Development of a 3D urban canopy model for evaluating cooling effect of urban green space

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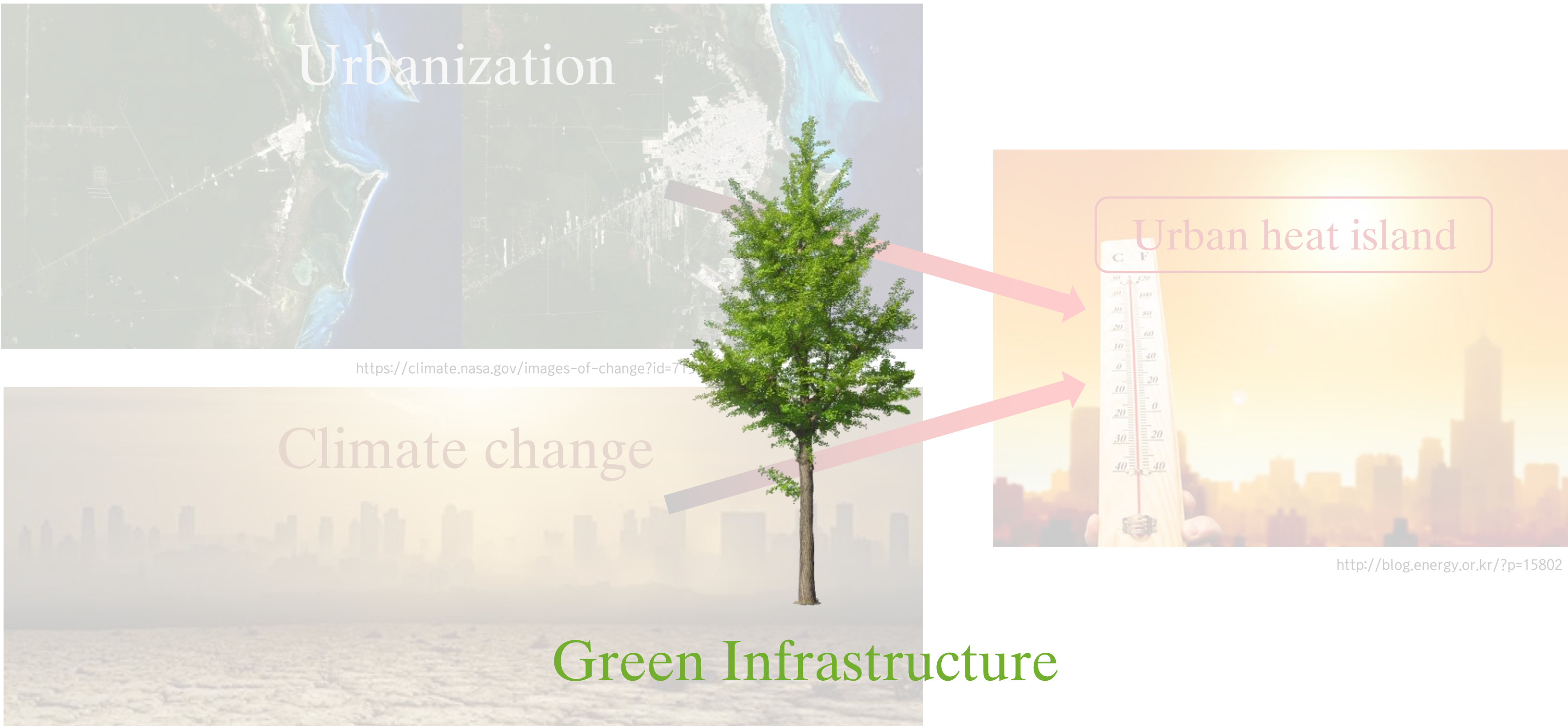
Introduction

https://climate.nasa.gov/images-of-change?id=713#713-growth-of-cancn,-mexico

http://www.climatechangecenter.kr/%EA%B8%B0%ED%9B%84%EB%B3%80%ED%99%94%EB%9E%80/

http://blog.energy.or.kr/?p=15802

Introduction



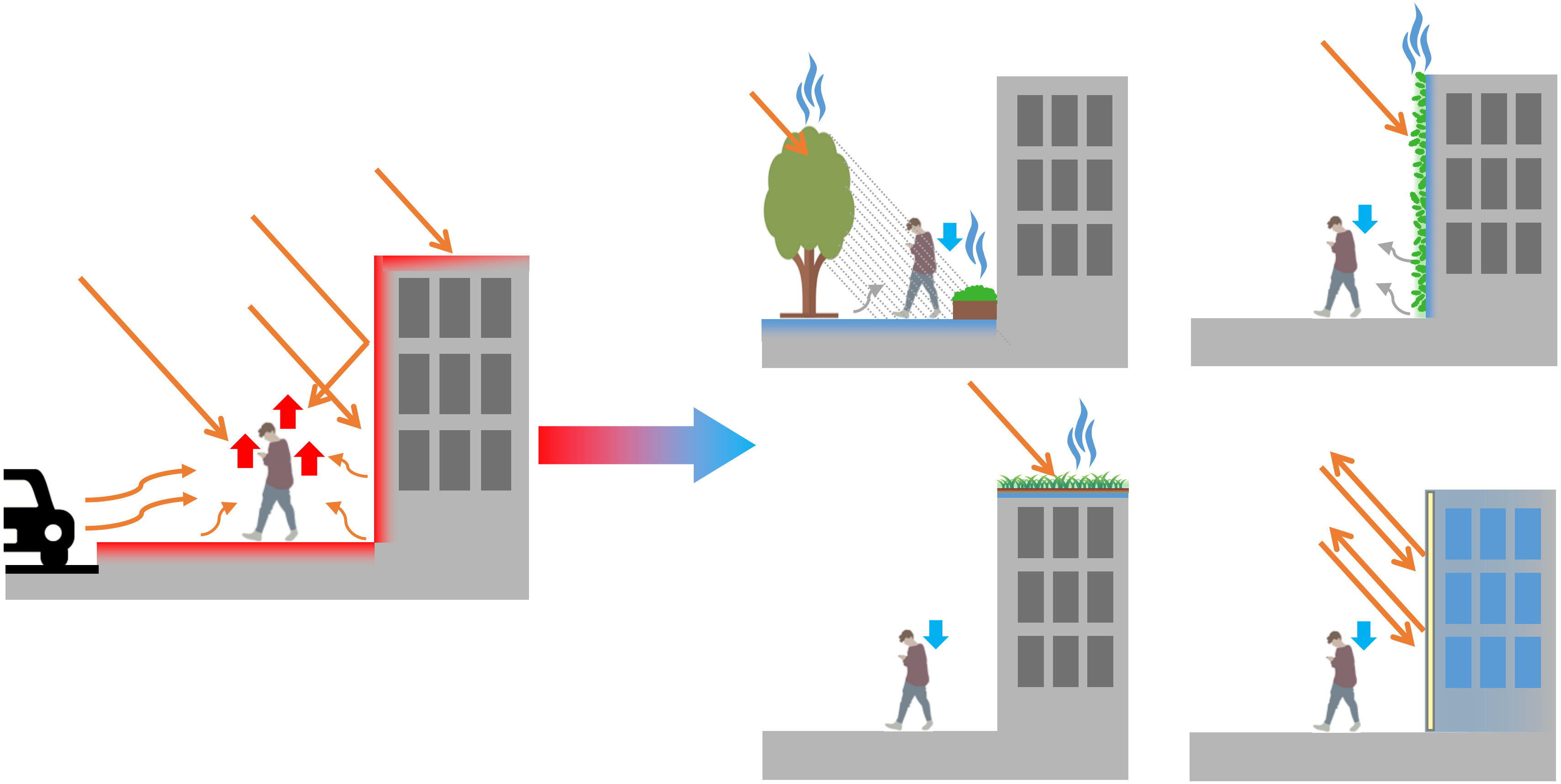
https://climate.nasa.gov/images-of-change?id=7

