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Method for evaluating the health risk in urban pedestrian space in extremely hot summer conditions based on the total analysis of mesoscale and microscale climates

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Introduction

- Heatstroke have increased rapidly in recent years with urban heat island and severe weather.

- In this study, the increase in the number of heatstroke patients caused by extremely hot summer conditions was regarded as a disaster,
  -> a new evaluation method for outdoor thermal environment based on the concept of risk evaluation was developed.

Concept of risk evaluation method

Formulation of health risk

- Commonly, when the society is struck by disaster, a risk that the society is exposed to defined as ...

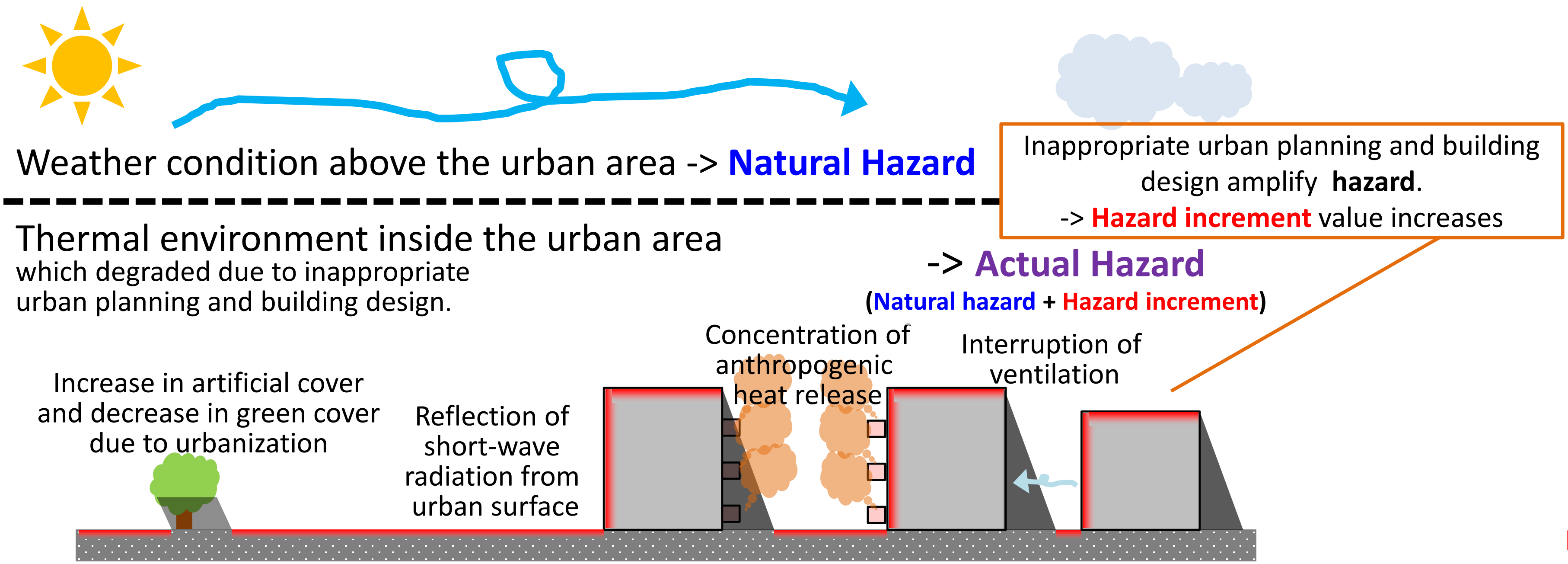
$$\textbf{\textit{Risk}} = \textbf{\textit{Magnitude of hazard}} \times \textbf{\textit{Intensity of influence on society}}$$
$$= f(\textbf{\textit{Hazard}}) \qquad \textbf{(1)}$$

f : a function that expresses the relationship between hazard and risk.

- In this study,
  Risk : Emergency transport ratio for heatstroke
  Hazard : Thermal index that indicates the severity of the thermal environment
  f : Emergency transport probability curve

