Evaluation of CO_2 reduction effects of buildings with green roofs by using a coupled urban-canopy and building-energy model

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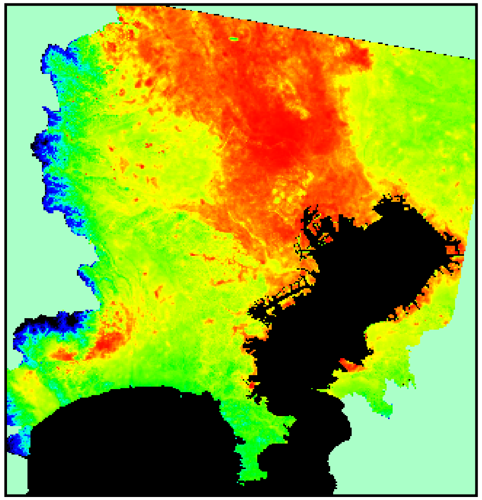
Background and objective

Urban Heat Island



The urban heat island in the summer is an important issue related to energy demands, the livability in residential areas, and the peak electric power load due to use of air-conditioning.

→ It is important to improve the urban thermal environment.

Global Warming

Energy saving is a topic of the utmost importance to prevent global warming.

→ Countermeasures to ever-increasing energy demand for air-conditioning are necessary.

Improving the thermal environment in urban areas is an important issue linked to both the global and urban environment.

Background and objective

Rooftop greening is one measure that can be used to improve the urban thermal environment.

Vegetation is known to be effective for reducing temperatures via **evapotranspiration processes**.

There is only limited room for large ground-greening projects in urban areas.

↓

This has lead to the increased popularity of rooftop greening projects.

Many studies have examined the effectiveness of rooftop greening for **mitigating heat island conditions** and **reducing energy consumption for cooling**, and rooftop greening is thought to be an effective measure for countering the urban heat island.

Background and objective

Previous Research

The evaluations based on actual measurements

If watering is performed to maintain rooftop greening, other environmental loads arise because of factors such as powering pumps.

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The evaluations based on u

It is necessary to accumulate detailed data on the surface heat balance, surface temperature, and the supplied amount of water.

Surface wetness was paramete

efficiency, vegetation community cond nce).

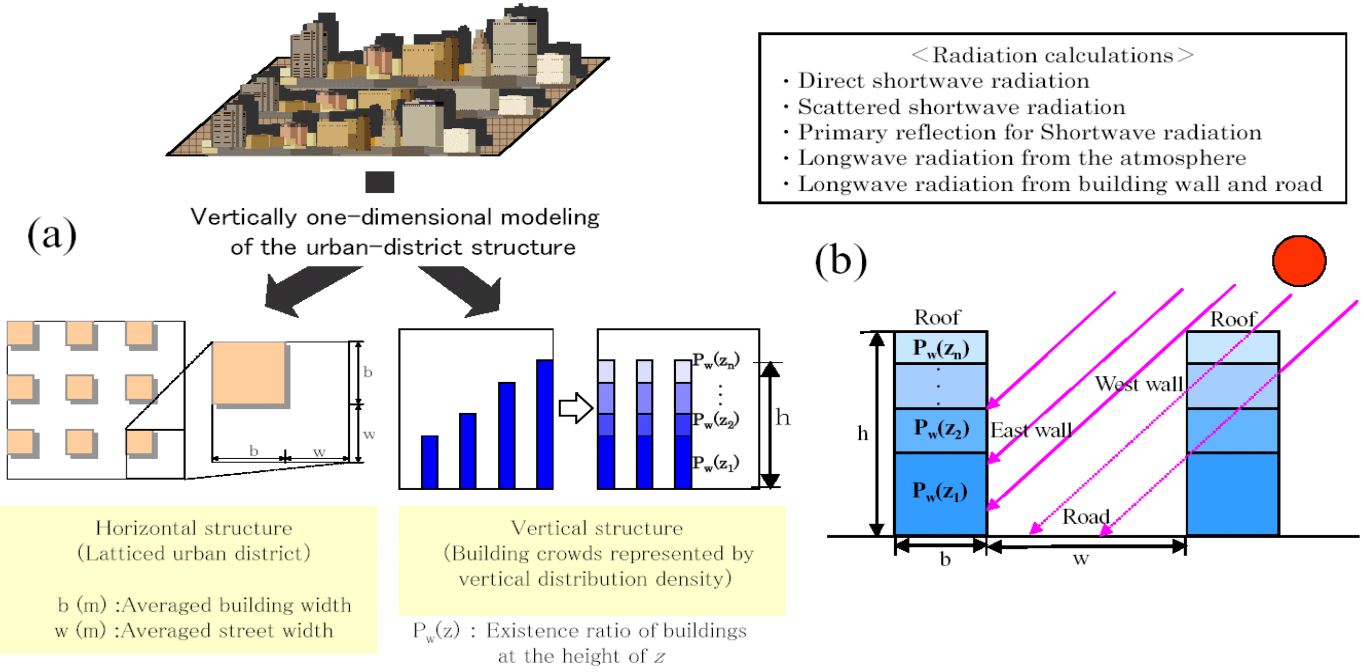
⟶ Calculations were performed without considering the amount of water used.

The objective of this research is to evaluate the effectiveness of rooftop greening in urban districts for the purpose of heat island mitigation and CO$_2$ emission reductions by taking into account the amount of water and needed for watering.

Coupled urban-canopy and building-energy model

The coupled urban-canopy and building-energy model is used for predicting the heat loads of buildings and the changes in air temperature and energy consumption caused by air conditioning in urban districts.

Urban-canopy model



＜Radiation calculations＞

- Direct shortwave radiation
- Scattered shortwave radiation
- Primary reflection for Shortwave radiation
- Longwave radiation from the atmosphere
- Longwave radiation from building wall and road

Horizontal structure
(Latticed urban district)

b (m) :Averaged building width
w (m) :Averaged street width

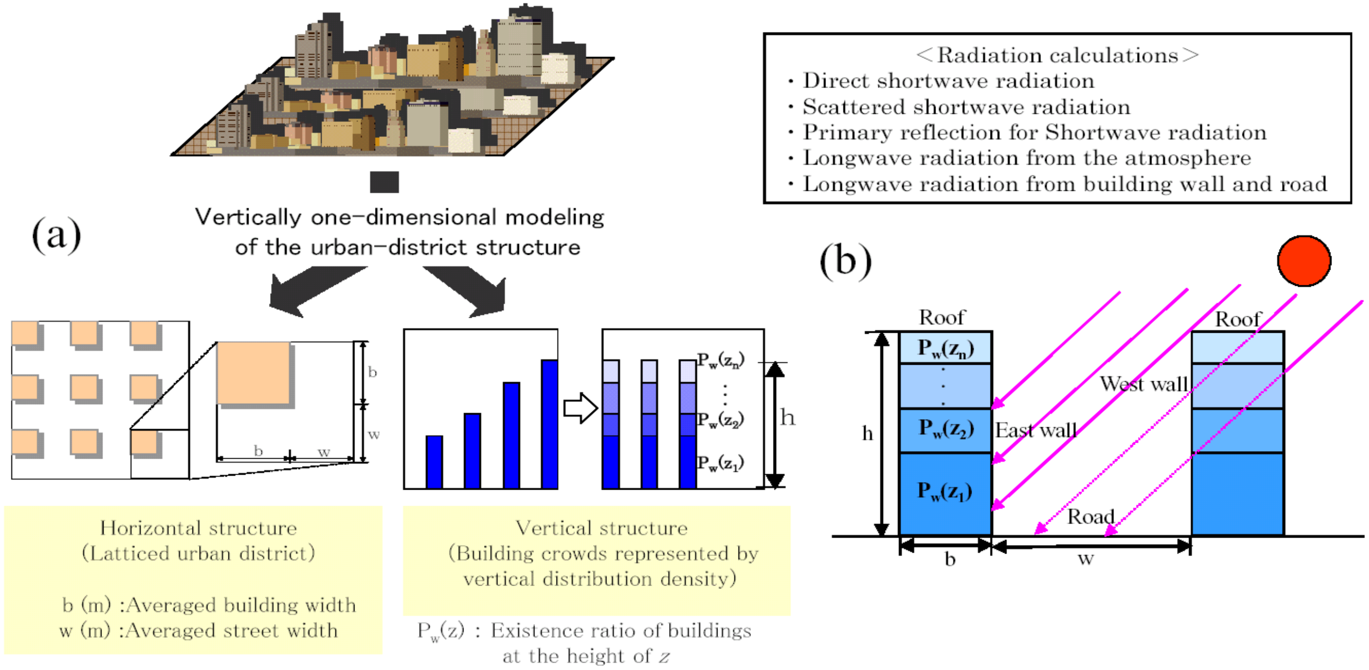
Vertical structure
(Building crowds represented by vertical distribution density)

$P_w(z)$: Existence ratio of buildings at the height of z

Ohashi et al.（2007）Journal of Applied Meteorology and Climatology

The urban-canopy model corresponds to a local atmospheric model that parameterizes city blocks with an average building width, building interval, and vertical distribution of buildings in order to express horizontally homogeneous city blocks as multiple one-dimensional vertical layers.

Urban-canopy model



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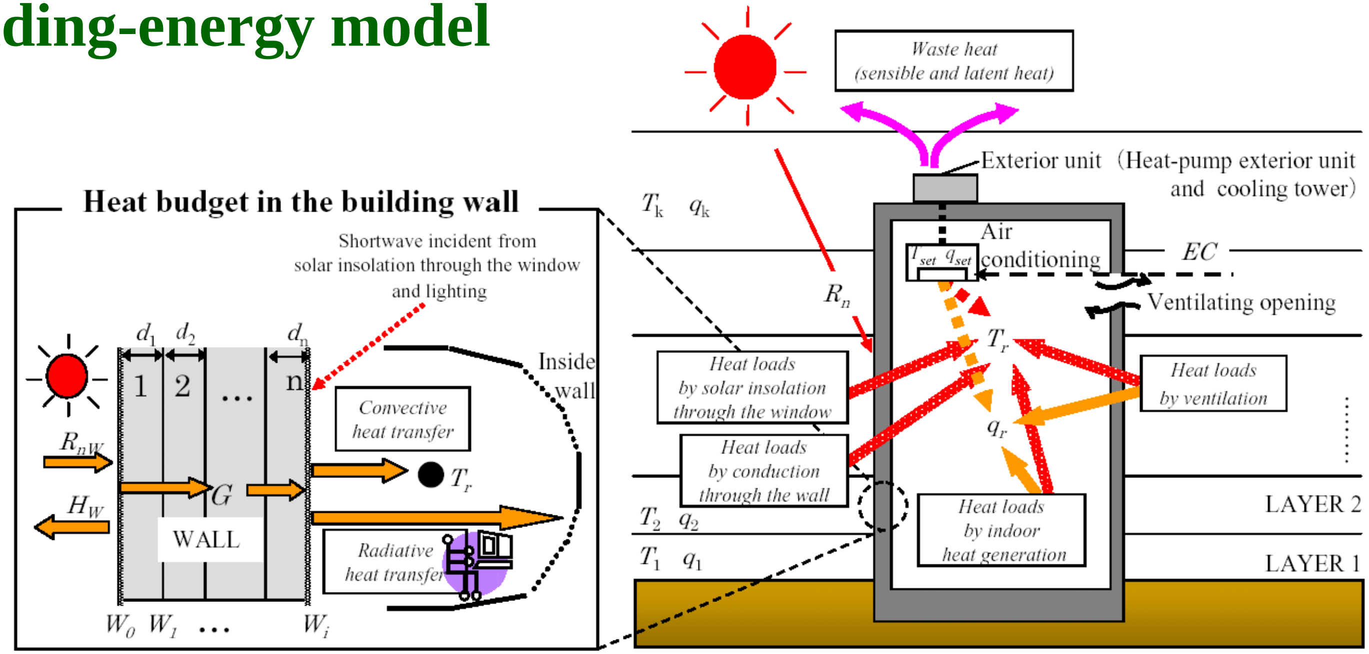
The building-energy model is used for calculating air-conditioning loads, and by incorporating the urban-canopy model, it is capable of calculating city-block-scale air-conditioning loads that include interaction with the outside atmosphere.

