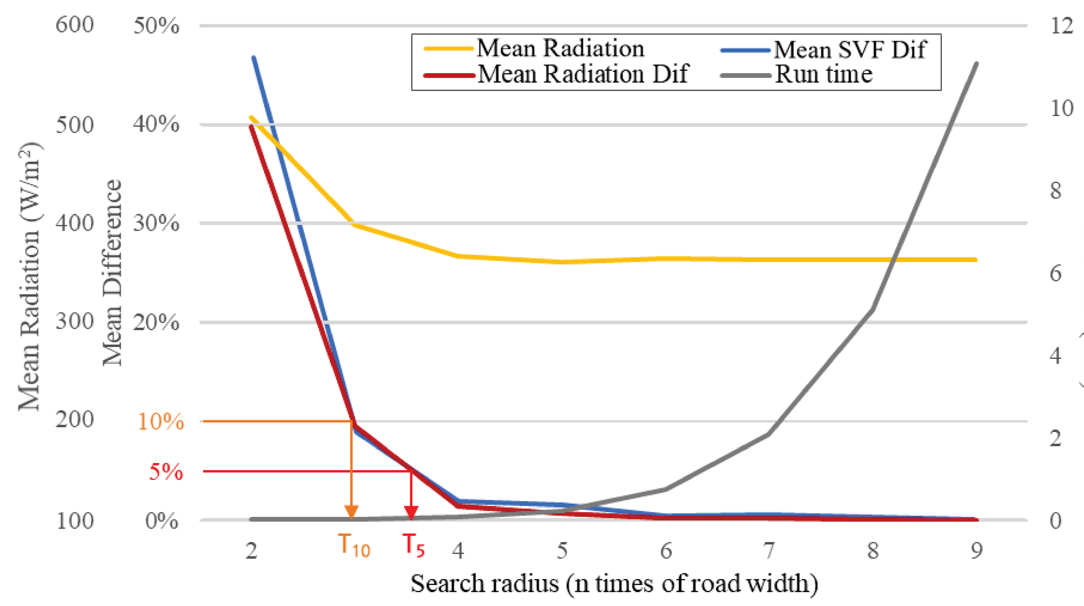


Fig a. Change of Net radiation and run time with search radius

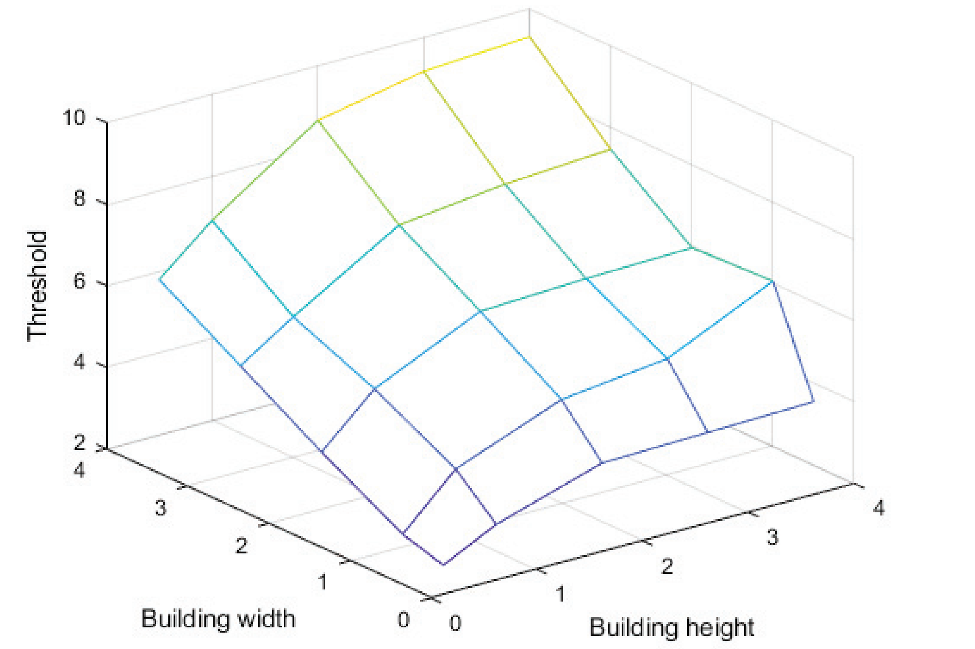