http://blog.energy.or.kr/?p=15802

http://www.climatechangecenter.kr/%EA%B8%B0%ED%9B%84%EB%B3%80%ED%99%94%EB%9E%80/

Research purpose

☑ 3D urban energy balance model



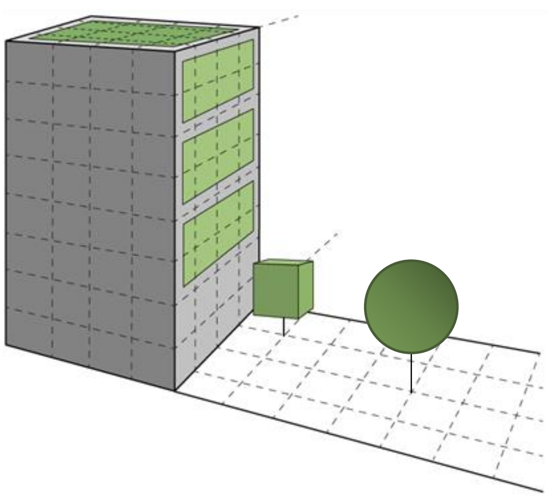
➢ To mitigate effectively

➢ Develop a 3D urban energy balance model for evaluating urban green space effects

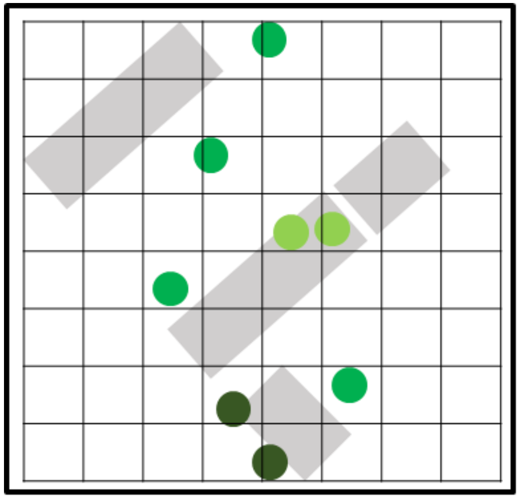
Research purpose

☑ 3D urban energy balance model

- Reflect various types of urban spaces and apply green infrastructure
- Diagnose thermal status according to urban spatial structure and materials



< 3D Structure>



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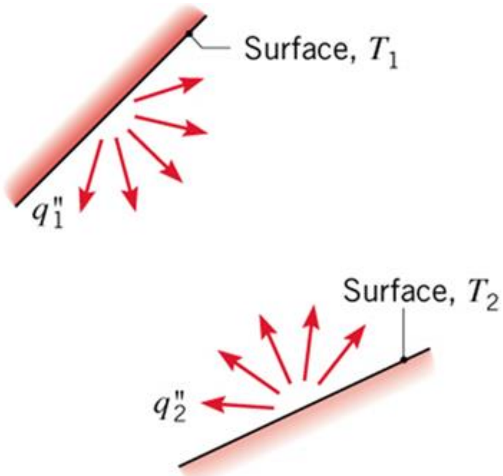
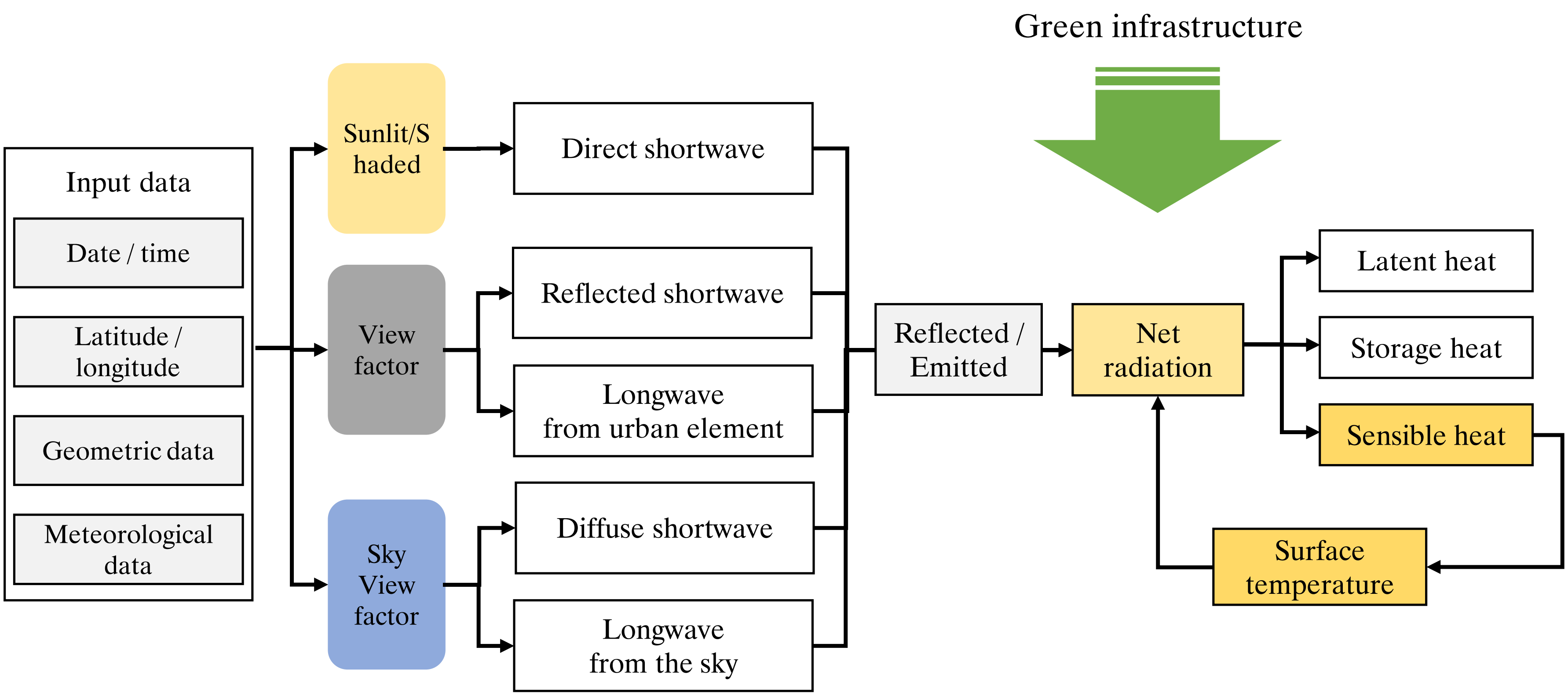