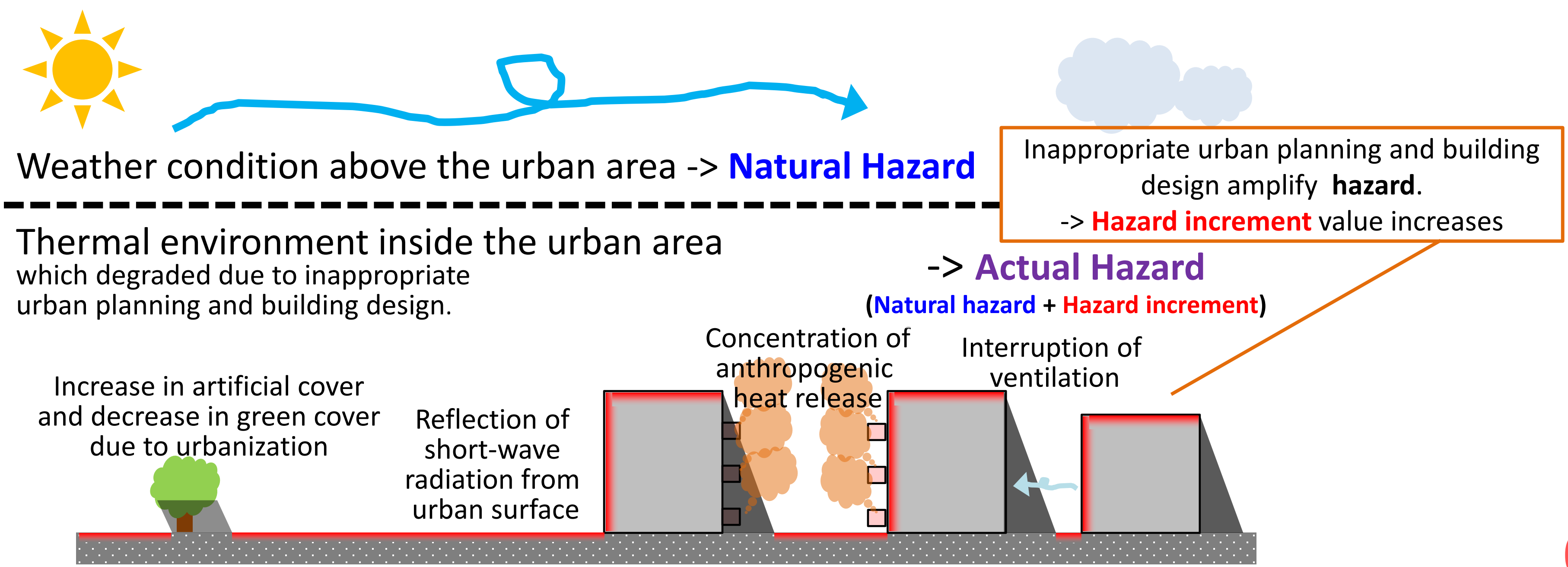
Definition of hazard in this study

- The thermal environment inside an urban area is formed by a combined influence of weather conditions above the urban area and urban structure, such as the building shape and arrangement, the green cover ratio, the intensity of exhaust heat, and so on.



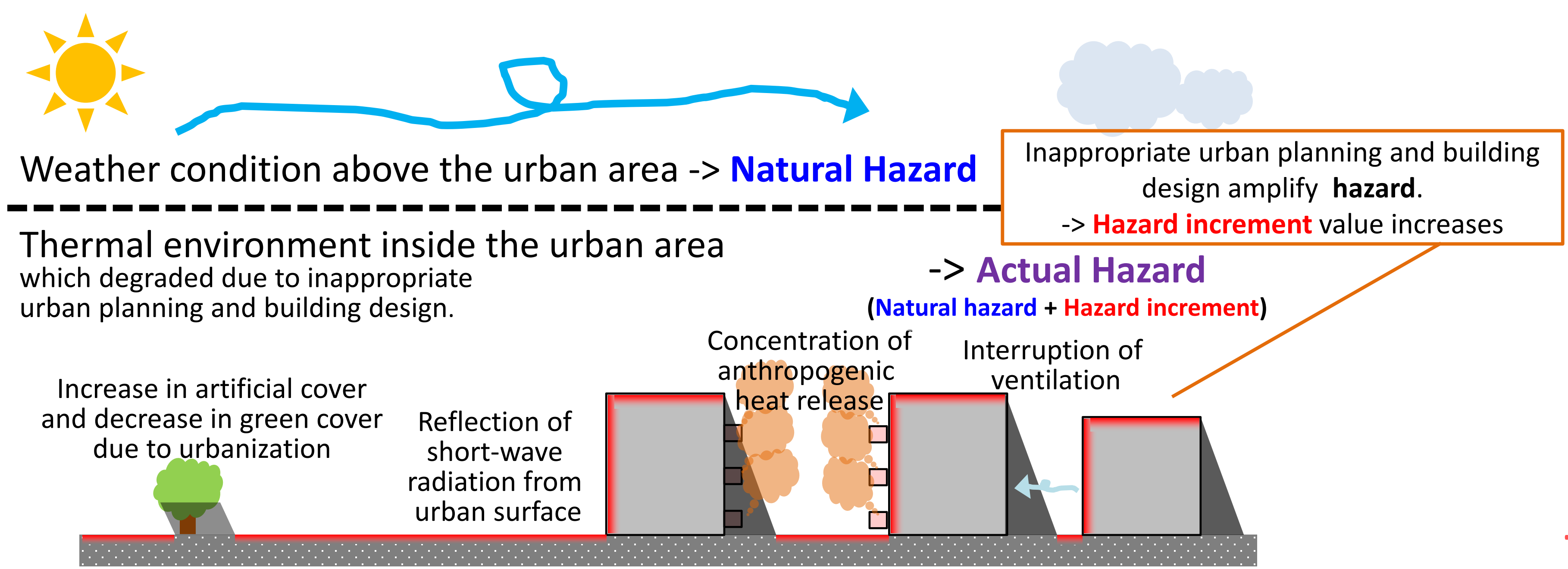
Definition of hazard in this study

- Inside an urban area, the thermal environment is often severer than that above it
  due to the effect of the urban structure.
  -> inappropriate urban planning and building design can amplify threats caused by weather conditions above an urban area.