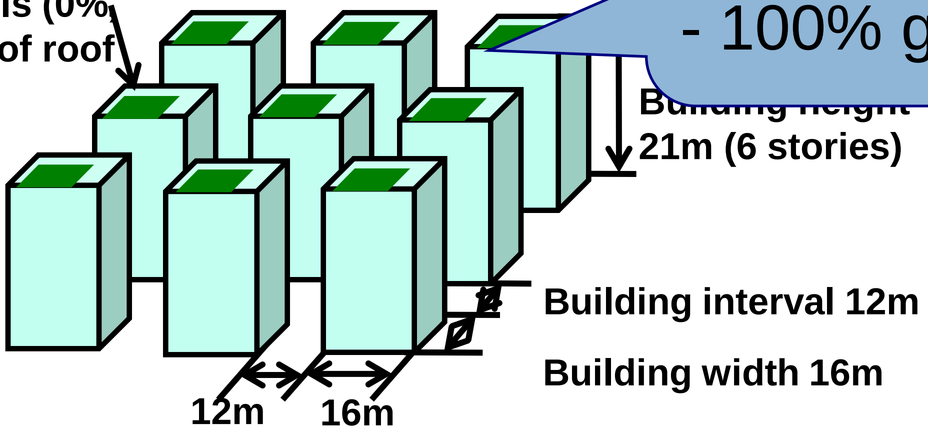
Building-energy model



Ohashi et al.（2007）Journal of Applied Meteorology and Climatology

Calculation condition

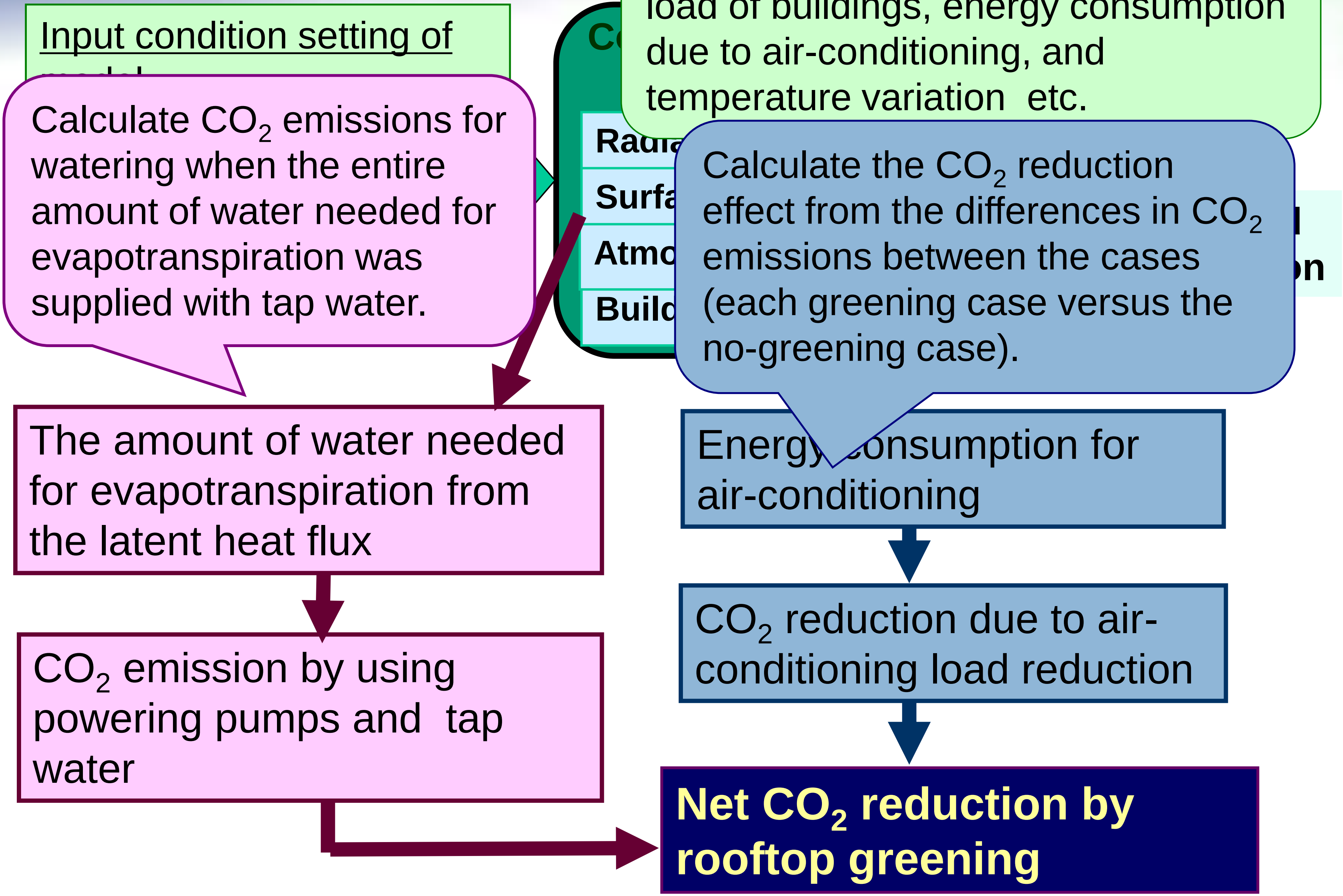
- **Target city block type**: **Office building district**
- **Weather condition**: **A period of consecutive fair weather summer days**
- **Calculation dates**: **August 8-10, 2002**



- No-greening case
- 50% greening case
- 100% greening case

We set the rooftop greening assumptions to three levels of 0%, 50%, and 100% (i.e., a no-greening case, a 50% greening case, and a 100% greening case, respectively).
Other parts of rooftops are set to be concrete surface.

Framework



Input condition setting of model

C

Radia

Surfa

Atmo

Build

on

Predict surface heat balance, heat load of buildings, energy consumption due to air-conditioning, and temperature variation etc.

Calculate CO_2 emissions for watering when the entire amount of water needed for evapotranspiration was supplied with tap water.

Calculate the CO_2 reduction effect from the differences in CO_2 emissions between the cases (each greening case versus the no-greening case).

The amount of water needed for evapotranspiration from the latent heat flux

CO_2 emission by using powering pumps and tap water

Energy consumption for air-conditioning

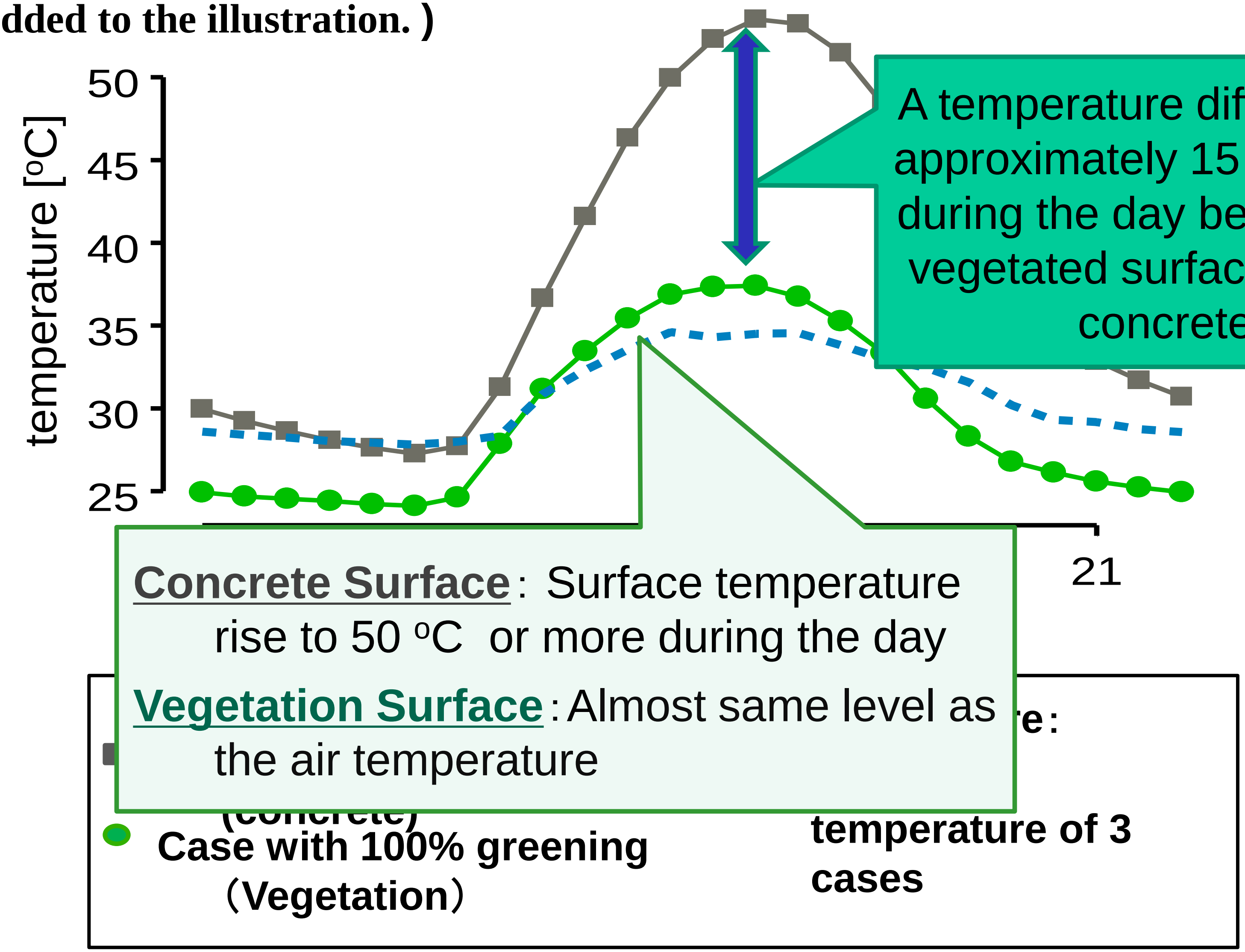
CO_2 reduction due to air-conditioning load reduction

Net CO_2 reduction by rooftop greening

Surface temperature of concrete and vegetation

The rooftop surface temperatures were calculated for the no-greening case and 100% greening case.

(For comparison, the average air temperatures for three cases at the rooftop level were also added to the illustration.)

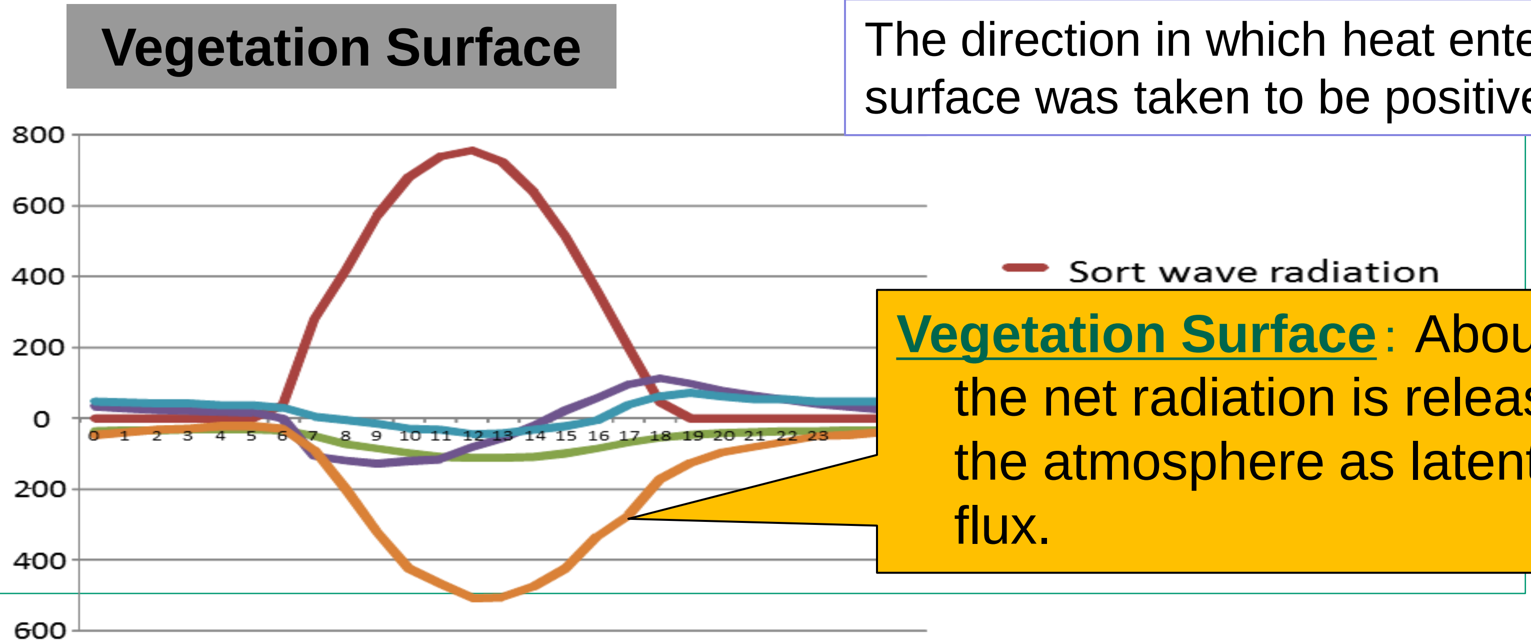


A temperature difference of approximately 15 ºC occurs during the day between the vegetated surface and the concrete.

Concrete Surface: Surface temperature rise to 50 ºC or more during the day

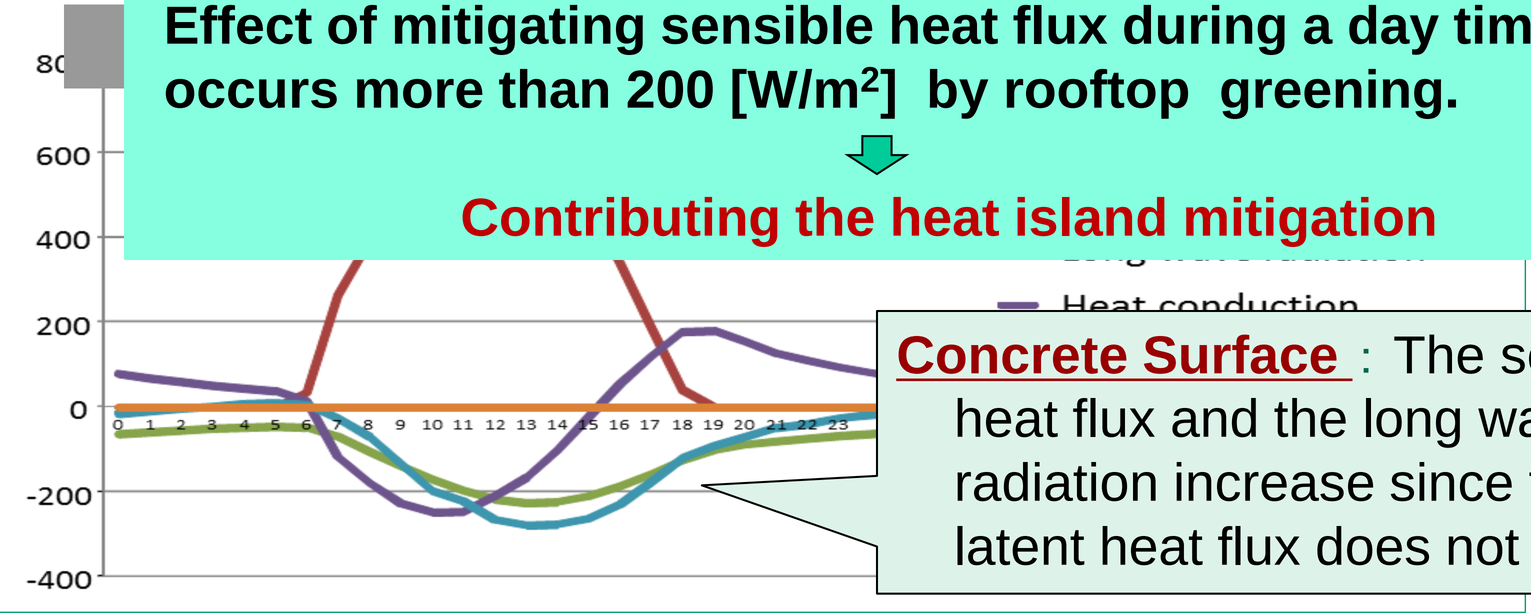
Vegetation Surface: Almost same level as the air temperature

Surface heat balance on rooftop surface


Vegetation Surface

The direction in which heat enters the surface was taken to be positive.