< Radiation transfer >

Modeling

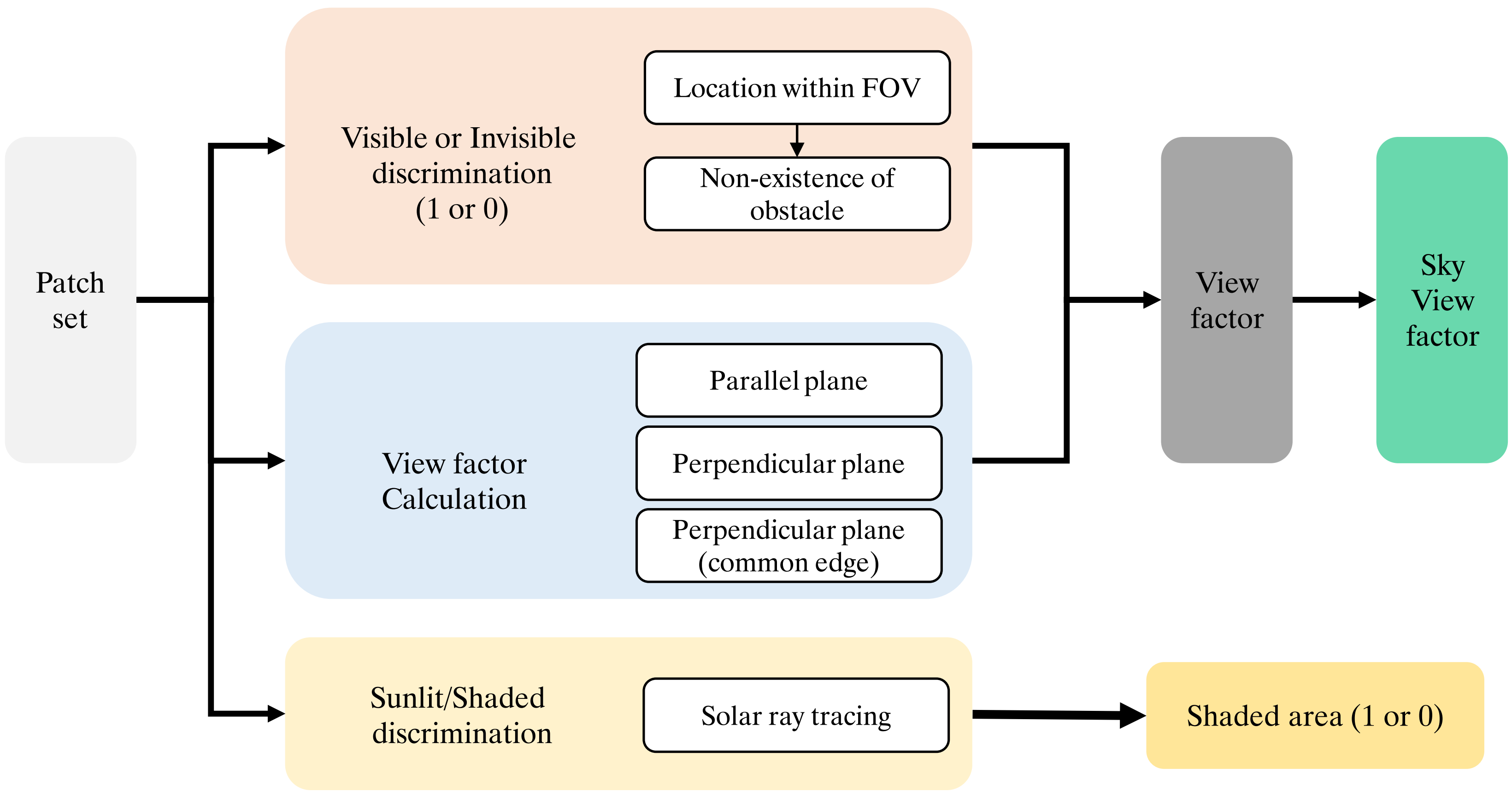
Process

- Calculate main spatial parameters according to the spatial structure, location and date
- Simulate radiation heat transfer and calculate heat budget considering meteorological data



Parameter

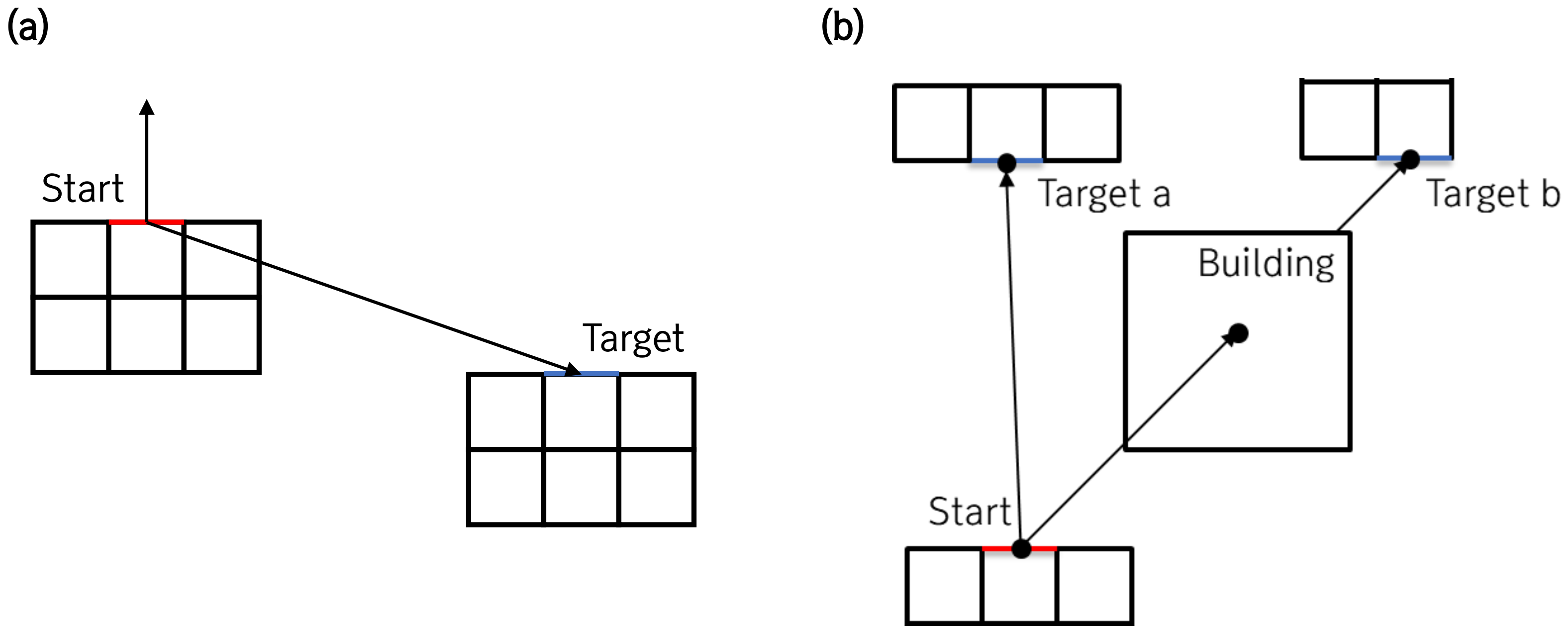
Parameter calculation



VF Calculation

☑ Parameter calculation - View Factor

- Visible or Invisible discrimination (1 or 0)