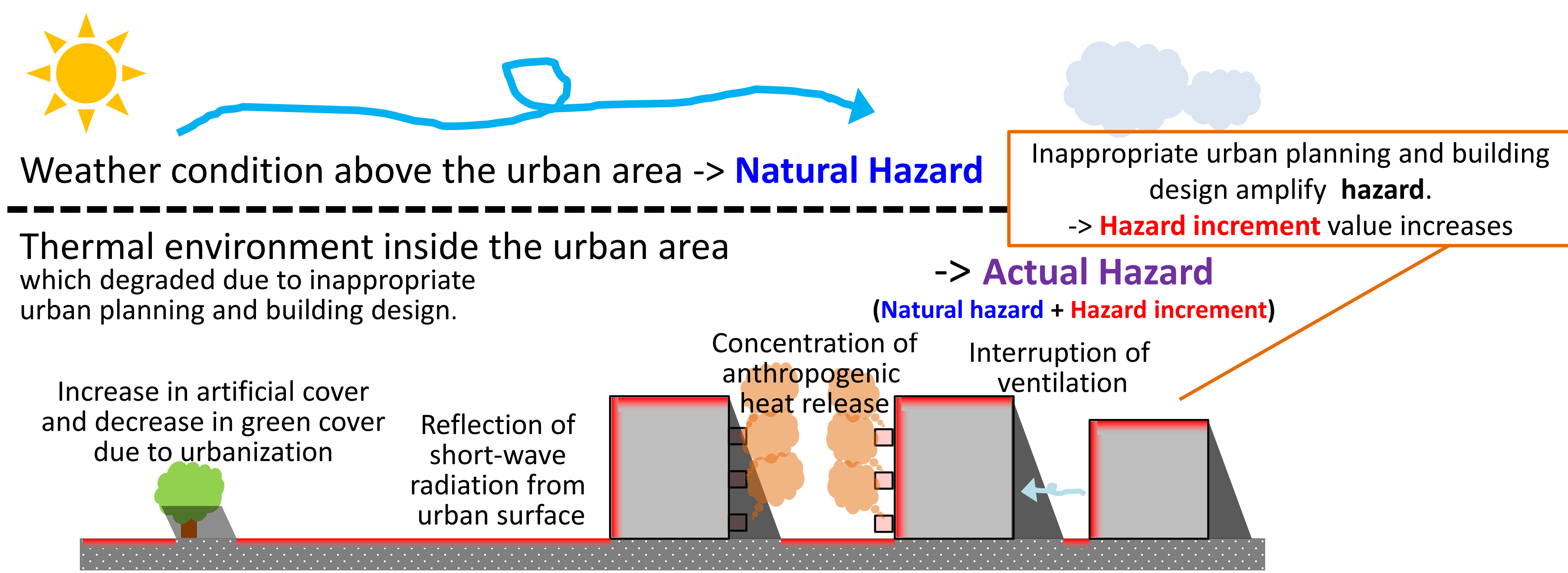
Definition of hazard in this study

- To distinguish between
  hazards that cannot be controlled by humans and
  hazards that can be controlled by modification of urban structures,
  "**natural hazard**" and "**actual hazard**" were defined.