Vegetation Surface: About half of the net radiation is released into the atmosphere as latent heat flux.



Effect of mitigating sensible heat flux during a day time occurs more than 200 [W/m²] by rooftop greening.

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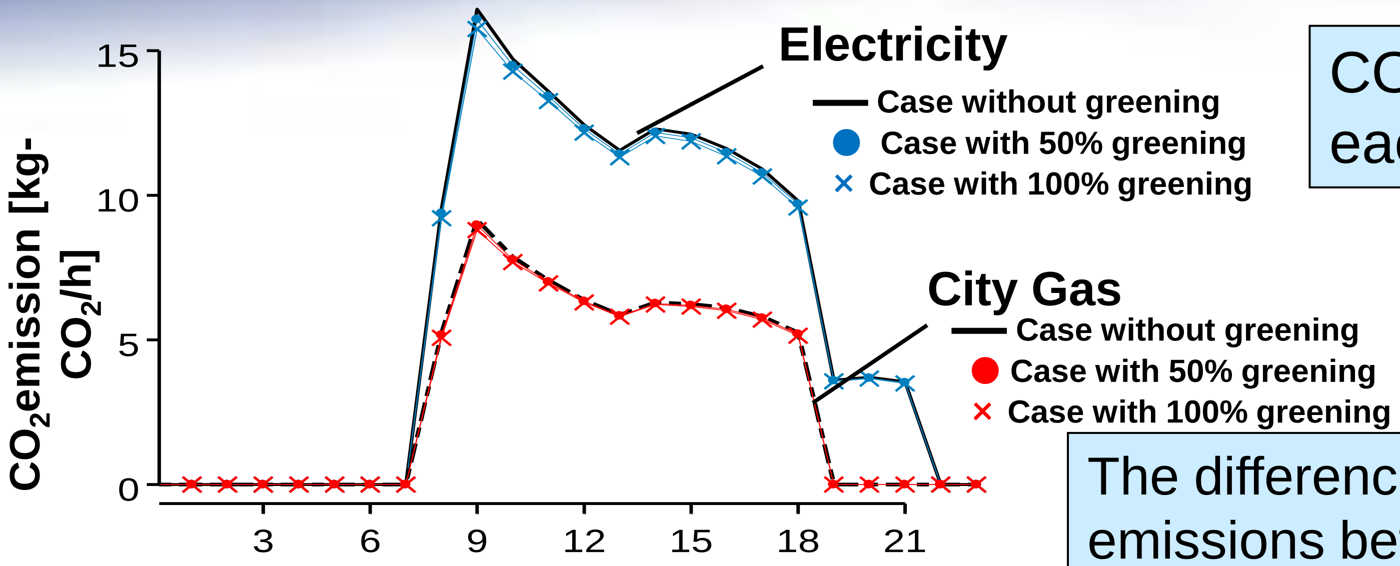
Contributing the heat island mitigation

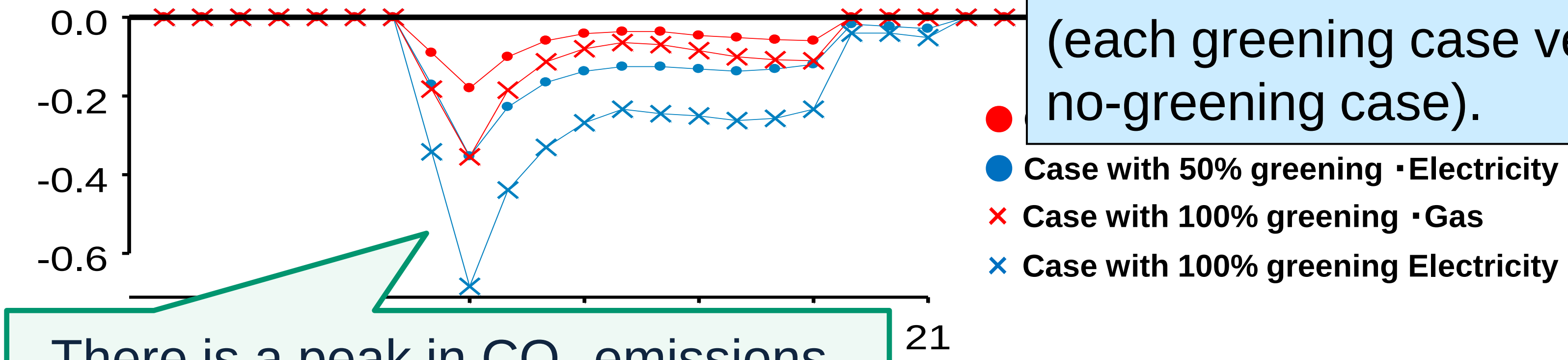
Concrete Surface : The sensible heat flux and the long wave radiation increase since the latent heat flux does not occur.

CO_2 reduction by cooling energy saving



CO_2 emission of each case

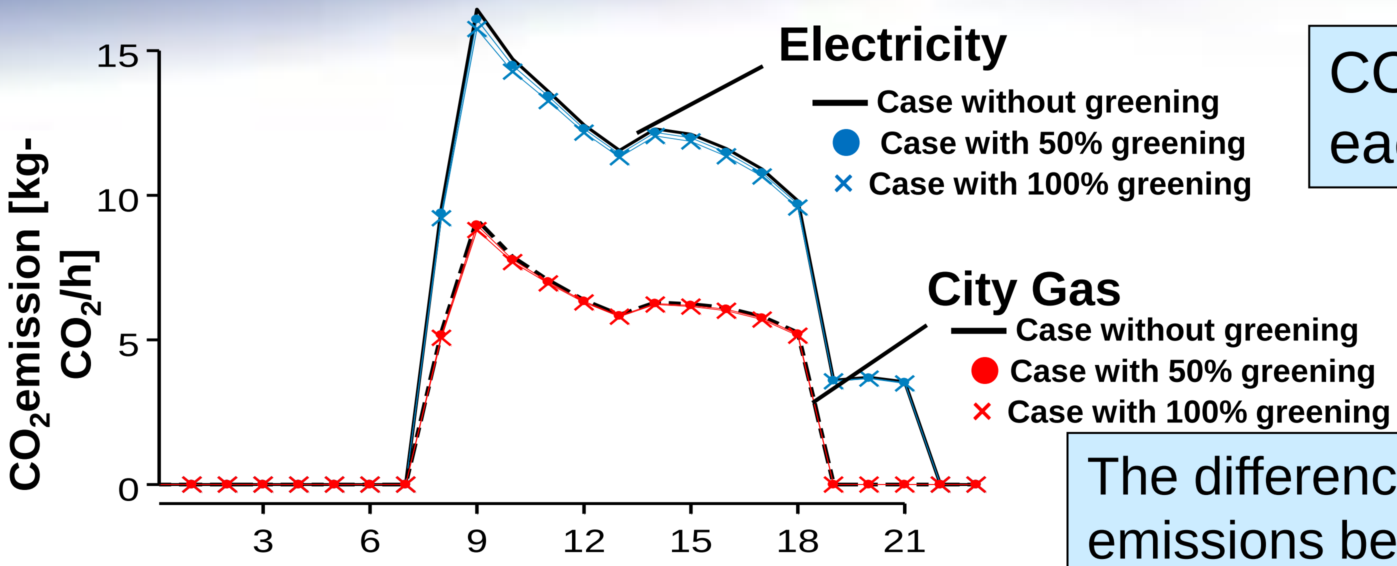
The differences in CO_2 emissions between the cases (each greening case versus the no-greening case).



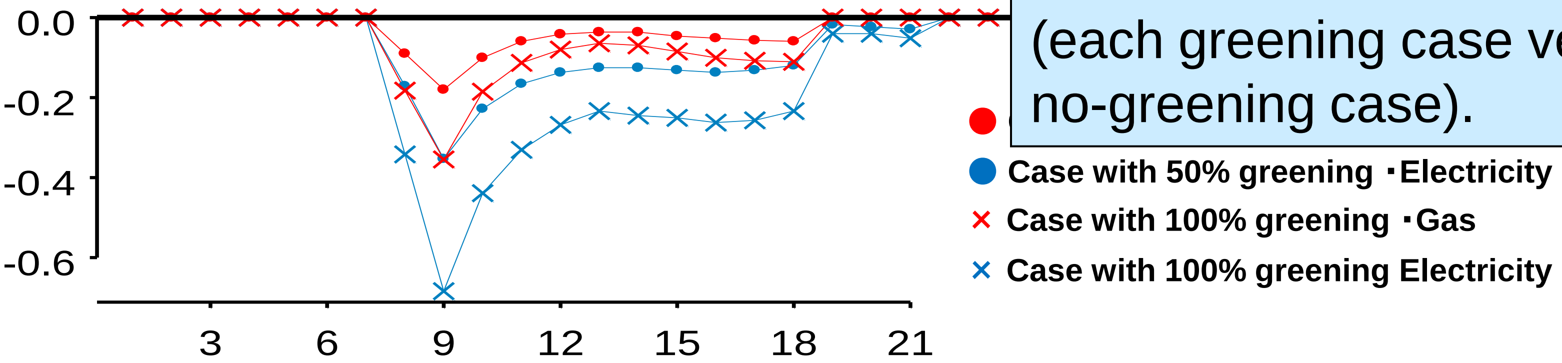
There is a peak in CO_2 emissions and a peak in CO_2 reductions due to greening at the start of operations in the morning when the cooling load was high.

CO_2 reduction by cooling energy saving

CO_2 emission of each case



The differences in CO_2 emissions between the cases (each greening case versus the no-greening case).

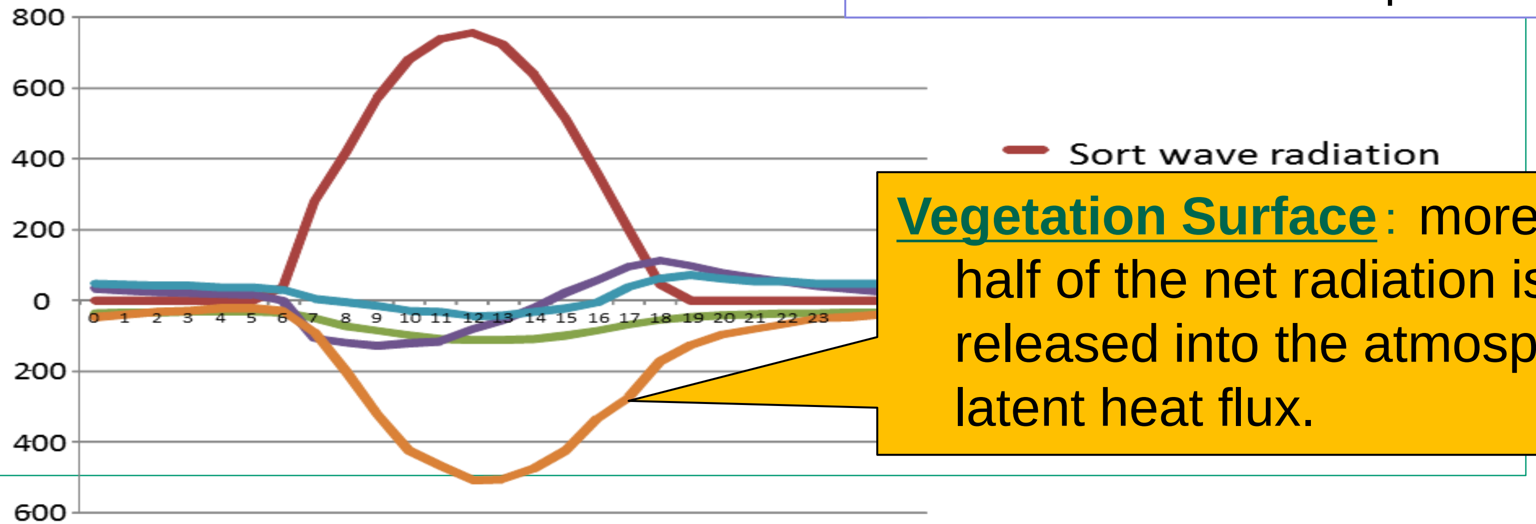


In terms of daily cumulative values, the CO_2 reduction effect was 2.93 kg-CO_2/day in the 100% greening case and 1.47 kg-CO_2/day in the 50% greening case.

Surface heat balance on rooftop surface

Vegetation Surface

The direction in which heat enters the surface was taken to be positive.



Vegetation Surface: more than half of the net radiation is released into the atmosphere as latent heat flux.

Effect of mitigating latent heat flux during a day time occurs more than 200 [W/m^2] by rooftop greening.