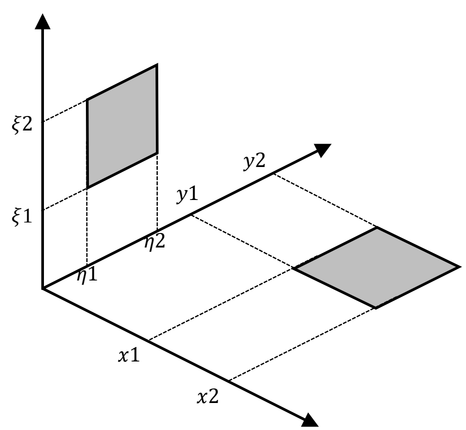
(a) Within FOV(field of view), (b) Non-existence of obstacle

VF Calculation

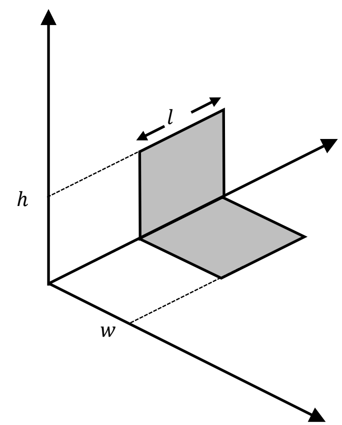
Parameter calculation - View Factor

- Calculation of View Factor by dividing tree inter-surface relationships

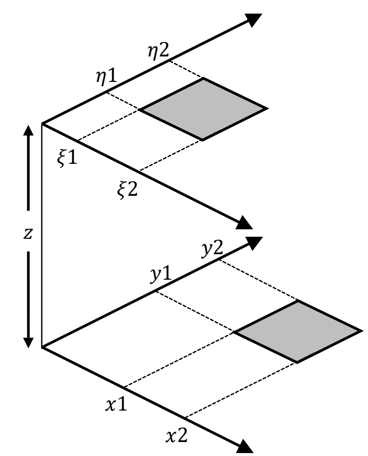
(1) Perpendicular plane



(2) Perpendicular plane (common edge)



(3) Parallel plane



Between walls or ground in different directions

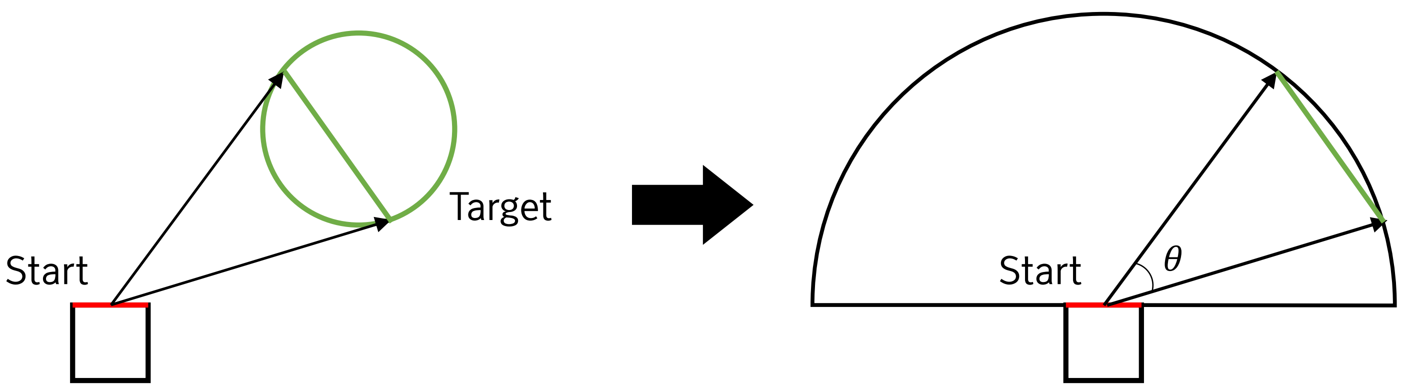
Between wall and roof

Between walls in the same direction

VF Calculation

Parameter calculation - View Factor

- Calculation of (Spherical tree) View Factor as the ratio of the outer area



$VF =$ 

$$= 1 - \cos\frac{\theta}{2}$$

SVF Calculation

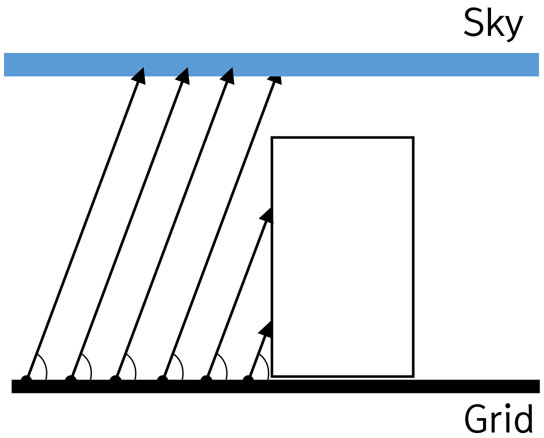
☑ Parameter calculation - Sky View Factor

- Subtract the sum of view factor from each surface (i) to all surfaces ($1,2,3, \dots , \mathrm{n}$) from 1

$$\mathrm{SVF}_i = 1 - \sum_{k=1}^{n} ViewFactor_{i,k}$$

☑ Parameter calculation - Sunlit/Shaded

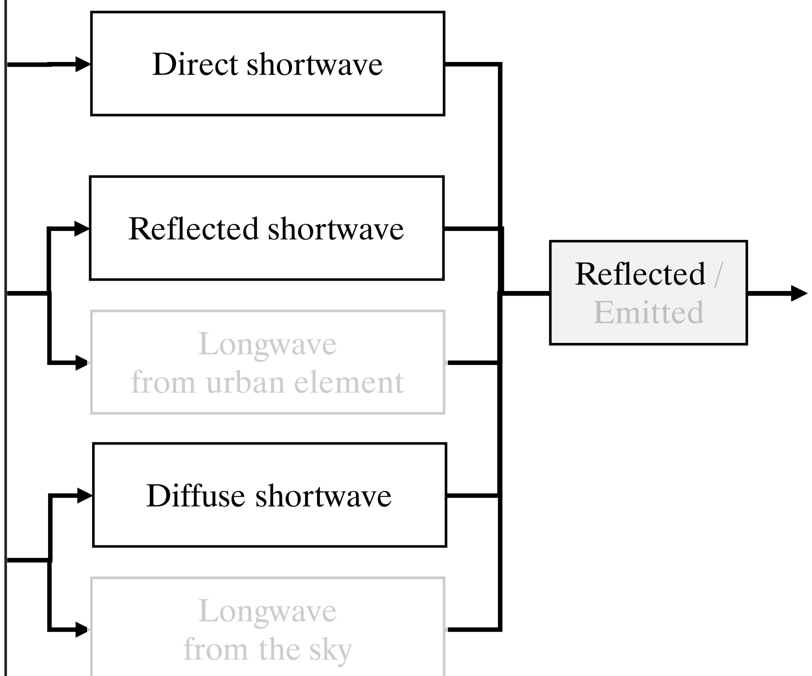
- Determine whether there is a intersection at the angle of solar radiation from the center of each grid