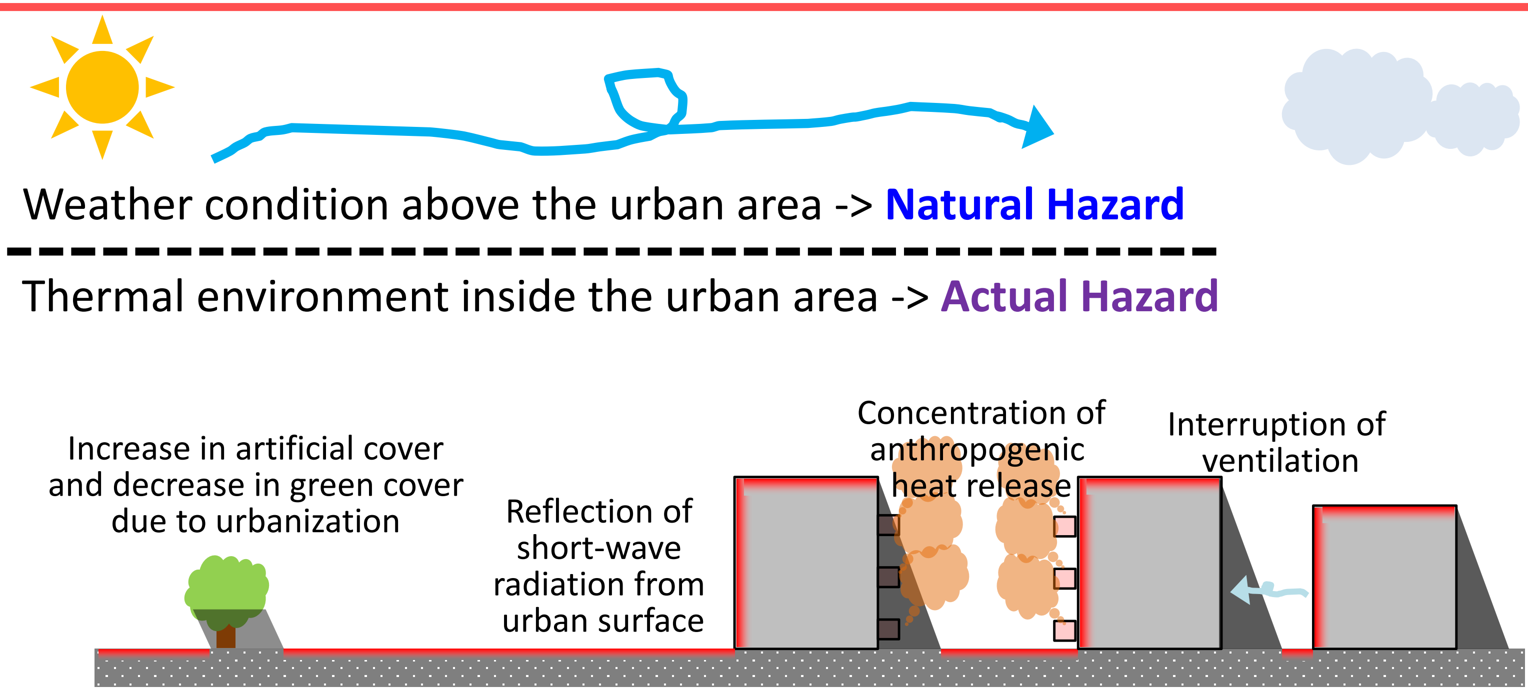


Definition of hazard in this study

- Natural hazard is an uncontrollable hazard, which can be estimated from weather conditions above an urban area.
- Actual hazard is a hazard that pedestrians are exposed to because of the thermal environment inside the urban area.



Index of vulnerability of urban structures based on risk evaluation



- **The risk above an urban area, R_{above},** and **the risk inside the urban area, R_{inside},** can be estimated from the values of natural and actual hazards,

$$R_{above} = f(\text{Natural hazard}) \qquad (2)$$

$$R_{inside} = f(\text{Actual hazard}) \qquad (3)$$

Index of vulnerability of urban structures based on risk evaluation

- Dividing formula (3) by (2), we get

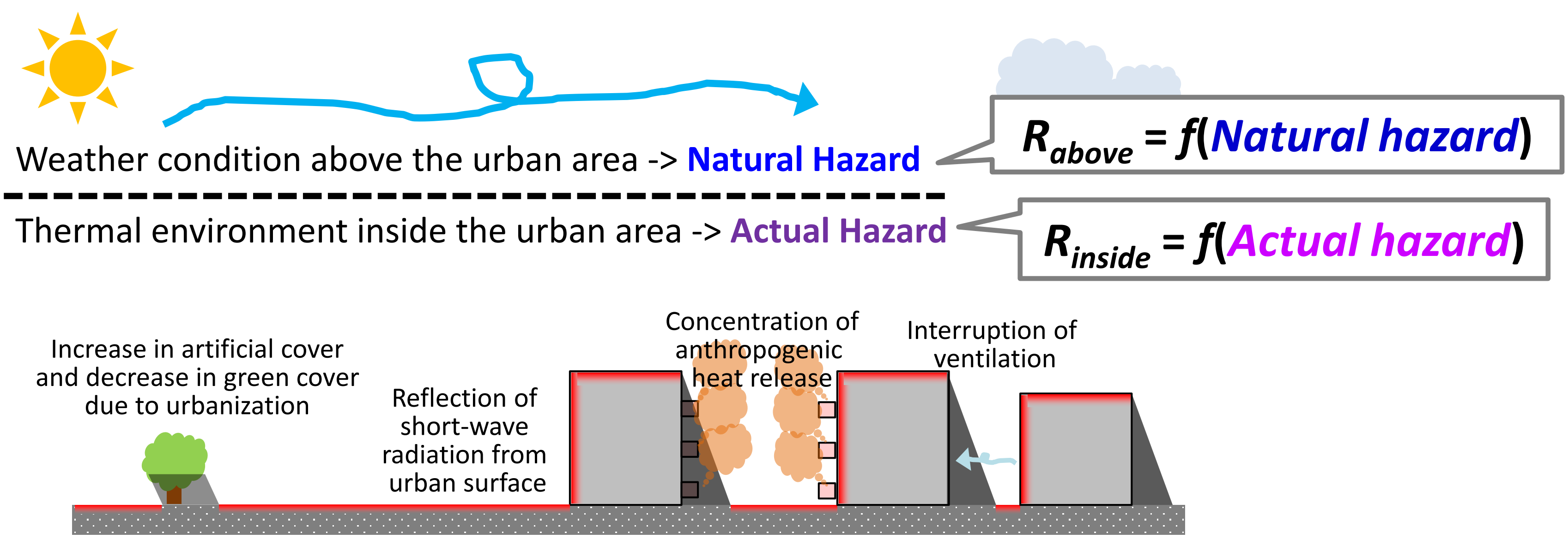
$$R_{inside} / R_{above} = f(\textit{Actual hazard}) / f(\textit{Natural hazard}) \qquad (4)$$

- Right hand side of formula (4) is defined as **risk amplification ratio**.
- This ratio is an index that comprehends the increase in health risks caused by amplification of hazards inside an urban area because of thermal vulnerability included by the urban area.

Index of vulnerability of urban structures based on risk evaluation

- To derive the risk amplification ratio,

  Risk amplification ratio = R_{inside} / R_{above}



Natural hazard -> mesoscale climate simulation

Actual hazard -> microscale climate simulation

Emergency transport probability curve, *f*

-> analysis of the emergency transport data

Estimation of emergency transport probability curves for heatstroke based on emergency transport data analysis

Estimation of emergency transport probability curves for heatstroke

- From the comparison between emergency transport data and meteorological data, a thermal index that is strongly linked to the increase in the number of occurrence of heatstroke was investigated and the emergency transport probability curves were estimated.

Outline of emergency transport data

- Five years’ emergency transport data from 2008 to 2012 were provided by fire departments located in nine major cities of Japan.