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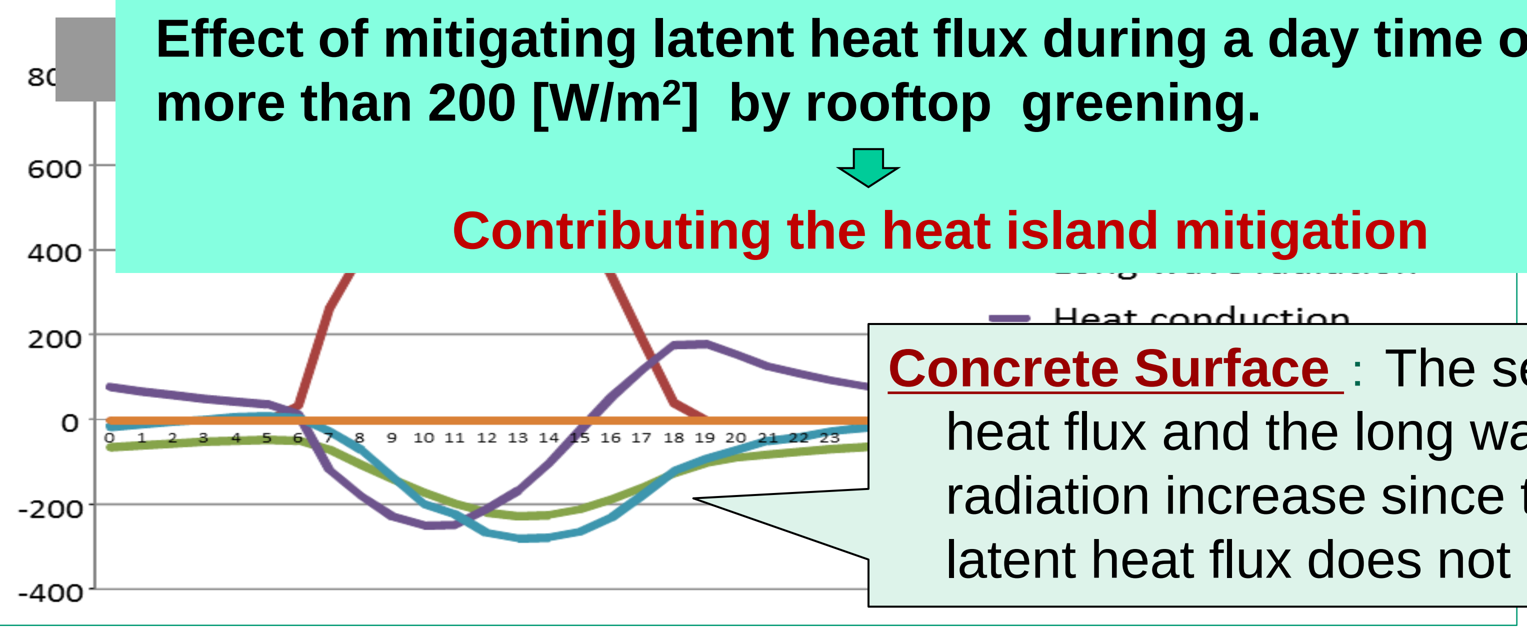
Contributing the heat island mitigation

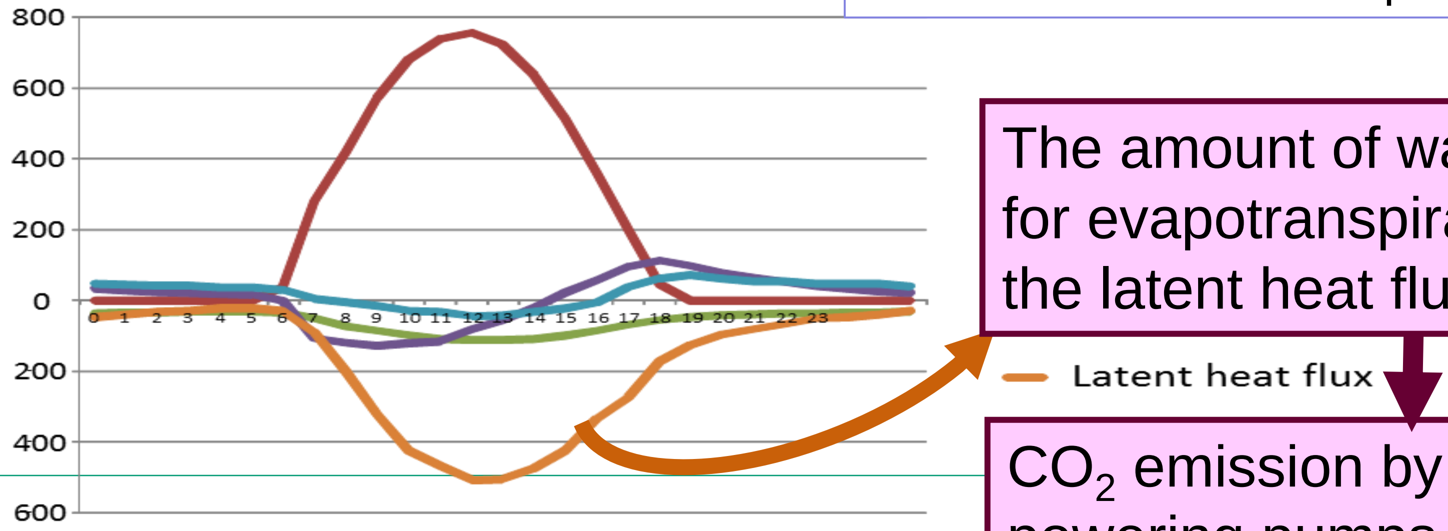


Concrete Surface: The sensible heat flux and the long wave radiation increase since the latent heat flux does not occur.

Surface heat balance on rooftop surface

Vegetation Surface

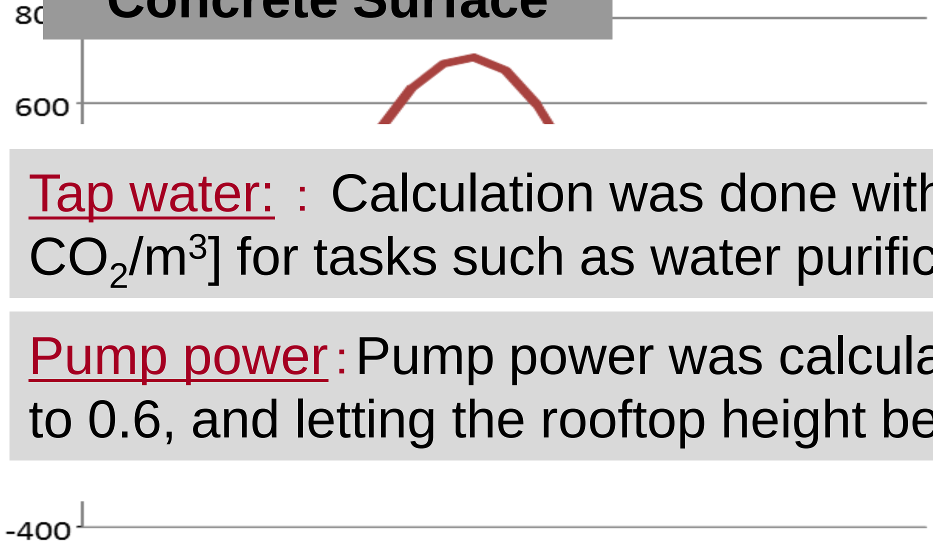
The direction in which heat enters the surface was taken to be positive.



The amount of water needed for evapotranspiration from the latent heat flux.

CO$_2$ emission by using powering pumps and tap water.

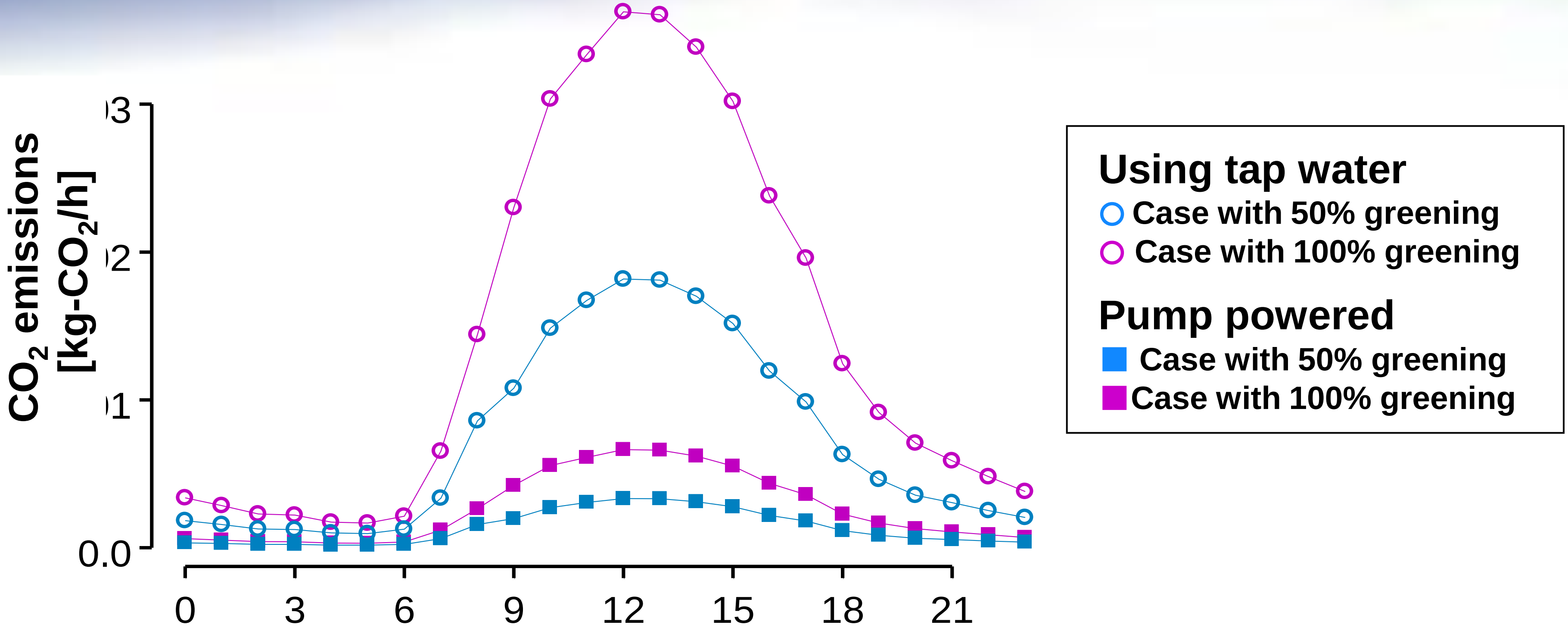
Concrete Surface



Tap water: : Calculation was done with CO$_2$ emissions of 0.193 [kg-CO$_2$/m^3] for tasks such as water purification, delivery and distribution

Pump power : Pump power was calculated by setting pump efficiency to 0.6, and letting the rooftop height be the lifting height.

CO_2 emissions due to watering



CO_2 emissions due to irrigation in each case

CO_2 emissions due to powering pumps;

-Case with 100% greening : 0.064[kg-CO_2/Day]

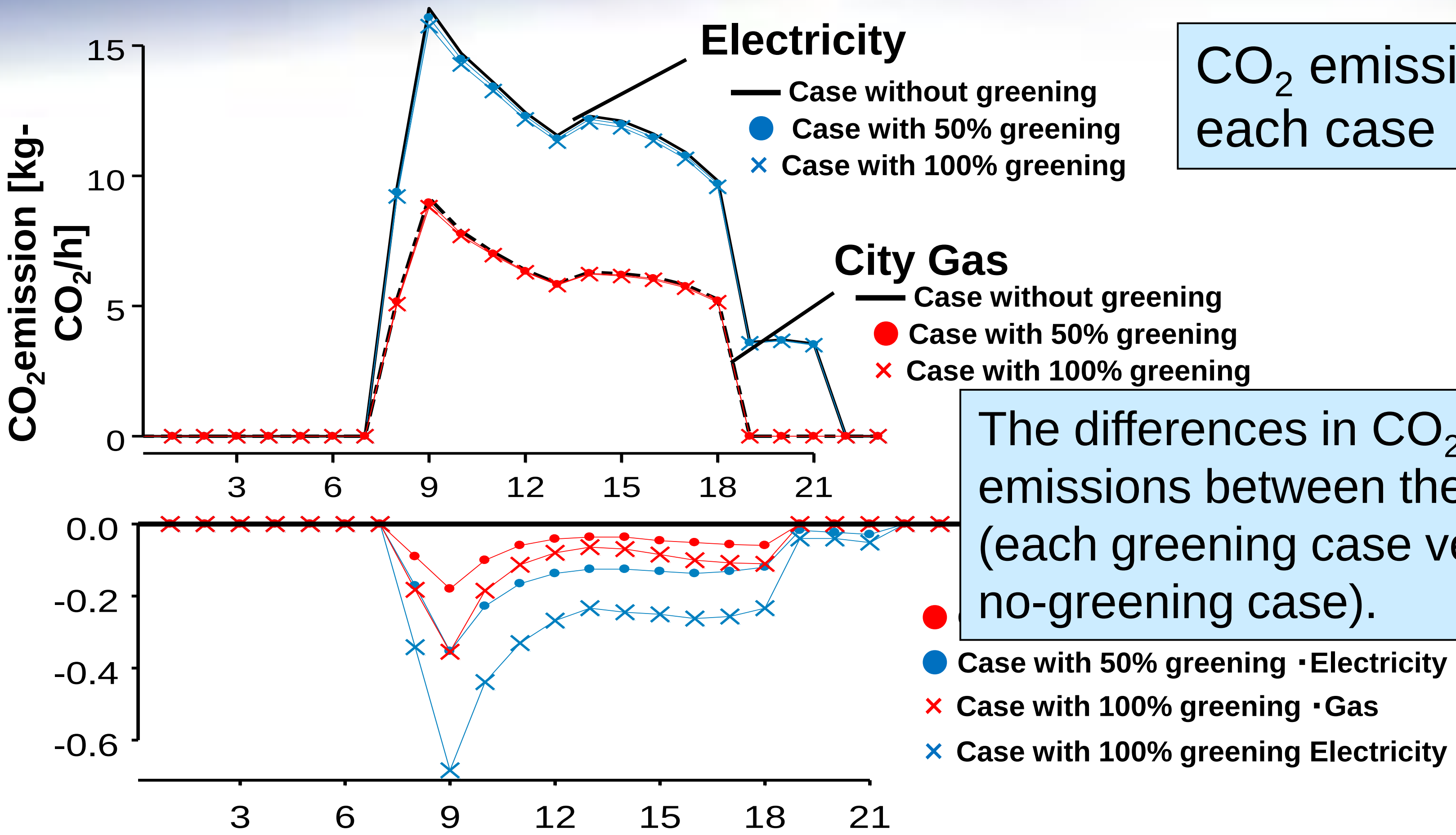
-Case with 50% greening : 0.032[kg-CO_2/Day]