Radiation transfer

Shortwave length radiation

- Incident SW = Direct + Diffuse + Reflected(入) from element
- Leaving(出) SW = reflected from incident SW



1. SW radiation entering the atmosphere from global and extraterrestrial solar radiation (← location, date, time)
2. Divide into direct and diffuse radiation (← cloud fraction)
3. Direct SW (← sunlit/shaded)

$$S_{dir} \times P_{sunlit/shaded}$$

4. Diffuse SW (← SVF)

$$S_{dif} \times SVF$$

5. Leaving (入) SW (← VF)

$$\sum_{i=2}^{n} (S_{out(i)} \times F_{i\to 1})$$

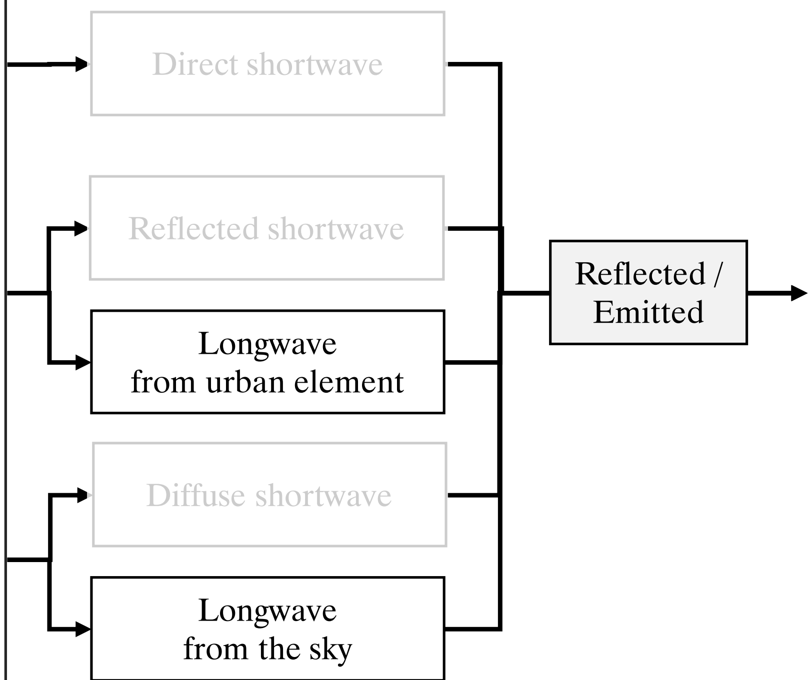
6. Reflected(出) SW (← albedo)

$$S_{out} = S_{in} \times a$$

Radiation transfer

Longwave length radiation

- Incident LW = from sky + from element
- Leaving LW = reflected LW + emitted LW



1. Atmosphere LW

   (← air temperature, water vapor pressure, cloud fraction)

   $$(\varepsilon_s + (1 - \varepsilon_s)F_c)\sigma T_a{}^4$$

2. LW from sky (← SVF)

   $$L_{sky} \times SVF$$

3. LW from urban element (← VF)

   $$\sum_{i=2}^{n} (L_{out(i)} \times F_{i \to 1})$$

4. Reflected LW (← emissivity)

   $$(1 - \varepsilon_0)L_{in}$$

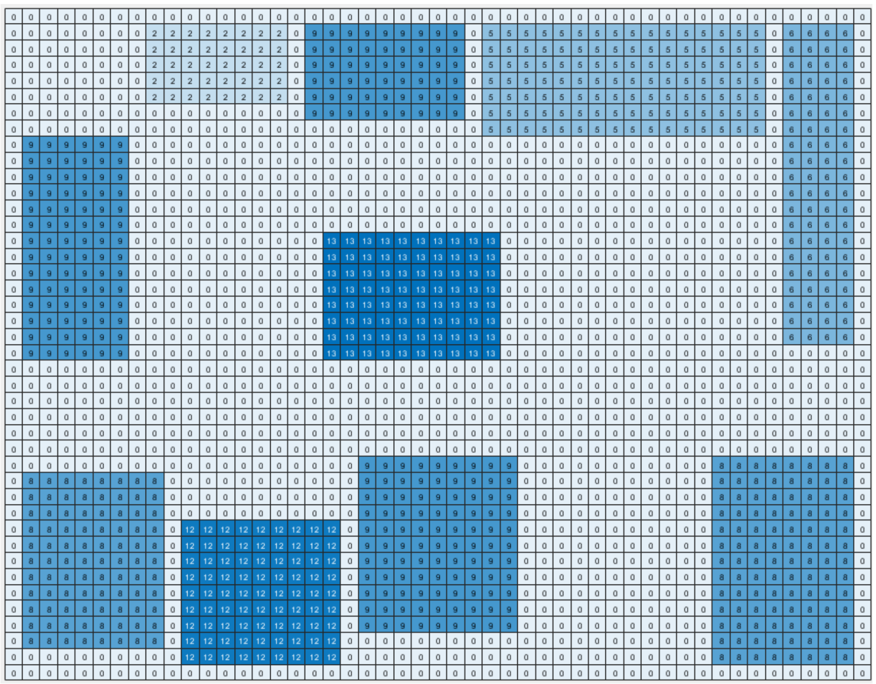
5. Emitted LW (← emissivity, surface temperature)

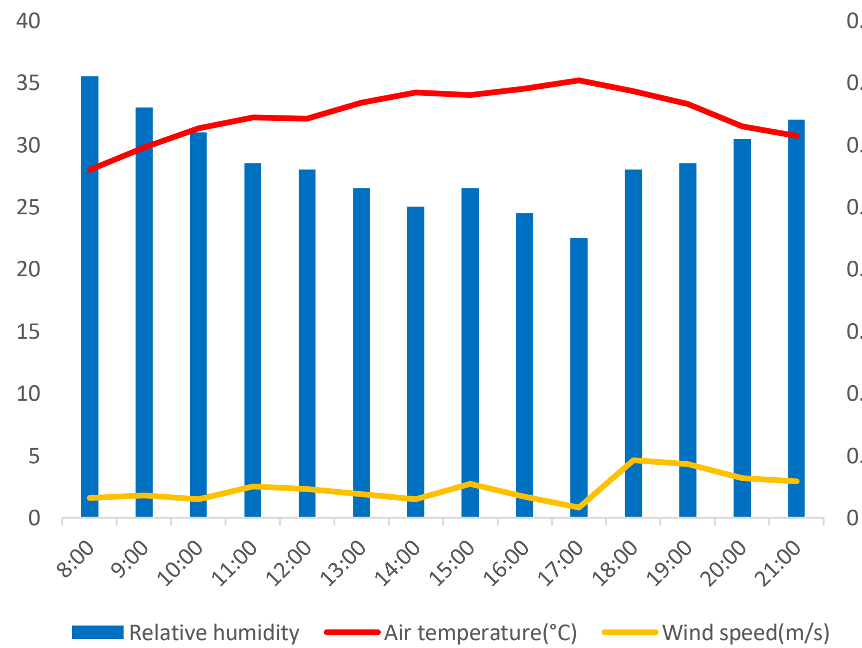
   $$\sigma \varepsilon_0 T_s{}^4$$

Simulation

Case analysis

- Seoul, Korea (Mid-rise commercial area). latitude longitude 37.614, 127.046)
- 10 buildings. The average height is 16.2m.
- 2021/07/27 07:00 (sunrise time) to 19:00 (sunset time)