	City	Patients
Emergency transport	Sendai	1,268
	Tokyo	7,615
	Yokohama	2,074
	Shizuoka	584
	Yokohama	794
	Nagoya	4,418
	Osaka	3,160
	Kobe	1,800
	Fukuoka	1,495

Outline of meteorological observatory data

- Air temperature and Wet bulb globe temperature (WBGT) were derived from meteorological observatory data.

$$WBGT = 0.7T_w + 0.2T_g + 0.1T_a$$

T_w: wet-bulb temperature

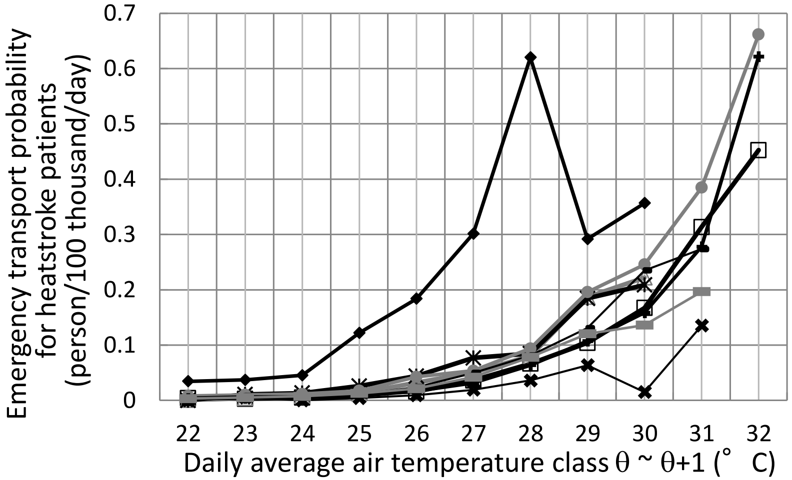
(estimated from air temperature, atmospheric pressure, dew-point temperature)

T_g: glove temperature

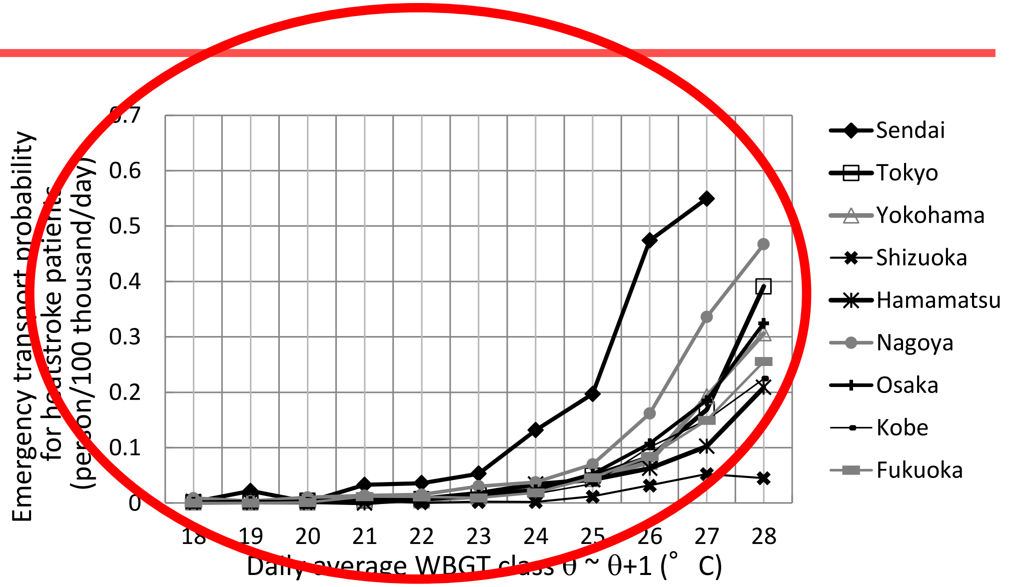
(estimated from air temperature, wind velocity, amount of global solar radiation)

T_a: dry-bulb temperature (=air temperature)

Analysis results



Relation between air temperature and emergency transport ratio



Relation between WBGT and emergency transport ratio

- WBGT correlated with the number of heatstroke patients more clearly than air temperature.
  <u>-> the relationship between WBGT and the emergency transport ratio was defined as the emergency transport probability curve</u>.

Analysis results

- In addition, thresholds of air temperature and WBGT for rapid increases in heatstroke patients were estimated.
- The thresholds in Sendai were lower than those in other cities.

City	**Average air temperature** in the summer season	Threshold of daily average of **air temperature**	Threshold of daily average of **WBGT**
Sendai	20	**28**	**26**
Yokohama	23	29	27
Hamamatsu	24	29	28
Shizuoka	24	31	27
Tokyo	24	32	28
Nagoya	24	32	27
Fukuoka	25	31	28
Kobe	25	30	28
Osaka	25	32	28

Application of the risk evaluation method

Extraction of at-risk area based on mesoscale climate analysis

Calculation conditions for a mesoscale climate analysis

- WRF modeling system was used.
- The calculation periods were a total of four months including the days when the daily number of occurrences of emergency transport for heatstroke was in the top ten.