CO_2 emissions due to the use of tap water

-Case with 100% greening : 0.35[kg-CO_2/Day]

-Case with 50% greening : : 0.18[kg-CO_2/Day]

CO_2 reduction by cooling energy saving

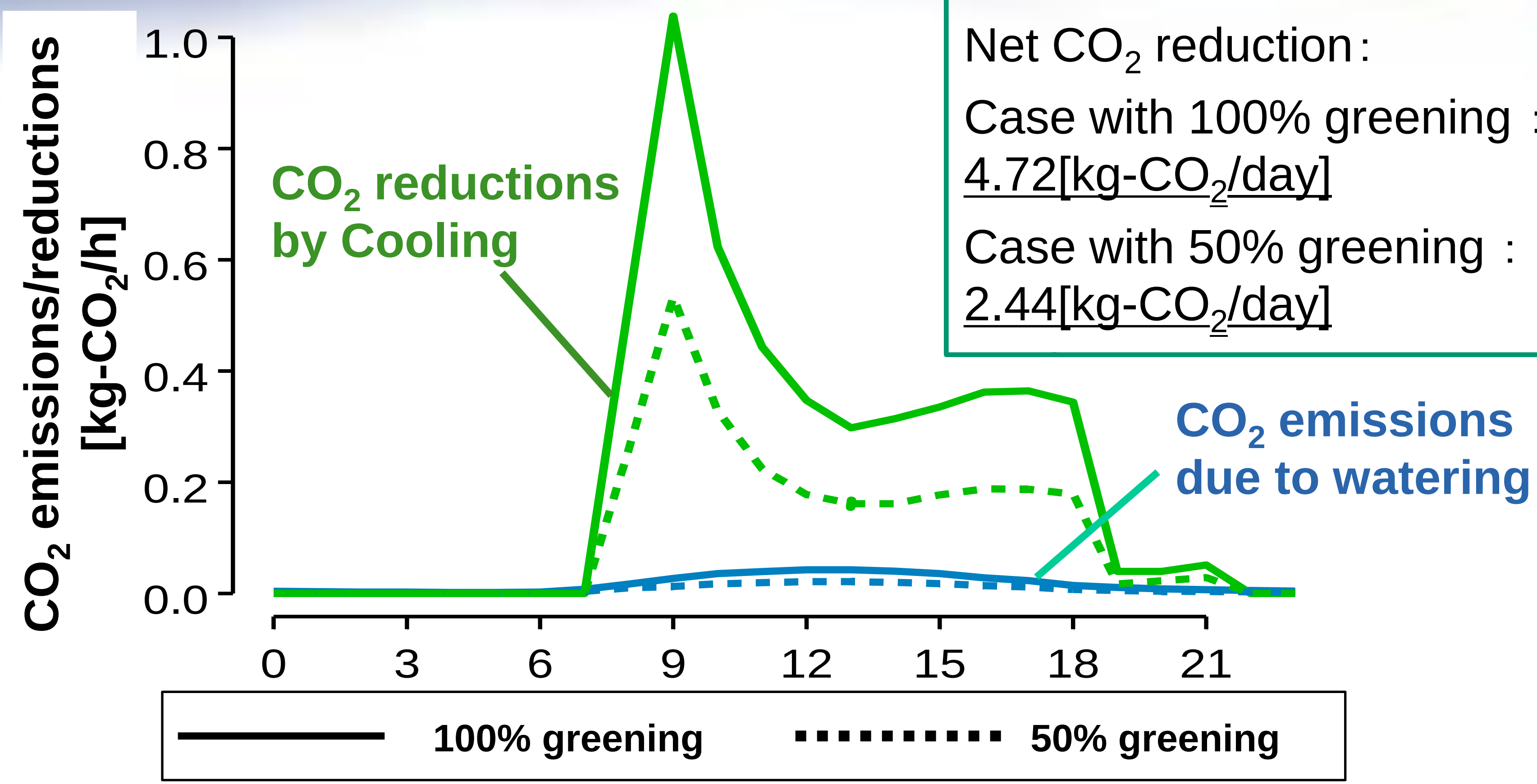


CO_2 emission of each case

The differences in CO_2 emissions between the cases (each greening case versus the no-greening case).

In terms of daily cumulative values, the CO_2 reduction effect was 2.93 kg-CO_2/day in the 100% greening case and 1.47 kg-CO_2/day in the 50% greening case.

CO_2 reductions due to rooftop greening



Net CO_2 reduction：

Case with 100% greening ：
4.72[kg-CO_2/day]

Case with 50% greening ：
2.44[kg-CO_2/day]

CO_2 reduction due to cooling energy is clearly greater than CO_2 emissions due to watering.

~~The~~ CO_2 reduction effect can be obtained using rooftop greening even when taking into account CO_2 emissions due to watering.

Conclusion

This research evaluated the effectiveness of rooftop greening for mitigating urban heat island conditions and reducing CO_2 emissions while taking into account the amount of water needed for evapotranspiration.

In this research, **a coupled urban-canopy and building-energy model** was used to carry out simulations.

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The CO_2 reduction effect of rooftop greening was evaluated. In particular, this evaluation was carried out by taking into account both the CO_2 reductions that resulted from the decreases in surface temperatures and cooling energy and the CO_2 emissions associated with watering. The data showed that the former was clearly greater in terms of direct effects. Thus, a CO_2 reduction effect can be achieved in buildings where rooftop greening is adopted.

One future research direction should be to incorporate a detailed water balance model that takes into account precipitation and the water retention effectiveness of the soil layer.

Thank you very much for your kind attention.

Table 1: Summary of calculation conditions for standard case

Temperature setting for cooling (℃)	26.0
Humidity setting for cooling (relative humidity: %)	50.0
Total transmission of solar insolation at window surface (-)	0.3
Amount of outside air introduced per unit floor area ($m^3/m^2/h$)	3.0
Position of air vent (for introducing outside air)	Each floor
Occupied floor area per person present indoors (m^2/person)	10.0
Air-conditioned area as a percentage of building total floor area (-)	0.75
Heat produced by human bodies per unit floor area (W/m^2)	Sensible heat: 6.27 Latent heat: 5.34
Building floor height (m/floor)	3.5
Thermal transmittance of outer walls ($W/m^2/K$)	0.68
Heat capacity per unit cross-sectional area of outer walls ($J/m^2/K$)	3.11×10^5
Heat source system, heat source equipment breakdown percentages	Electric heat pump: 66.9% Absorption type (City gas）: 33.1%

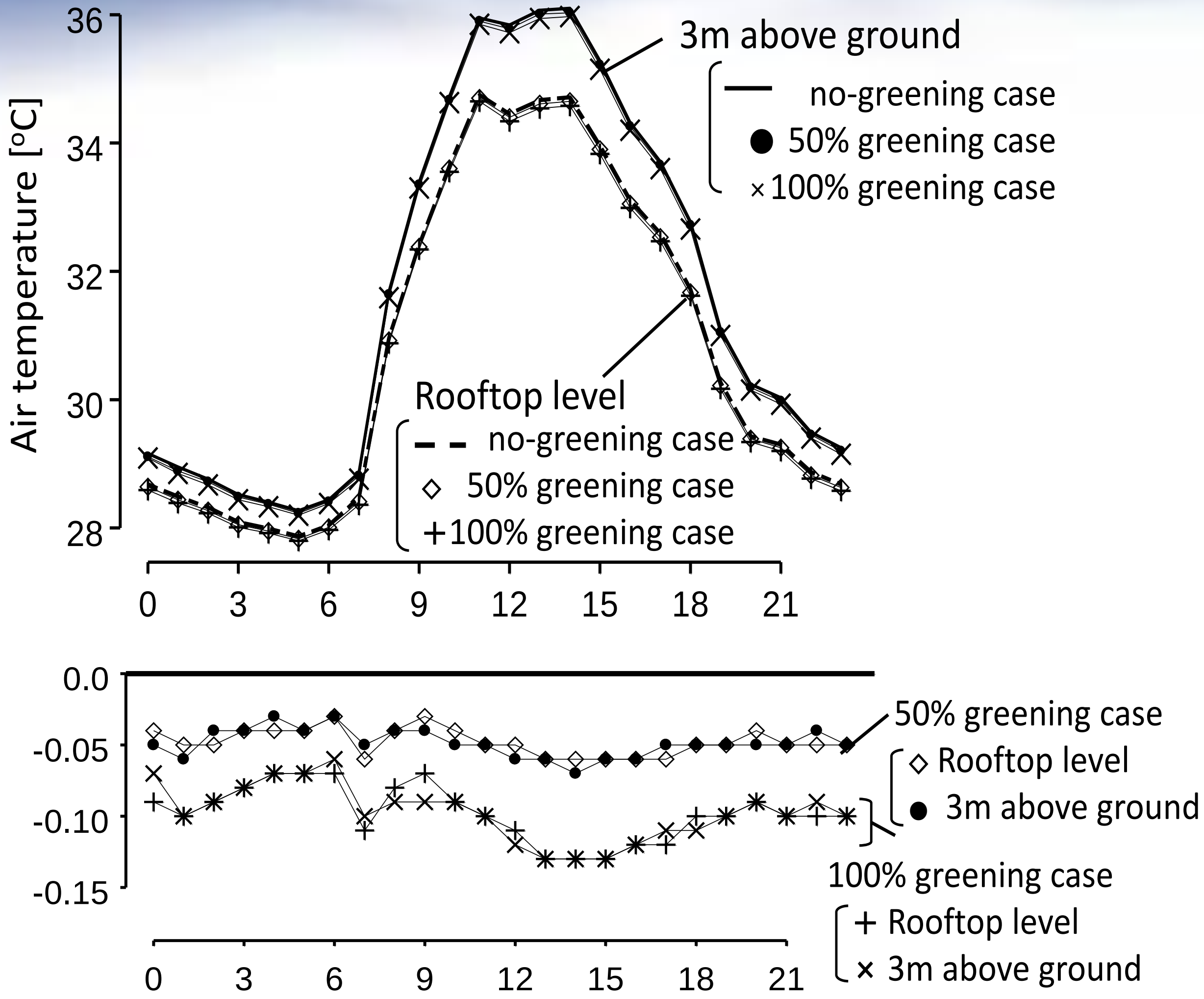


Fig. 2 (top) Temperature in each case scenario, and (bottom) the temperature differences for those cases (i.e., each case with greening - each case without greening).