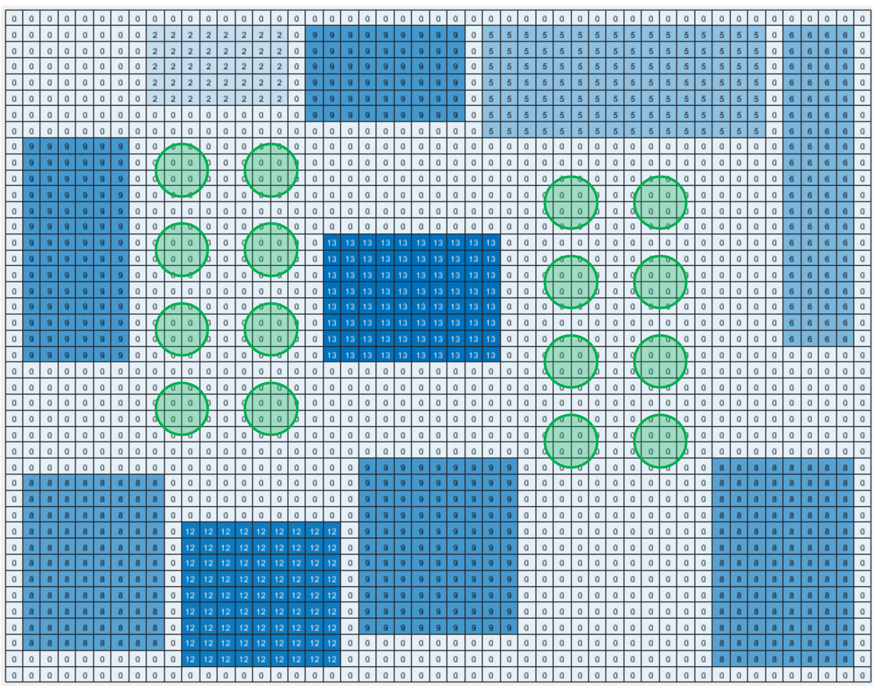




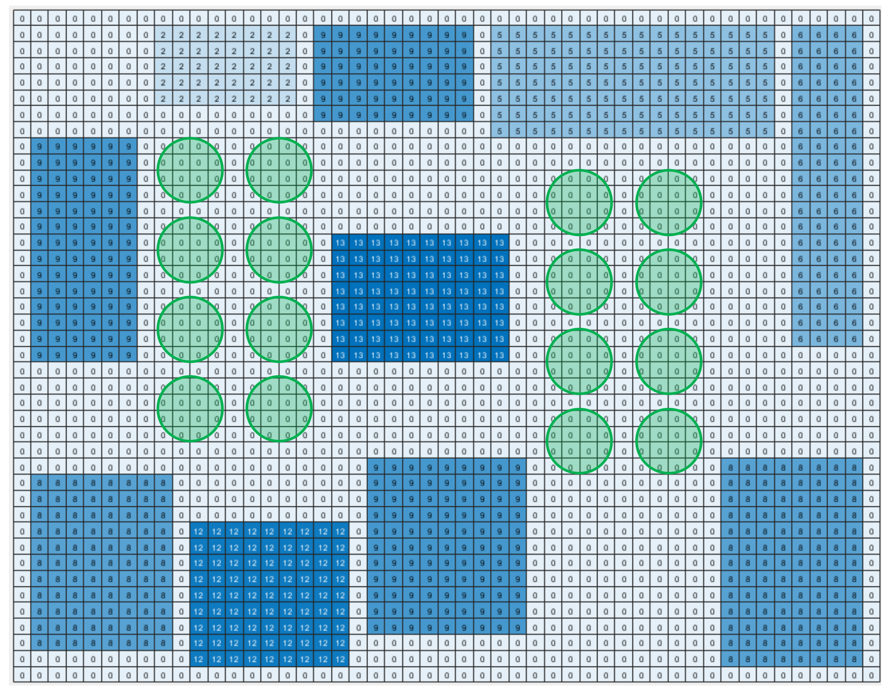
Simulation

Case analysis

- Crown width: 6m (small), 8m (big)
- Height: 13m (small), 15m (big)