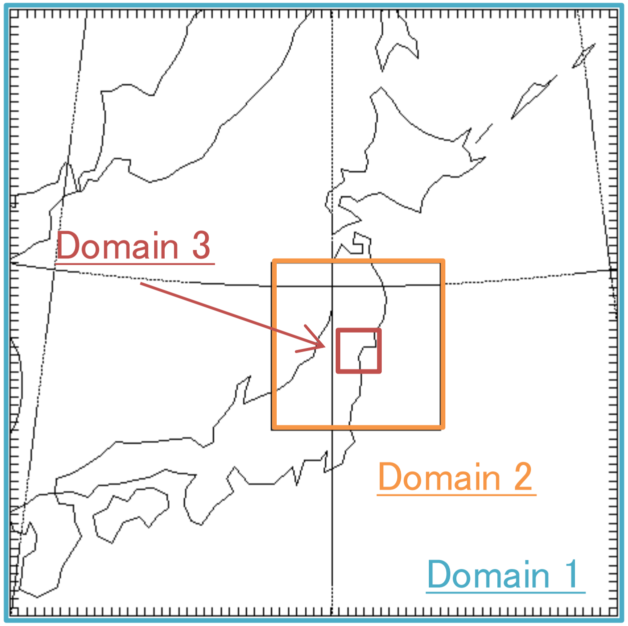
Rank	Date	Patients
1	2011/07/16	20
2	2012/07/28	16
3	2010/07/24	15
4	2010/07/22	13
5	2012/07/29	12
6	2010/08/05	11
7	2010/08/08	10
8	2010/08/07	9
9	2011/07/17	9
10	2010/08/06	8

Calculation conditions for a mesoscale climate analysis

- The spatial distributions of the average air temperature, absolute humidity, downward short-wave radiation, and wind velocity for the ten days were calculated and WBGT was estimated.

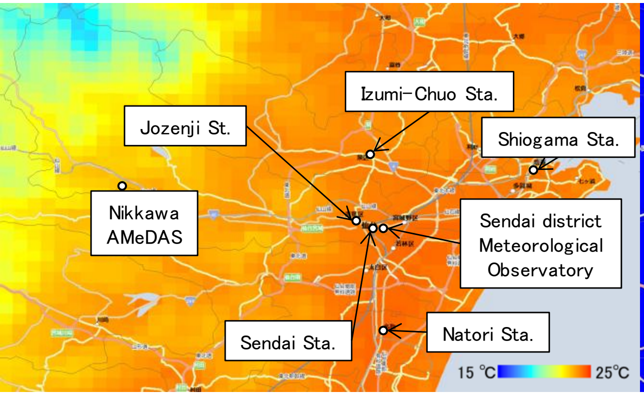
Mesh divisions

	Domain size (X×Y) [km^2]	Grid arrangement (I×J×K)	Grid size (X×Y) [km^2]
Domain 1	1800×1800	72×72×44	25×25
Domain 2	500×500	100×100×44	5×5
Domain 3	120×120	120×120×44	1×1

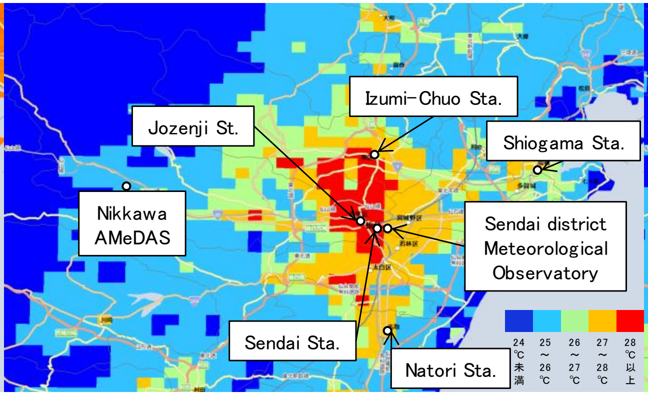


Computational domains

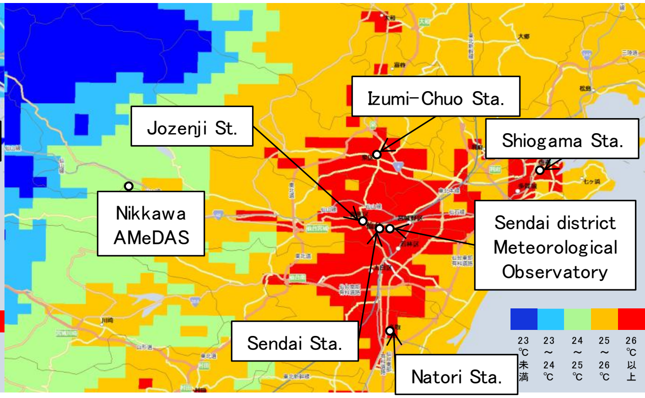
Spatial distribution of thermal indices (h=2m)



Wet bulb temperature, T_W



Air temperature, Ta



WBGT (=Natural Hazard)

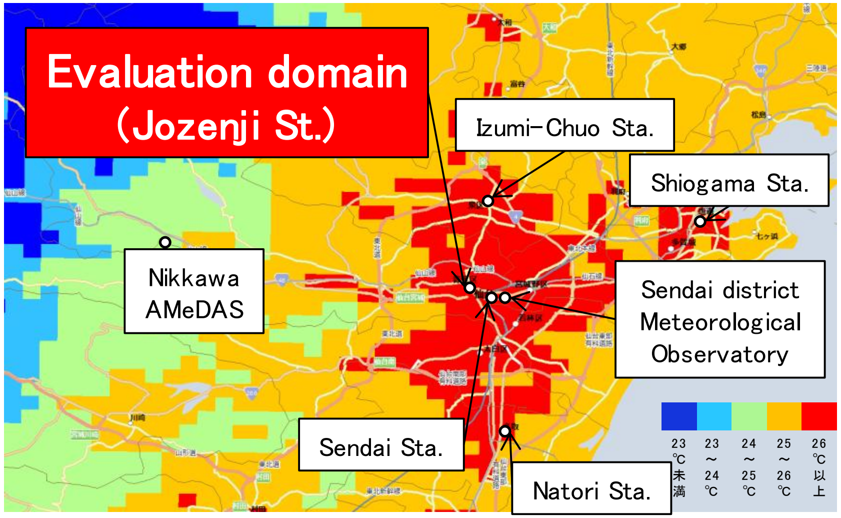
■ : Thermal index exceeds the threshold value