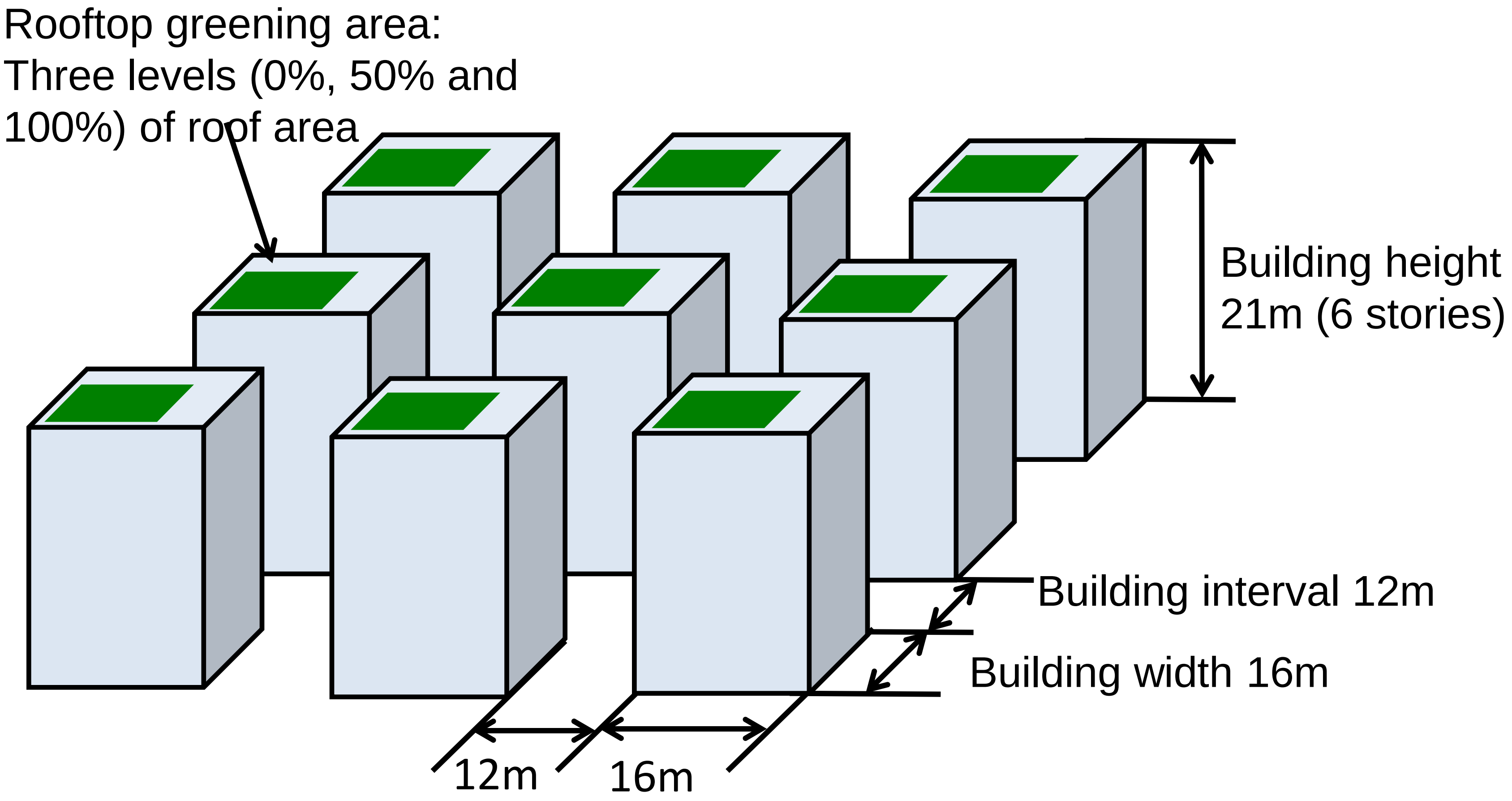


図-1 本研究における建物モデルの設定

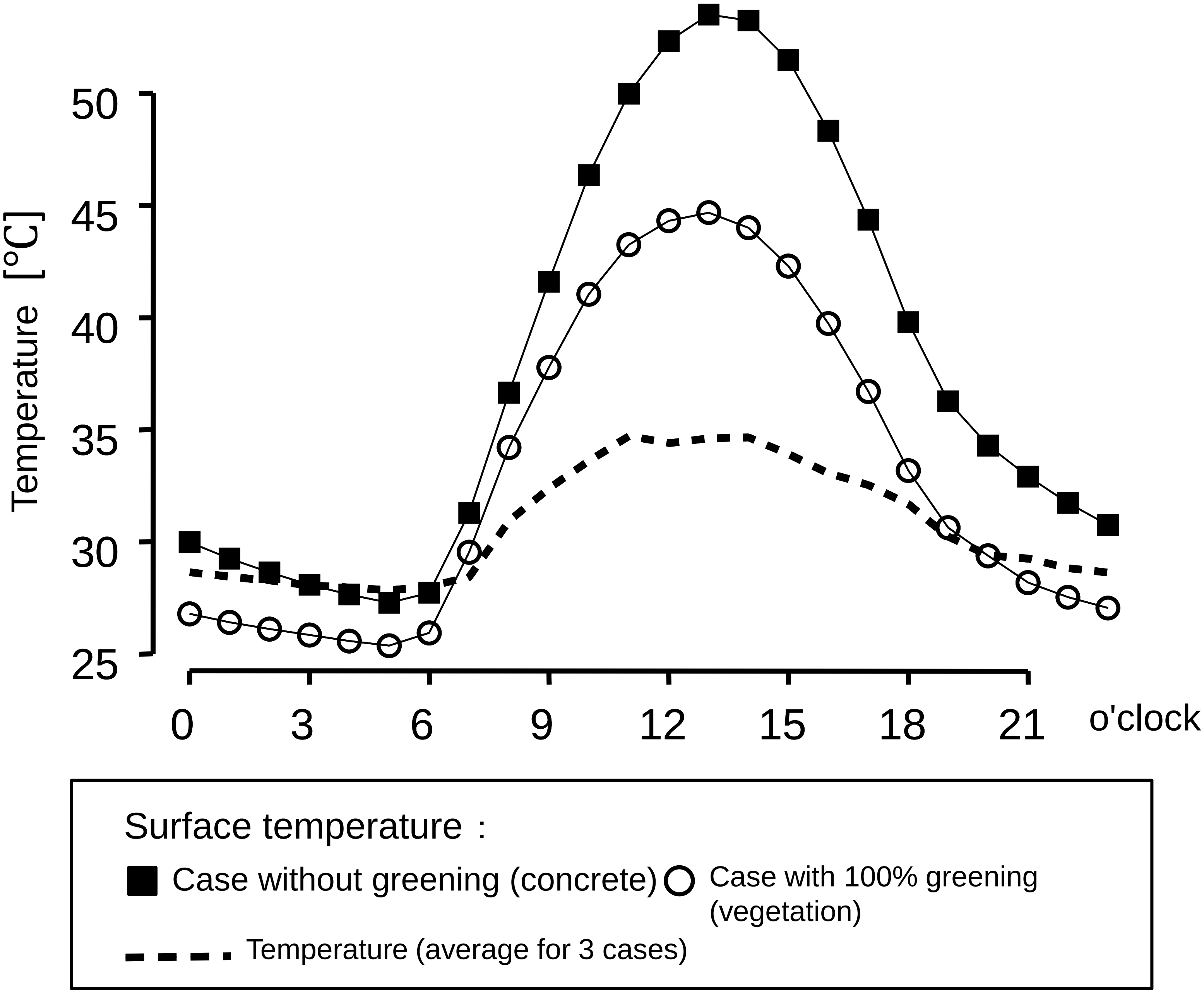
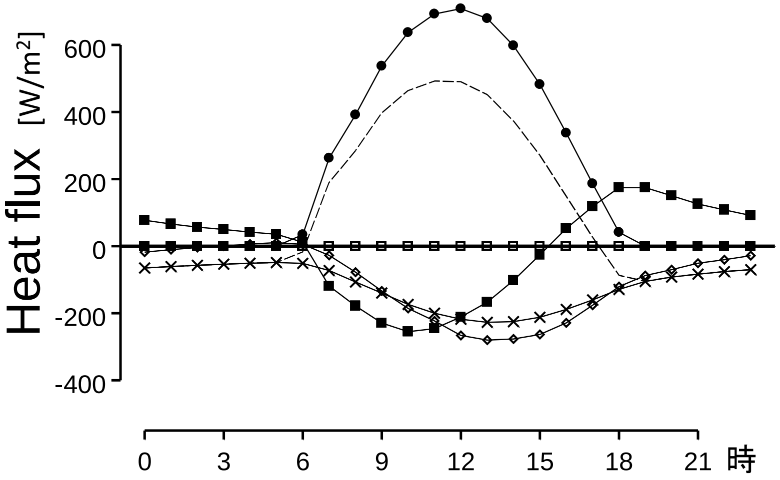


図2　屋上におけるコンクリートおよび植生の表面温度

(a) Case without greening (concrete)



(b) Case with 100% greening (vegetation)