- LAD: 0.5



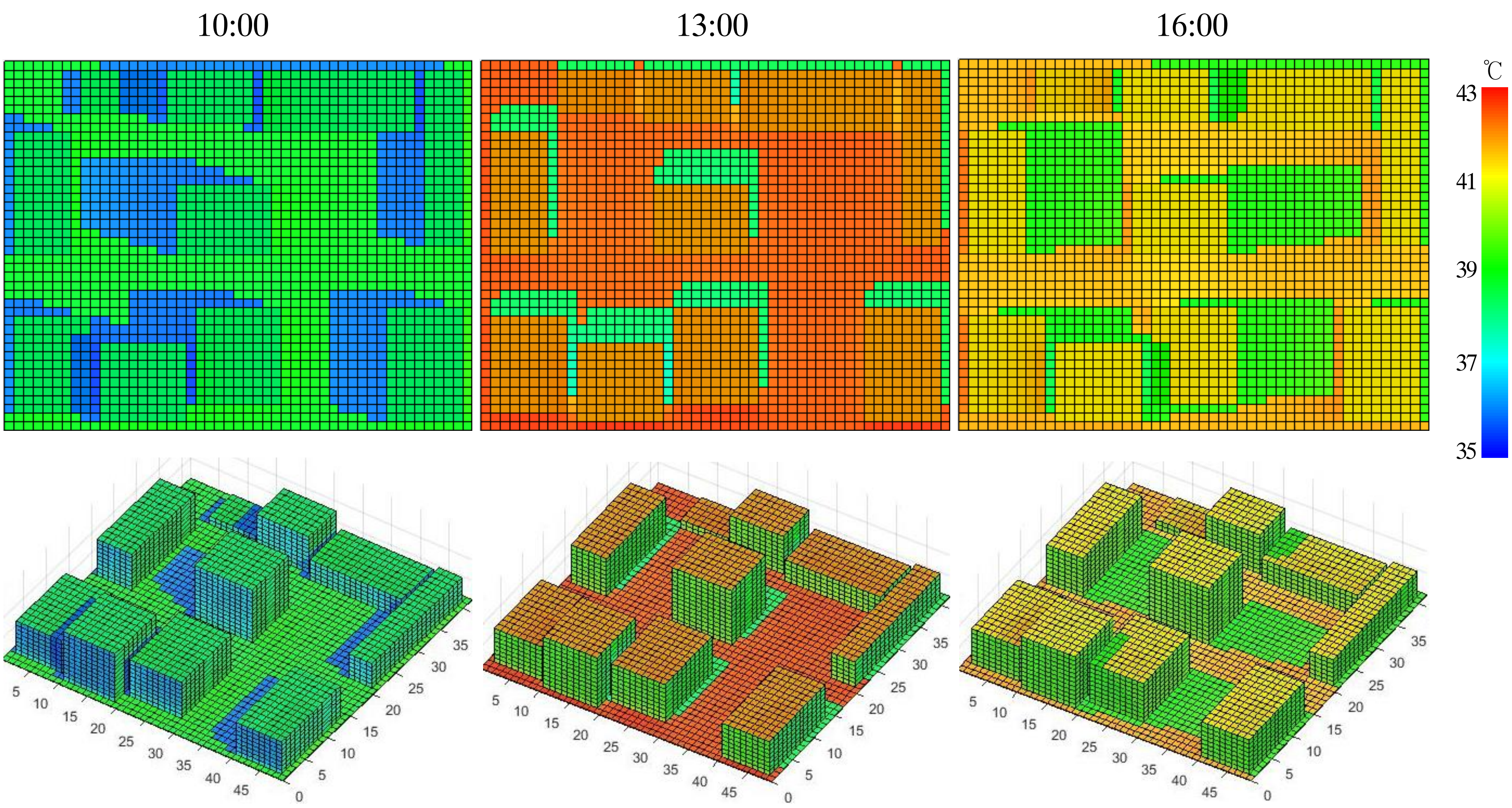
Scenario 1: small trees



Scenario 2: big trees

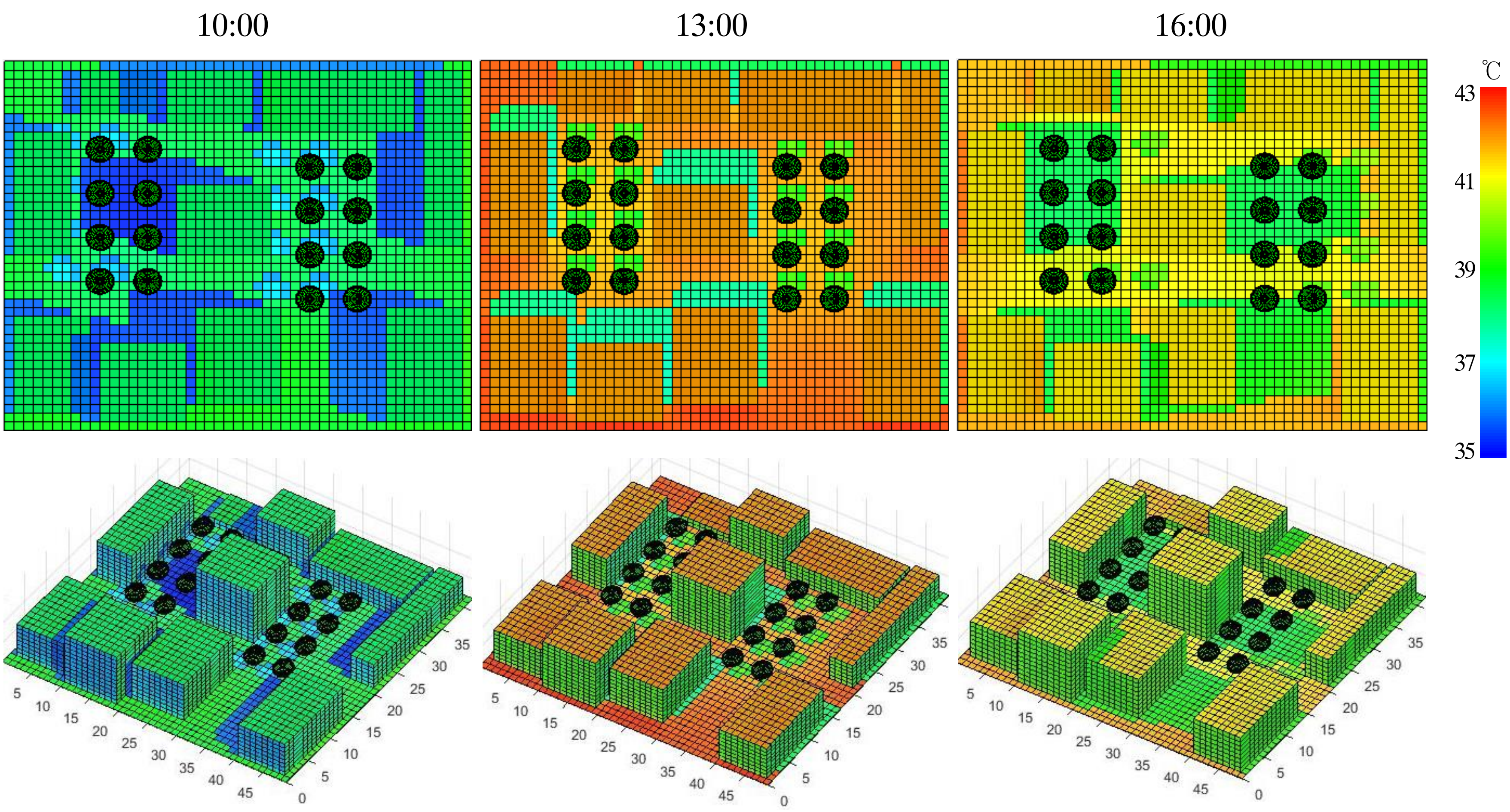
Results

☑ Base scenario (no tree)