$$WBGT = 0.7T_w + 0.2T_g + 0.1T_a$$

- The spatial distribution of WBGT shows a red zone larger than the area showing the spatial distribution of air temperature; this is due to the effect of wet bulb temperature.
- The difference between wet bulb temperatures in urban and coastal areas was smaller than that between air temperatures in these areas.

Natural hazard estimated from mesoscale climate simulation

- In the next, risk evaluation is discussed for the central region of Sendai located in the red zone.

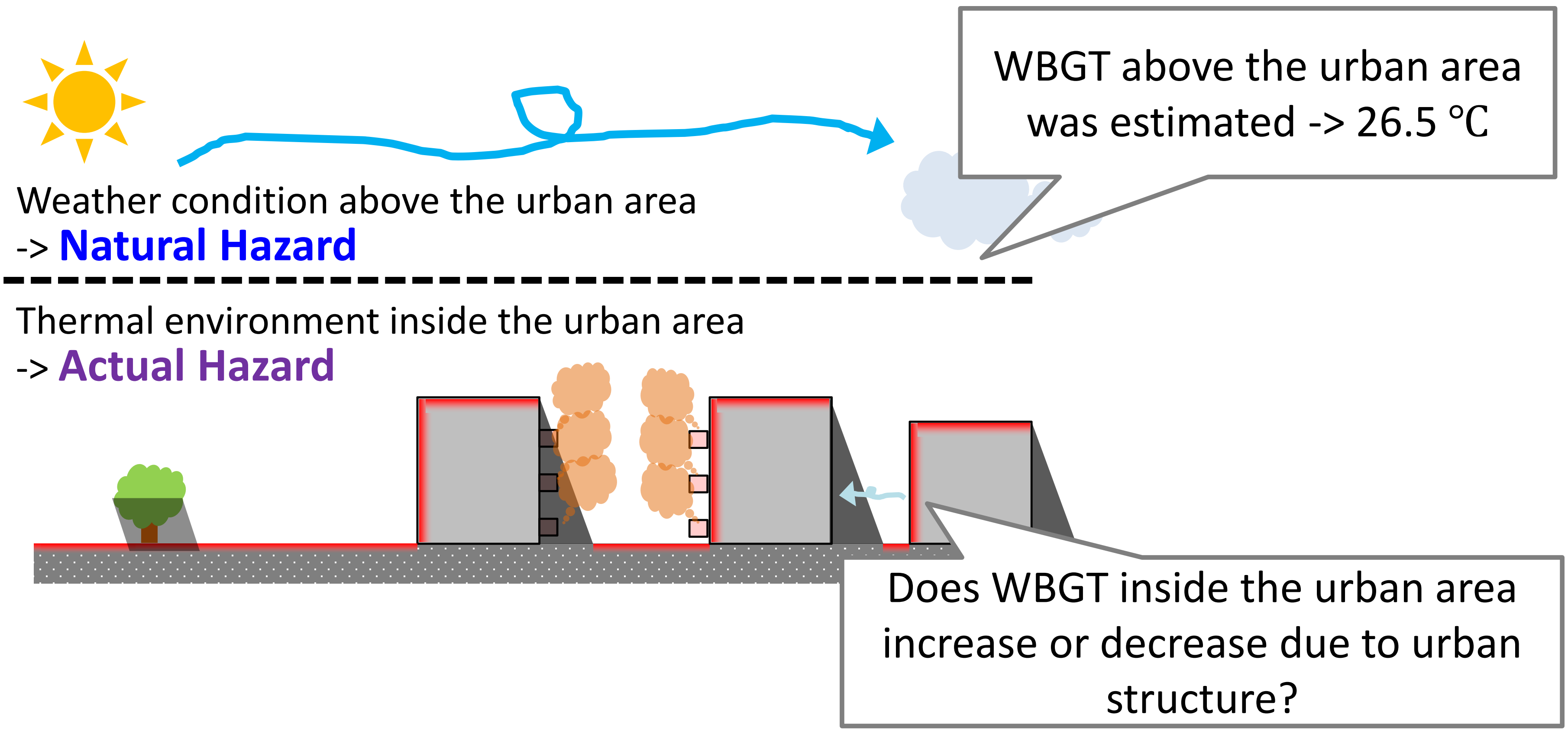


WBGT (=Natural Hazard)

- Analysis date: July 16, 2011 -> when the number of occurrences of emergency transport for heat stroke was the highest.
- Value of WBGT above urban areas at 12 p.m. on this date: **26.5 ℃**