Fig b. Threshold of search radius according to net radiation

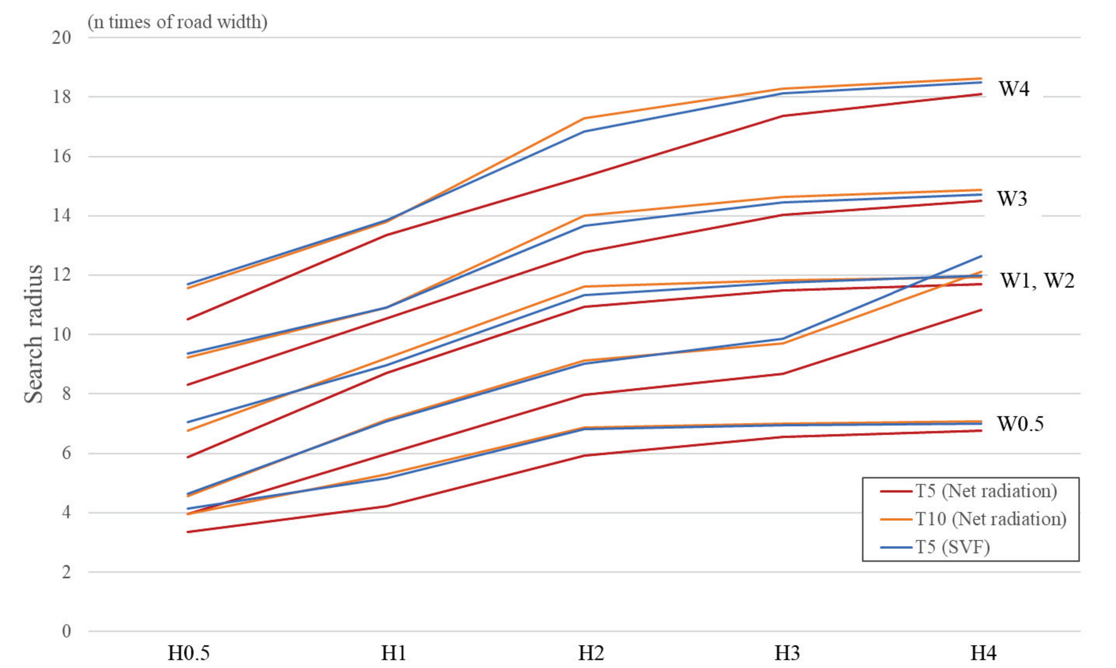


Fig c. The difference of threshold (T5, T10 of Net radiation and T5 of SVF)