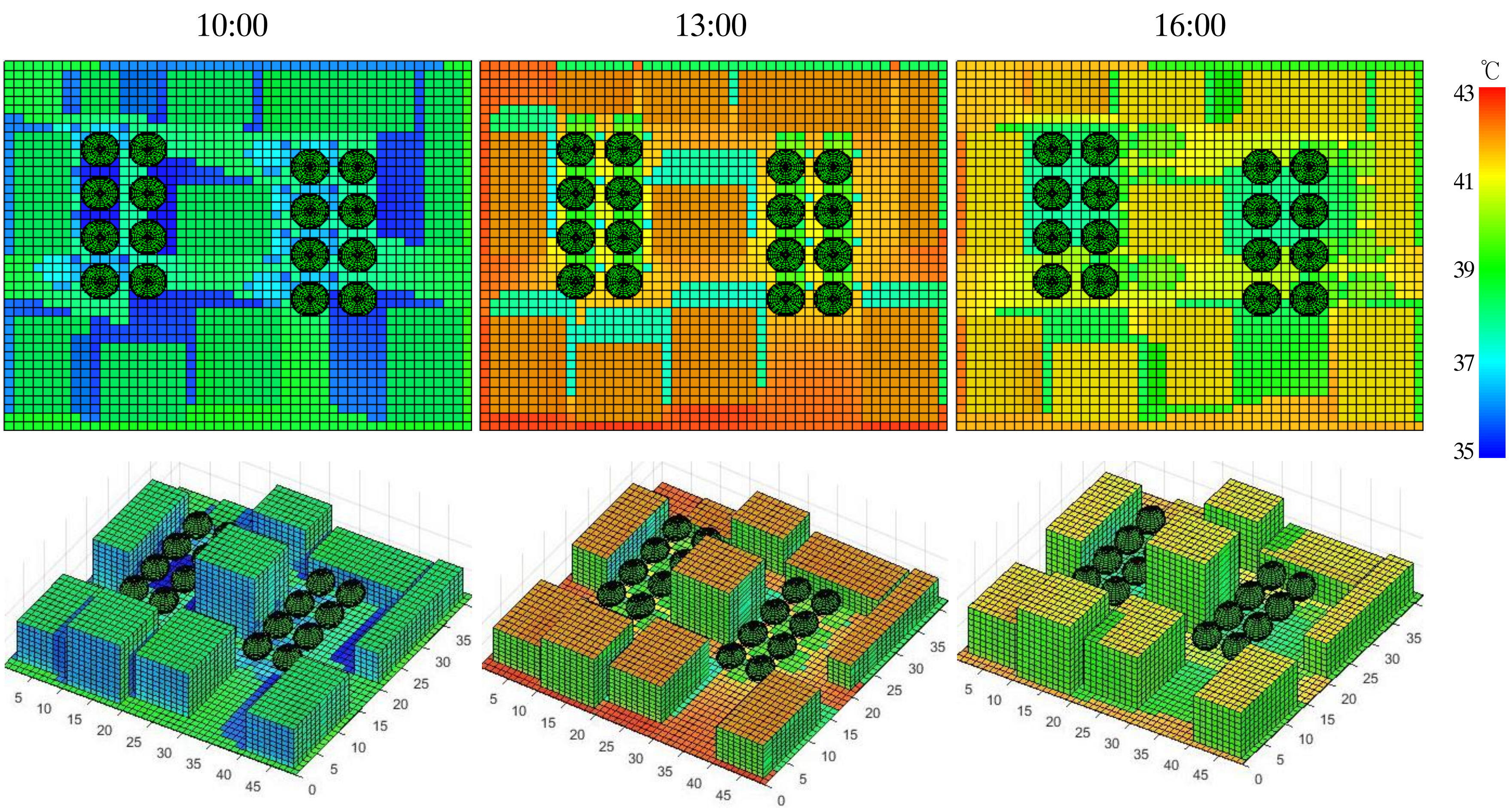
Results

Scenario 1 (small trees)



Results

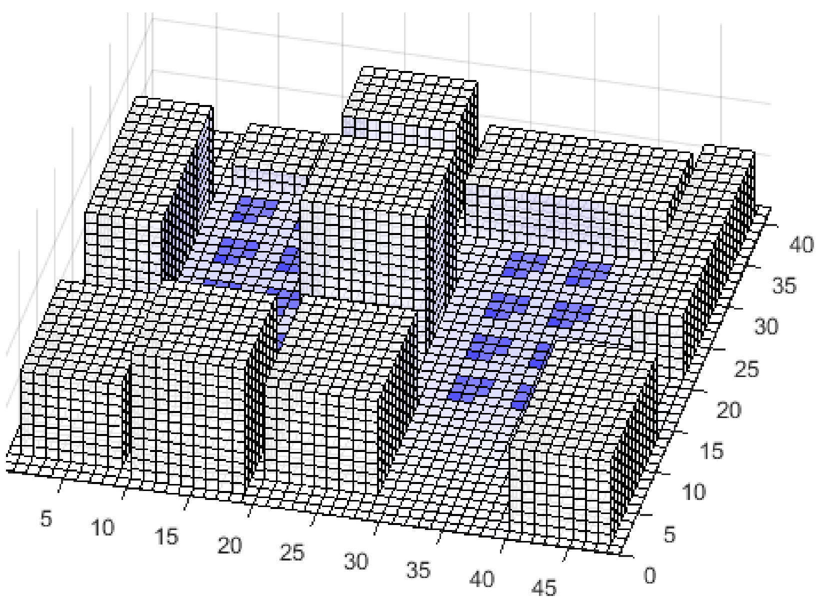
Scenario 2 (big trees)



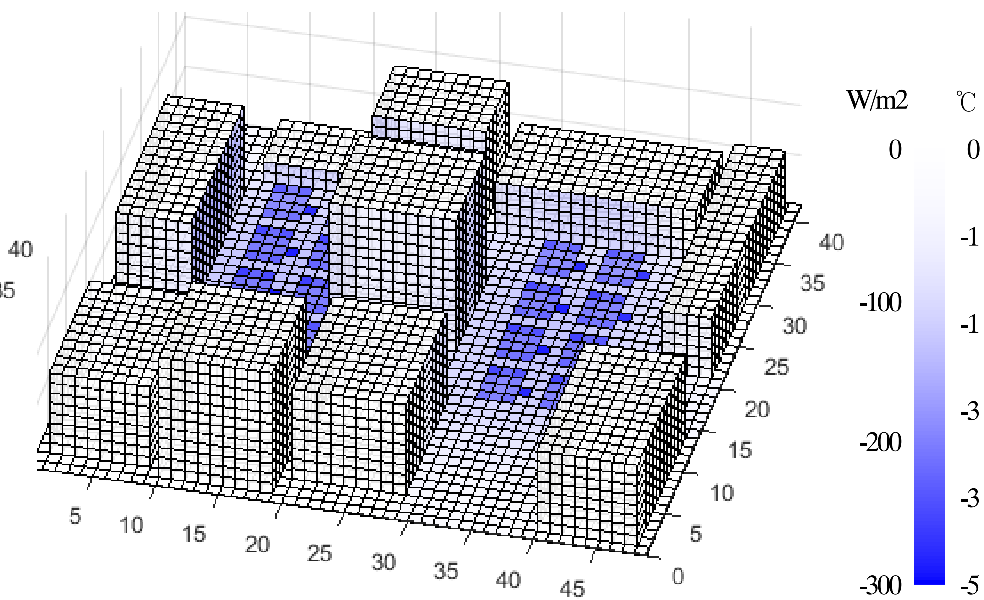
Results

Cooling effect

Scenario 1 – Base scenario



Scenario 2 – Base scenario



- Surface temperature decreases up to 5 degrees in both scenario
- Because the net radiation has been reduced by up to 300 W/m^2 due to tree shadow
- Big trees provide greater effects with dark shadows in shaded areas, and SVF reduction in surrounding areas

Conclusion

☑ Evaluating cooling effect of tree in 3D urban area

- Detailed 3D urban space thermal environment simulation
- Reflect various urban spaces and trees
- Convection and conduction are not reflected
- Validation required

☑ Future research plan

- Reflect latent heat flux in detail
- Application various greening (green roof, living wall) & Artificial structure (awning screens)
- Effective decision support for planting design

Appendix

Parallel plane

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

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

Buck, A. L. (1981)

Perpendicular plane

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

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

Buck, A. L. (1996)

Perpendicular plane (common edge)

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