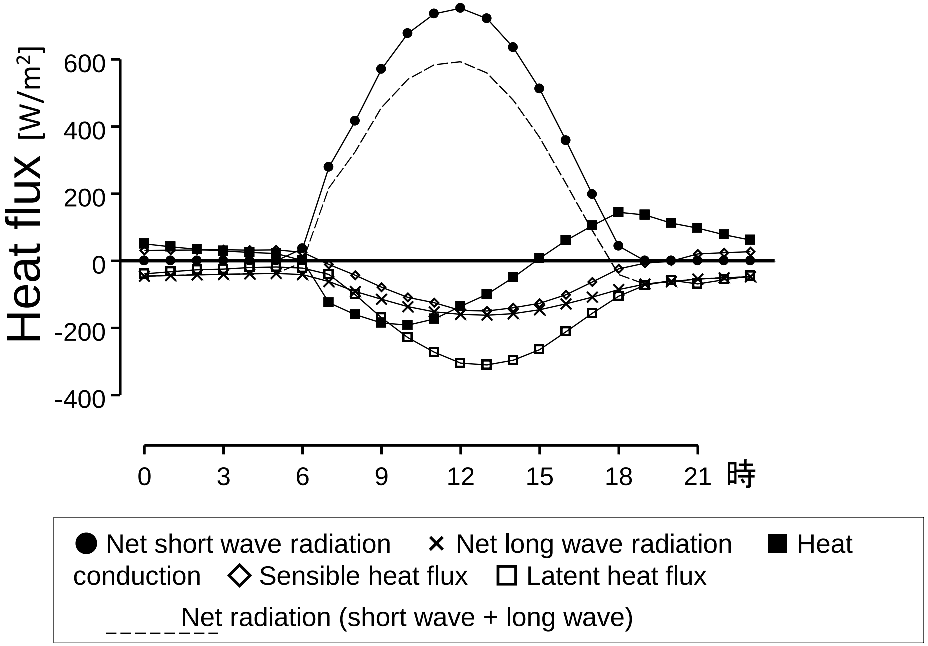


図3　屋上面における表面熱収支

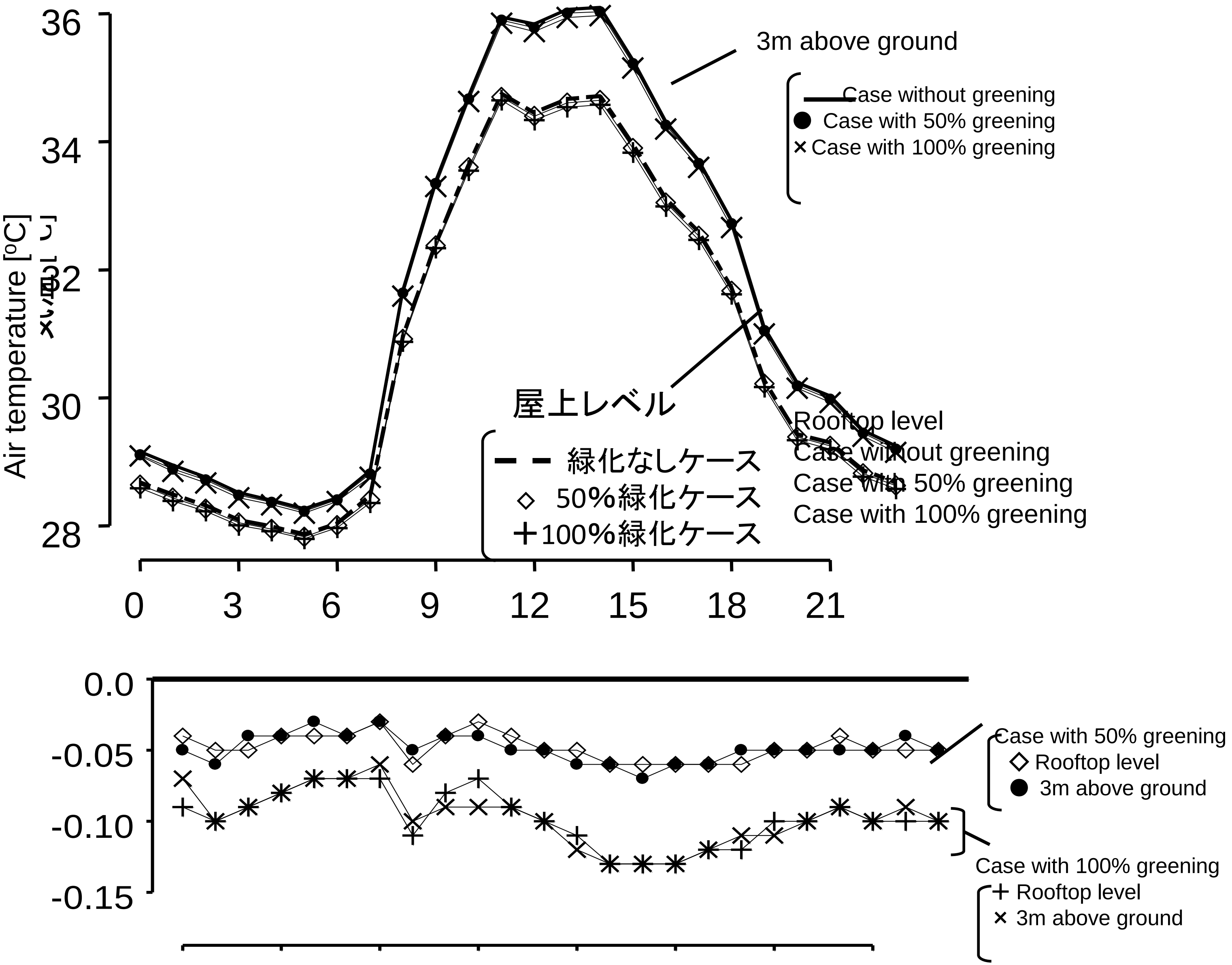


図4 各ケースにおける気温およびその緑化なしケースとの差

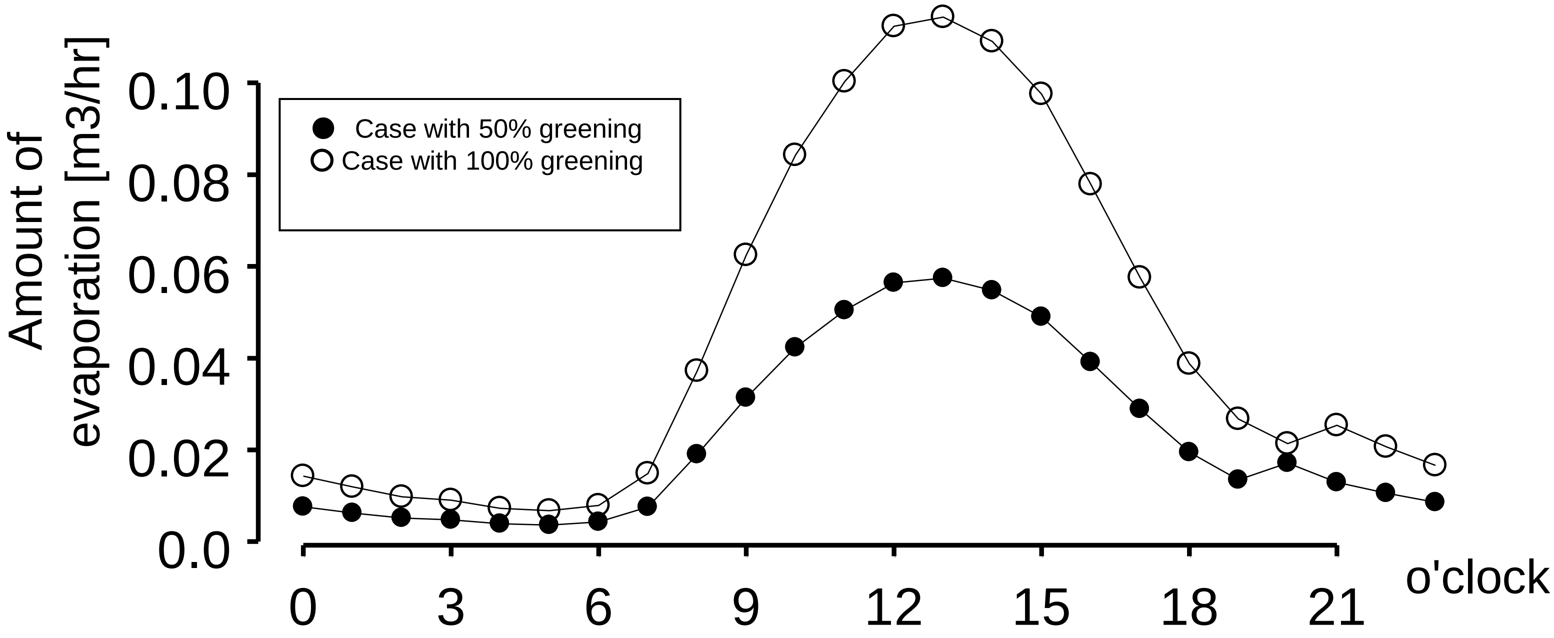


図5　各緑化ケースにおける蒸発量

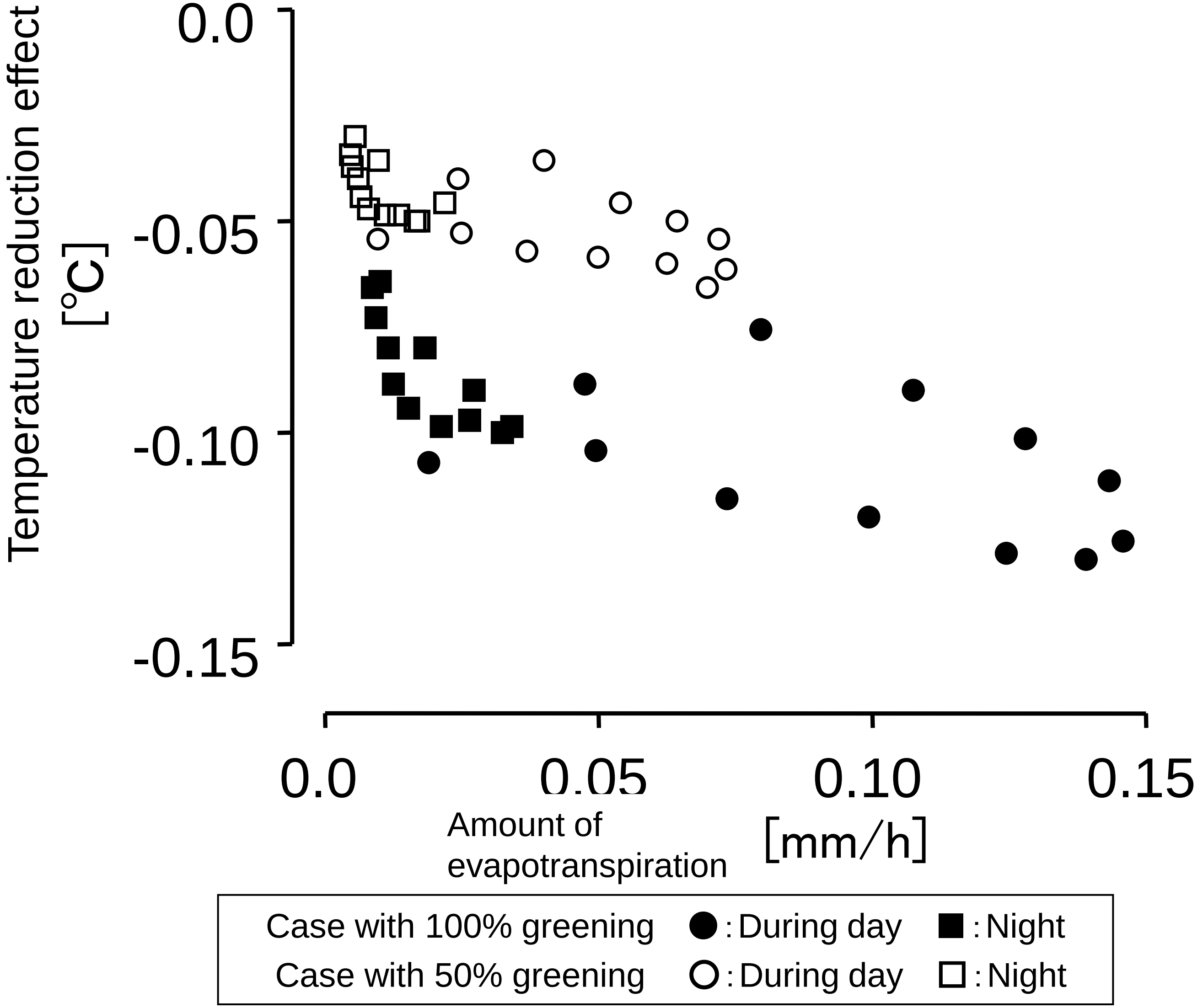


図6　蒸発散量と気温低下効果の関係

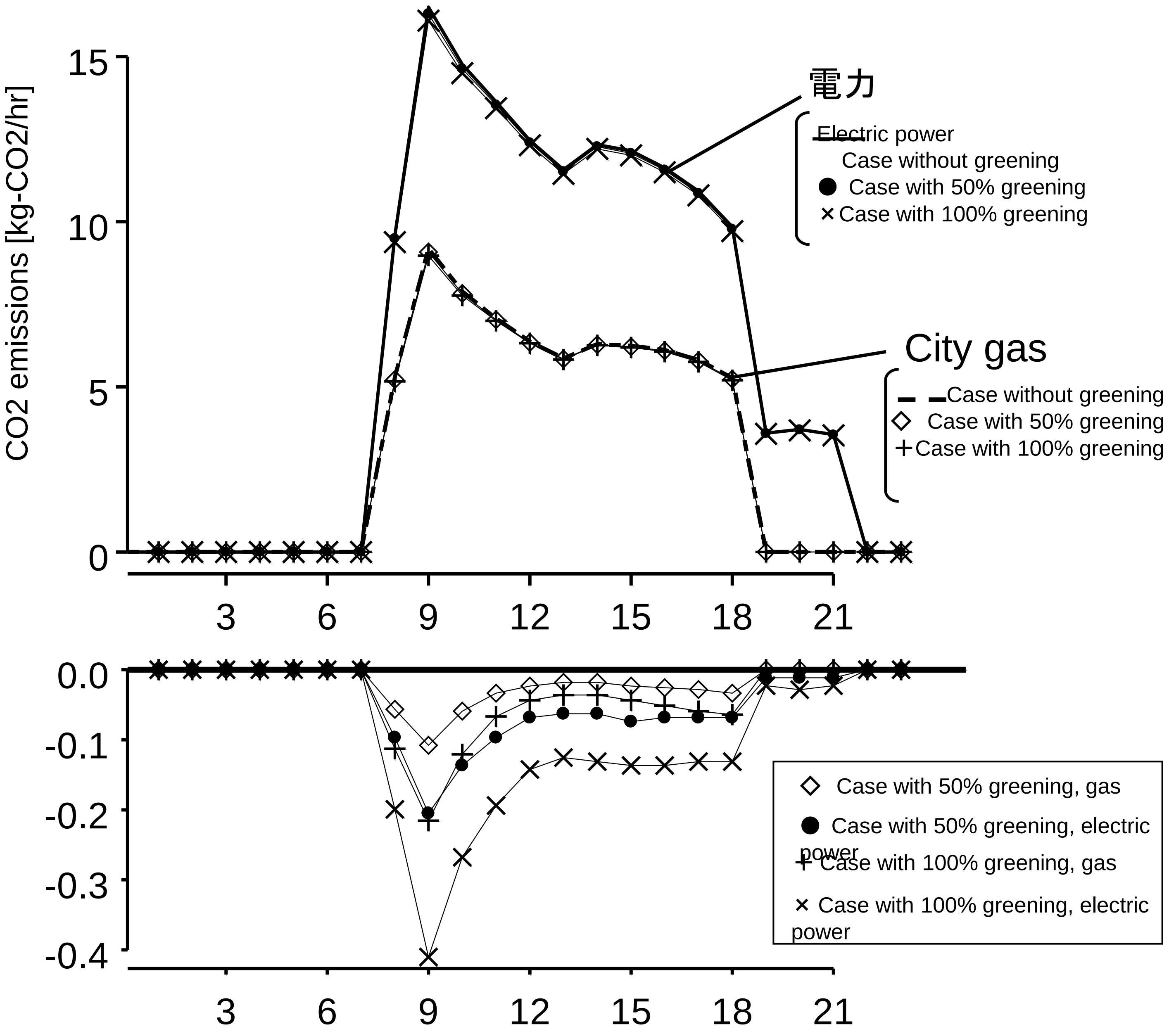
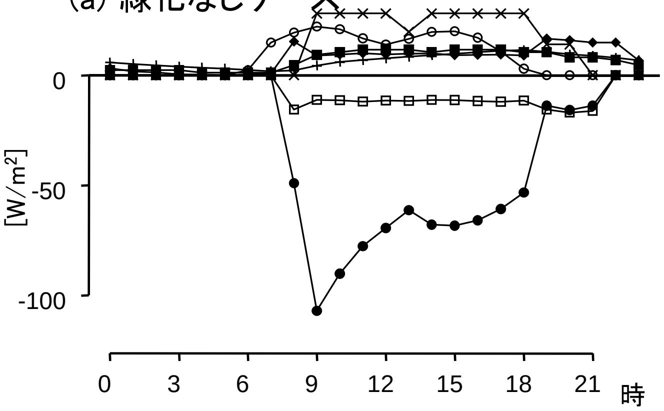
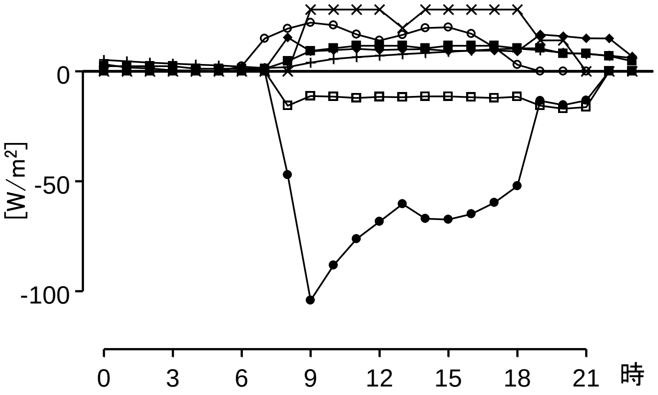


図7　各ケースにおけるCO_2排出量およびその緑化なしケースとの差

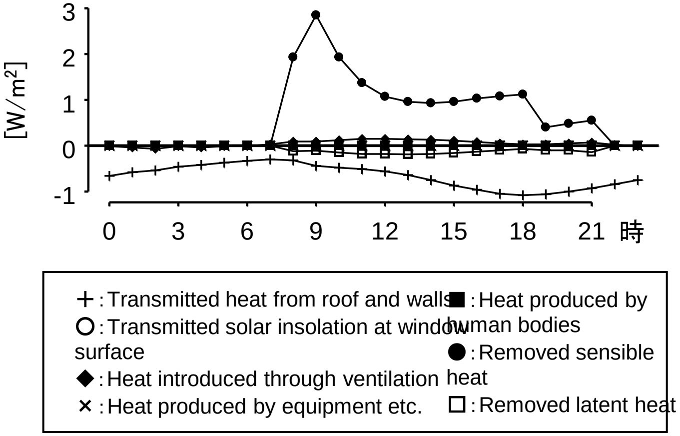
(a) 緑化なしケース



(b) 100%緑化ケース



(c) 両ケースの差



(a) Case without greening
(b) Case with 100% greening
(c) Difference between two cases