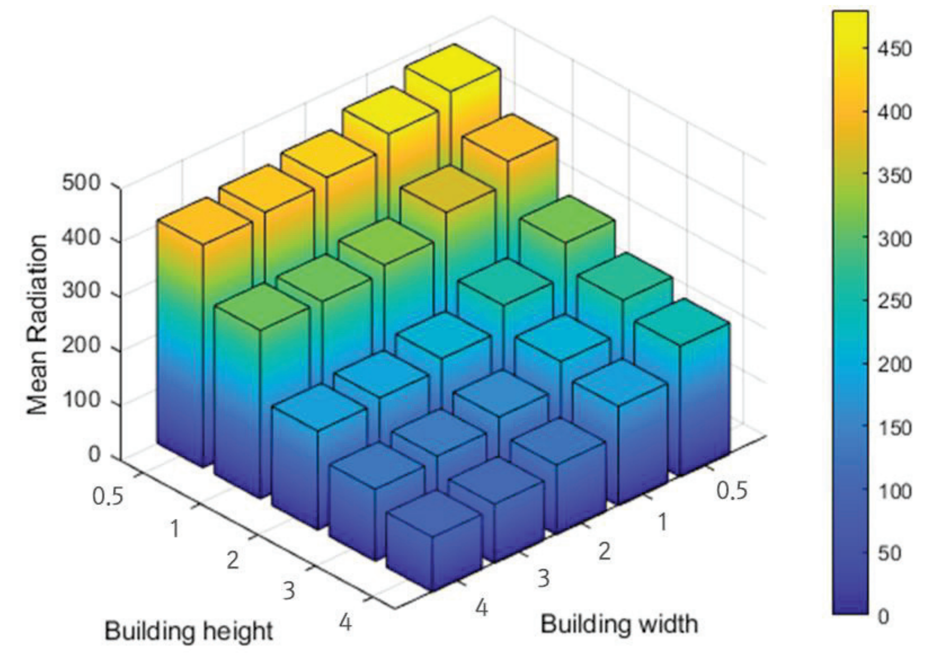


Fig d. Net radiation(W/m²) by urban form

As the search radius increased, errors of net radiation were significantly reduced and, conversely, the run time of model was significantly increased(Fig a). Building width affected threshold more than building height(Fig b). There was no significant difference in the threshold of two viewpoints, SVF and net radiation(Fig c). This result means that the SVF-based threshold is meaningful in terms of the actual thermal environment. Due to the high elevation of the sun position at 2 PM, the shadow area was small, so the influence of SVF on net radiant heat may be relatively high compared to other factors. T5 and T10 (threshold at less than 5% and 10% error) made a little difference(Fig c). The thermal environment varied sharply according to urban form because high-rise skyline reduced incoming shortwave radiation(Fig d). Unlike threshold pattern, building height affected urban heat more then building width.

Conclusions

This study provides an appropriate search radius that varies depending on the urban form. The width of the building had a greater impact on the threshold then height as opposed to net radiation pattern. When evaluating or modeling urban heat, it can provide a guide to determine the size of the space to consider. In terms of urban planning, it can also help determine the spatial units for creating a cooling city. It can be a more detailed guide when other factors(e.g. trees) as well as buildings are included.

Appendix

Equations for view factor

Parallel plane

$$F_{1-2} = \frac{1}{(x_2-x_1)(y_2-y_1)} \sum_{l=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{2}\left[(-1)^{(i+j+k+l)} G(x_i, y_j, \eta_k, \xi_l)\right]$$

$$G = \frac{1}{2\pi}\left\{(y-\eta)(x^2+\xi^2)^{\frac{1}{2}}\tan^{-1}(K) - \frac{1}{4}(x^2+\xi^2)(1-K^2)\ln[(x^2+\xi^2)(1+K^2)]\right\}$$

Buck, A. L. (1981)

Perpendicular plane

$$F_{1-2} = \frac{1}{(x_2-x_1)(y_2-y_1)} \sum_{l=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{2}\left[(-1)^{(i+j+k+l)} G(x_i, y_j, \eta_k, \xi_l)\right]$$

$$G = \frac{1}{2\pi}\begin{pmatrix} (y-\eta)[(x-\xi)^2+z^2]^{1/2}\tan^{-1}\left\{\frac{y-\eta}{[(x-\xi)^2+z^2]^{1/2}}\right\} \\ +(x-\xi)[(y-\eta)^2+z^2]^{1/2}\tan^{-1}\left\{\frac{x-\xi}{[(y-\eta)^2+z^2]^{1/2}}\right\} \end{pmatrix} - \frac{z^2}{2}\ln[(x-\xi)^2+(y-\eta)^2+z^2]$$

Buck, A. L. (1996)

Perpendicular plane (common edge)

$$F_{1-2} = \frac{1}{W\pi}\left(W\tan^{-1}\frac{1}{W} + H\tan^{-1}\frac{1}{H} - \sqrt{W^2+H^2}\tan^{-1}\sqrt{\frac{1}{W^2+H^2}} + \right.$$

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