図8 緑化なしケースおよび100%緑化ケースにおける室内熱収支の計算結果および両ケースの差

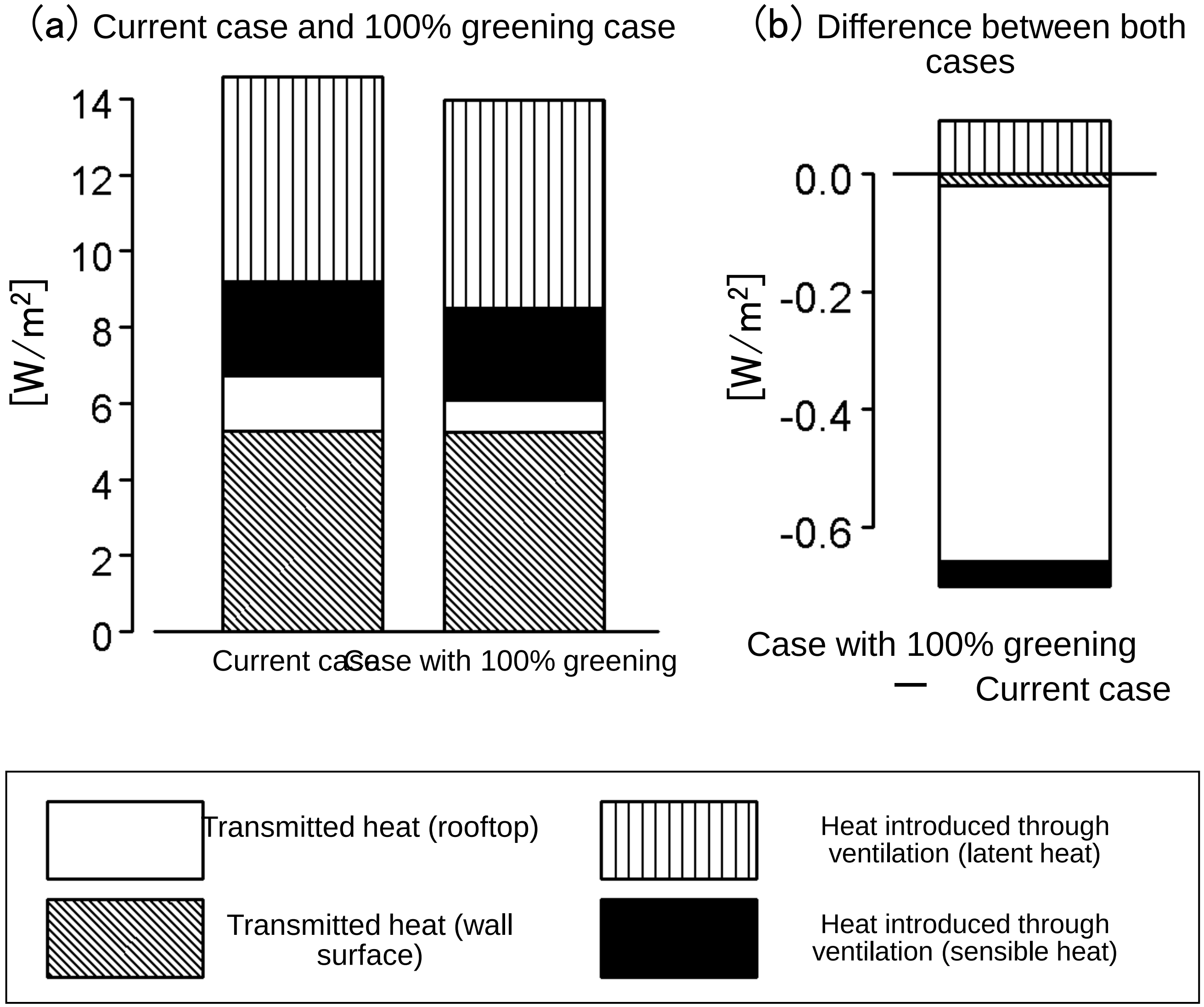


図9　貫流熱および換気侵入熱の詳細比較（日平均，床面積あたり）

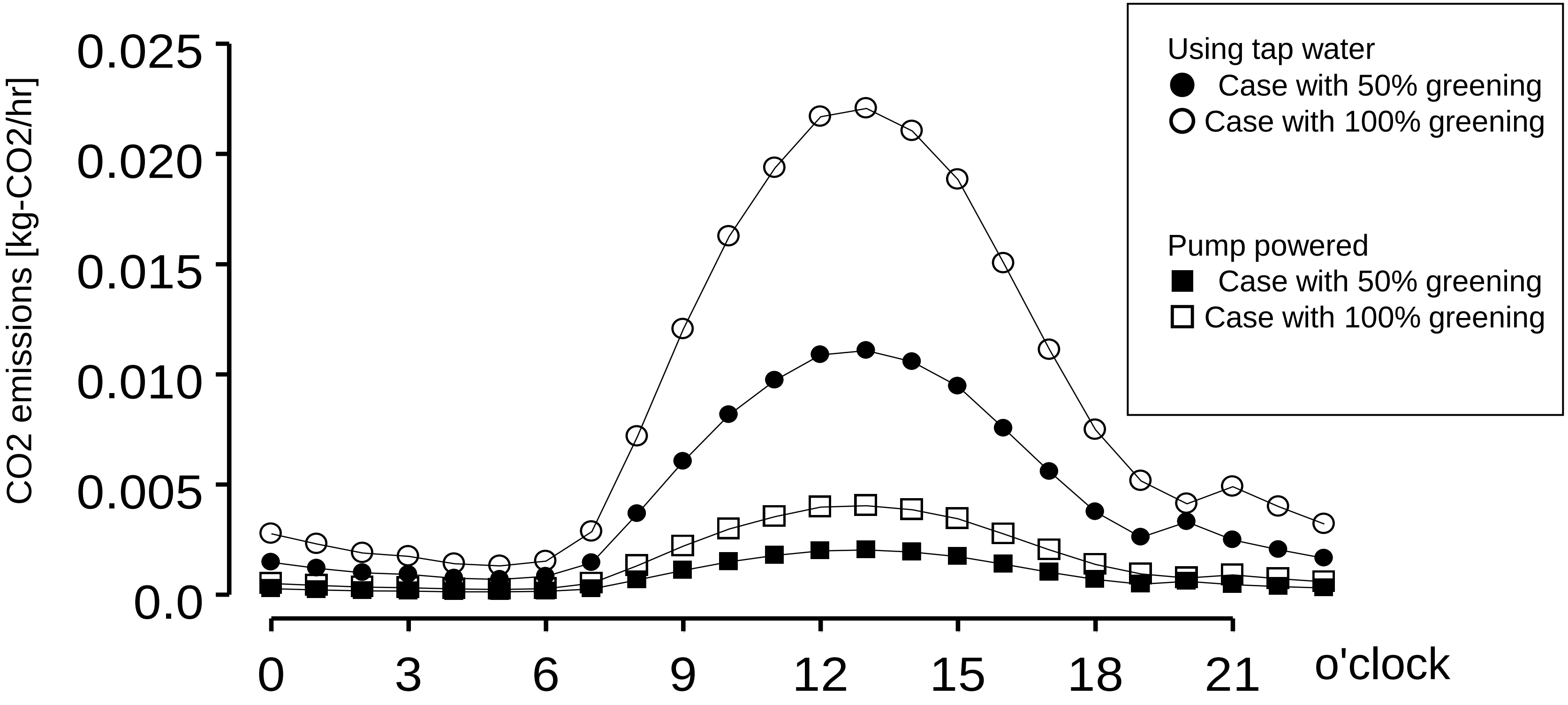


図10　各ケースにおける潅水によるCO$_2$排出量

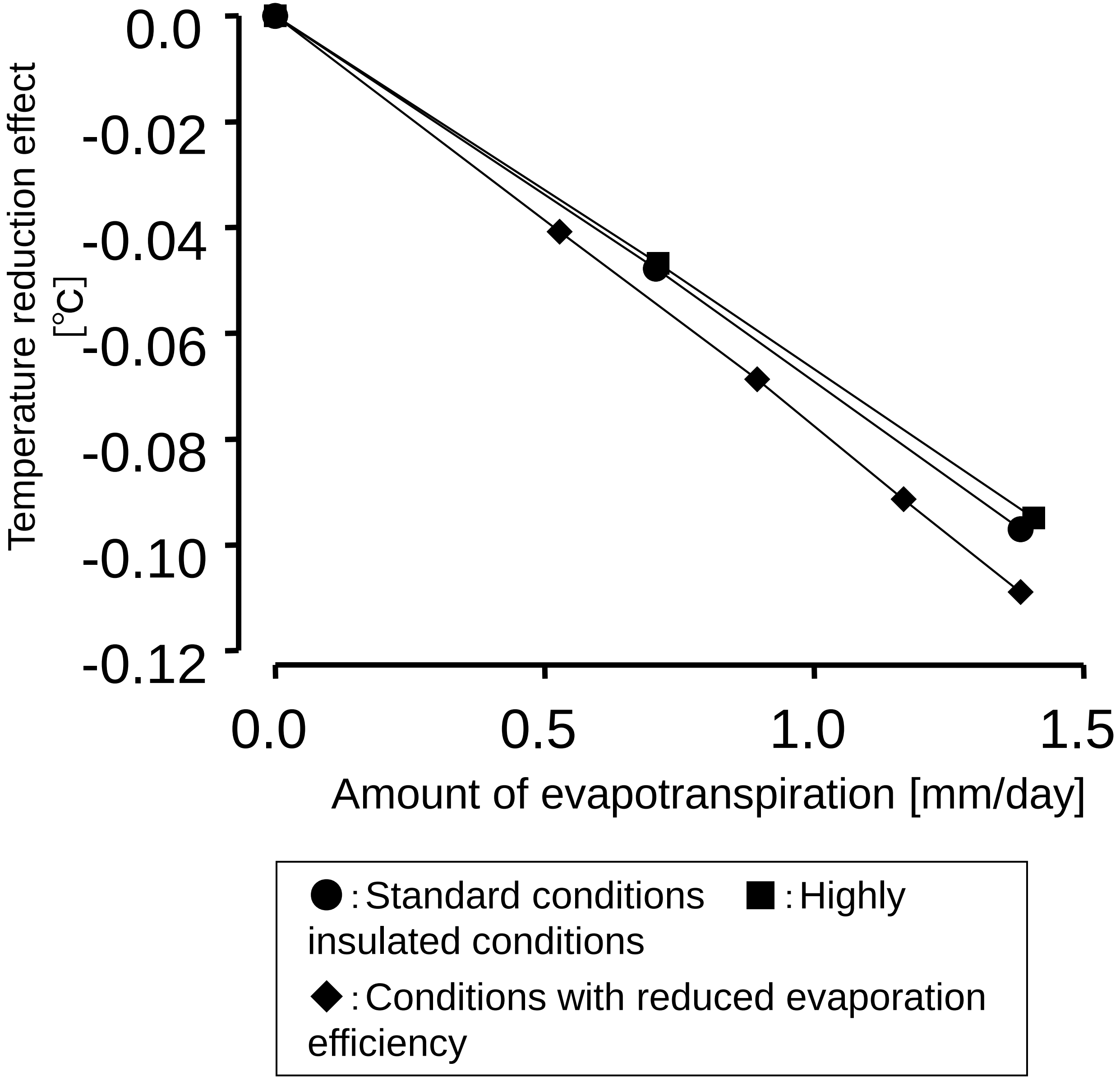


図11　蒸発散量と気温低下効果の関係

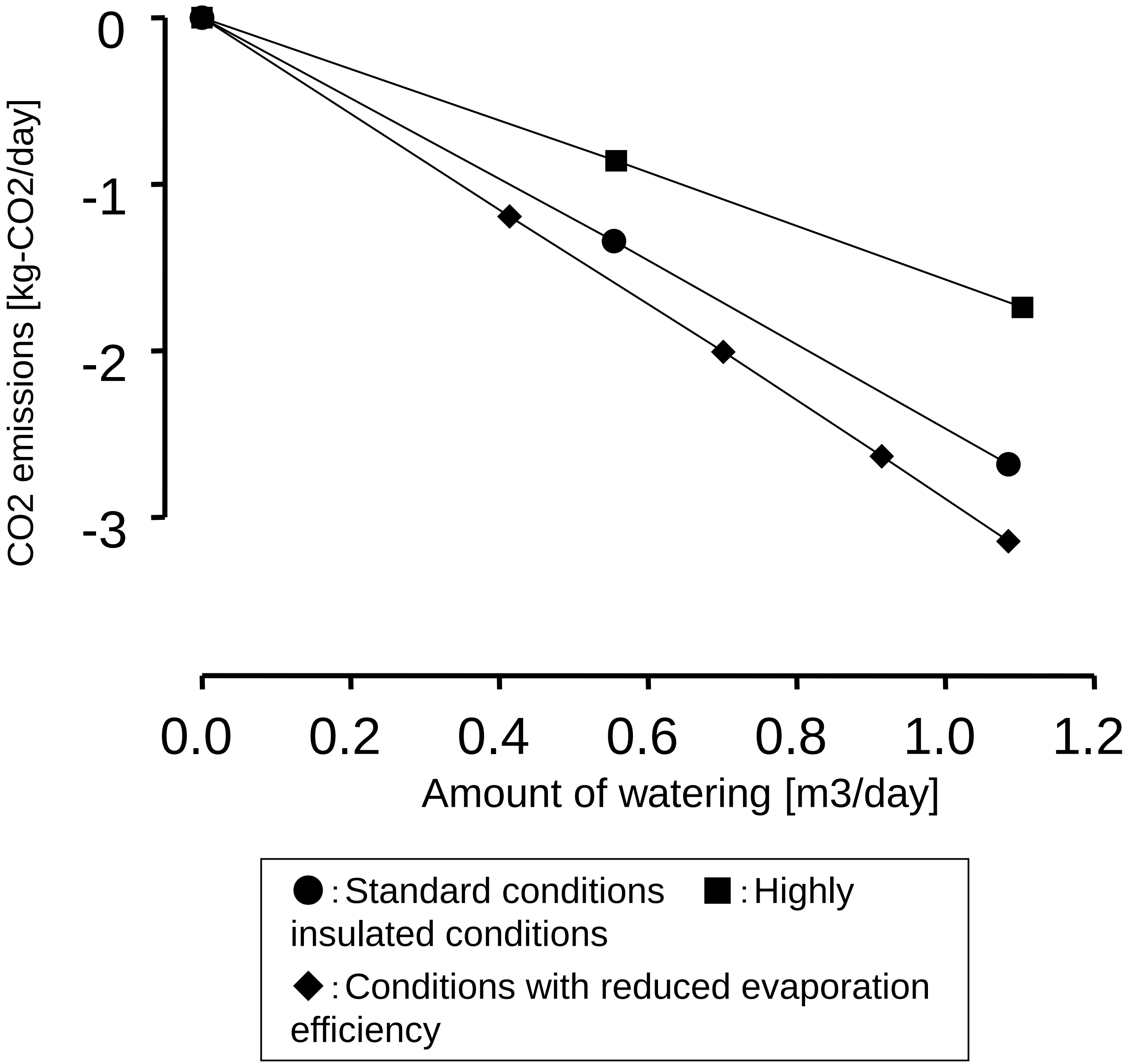


図12　散水量とCO2削減量の関係（1棟あたり）