Natural hazard estimated from mesoscale climate simulation

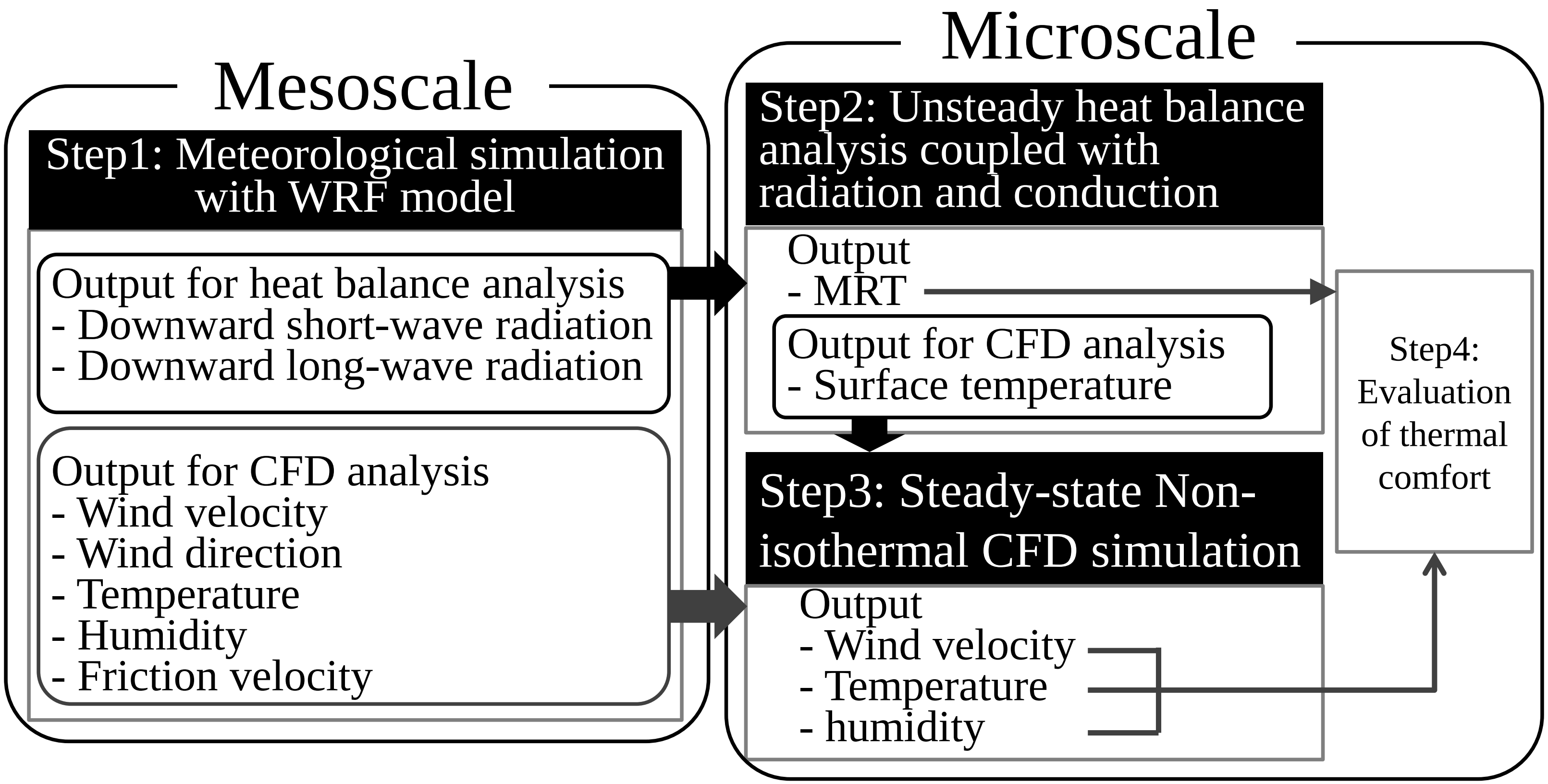
- The change in the actual hazard value due to urban structure will be estimated in the next section.



Application of the risk evaluation method

Evaluation of hazard distribution in pedestrian spaces through a combined analysis of mesoscale and microscale climates

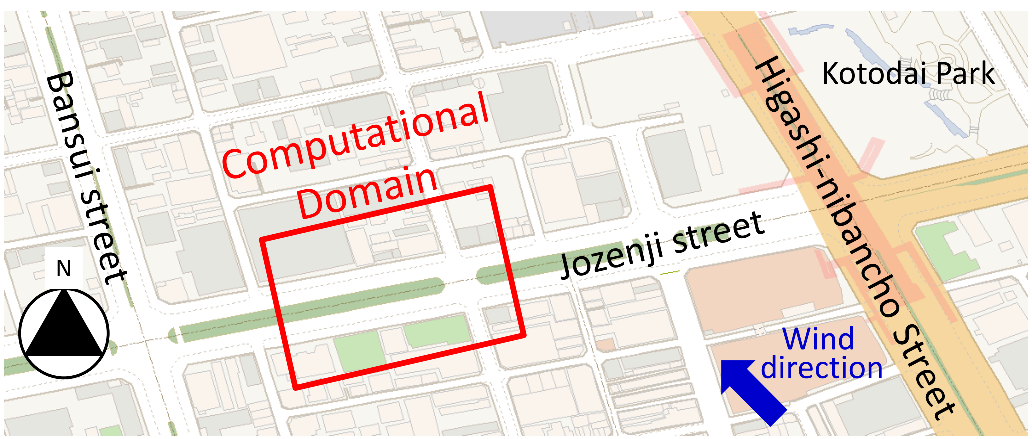
Calculation conditions for the microscale climate analysis



- A microscale climate analysis using the results of the mesoscale climate analysis as boundary conditions was performed.

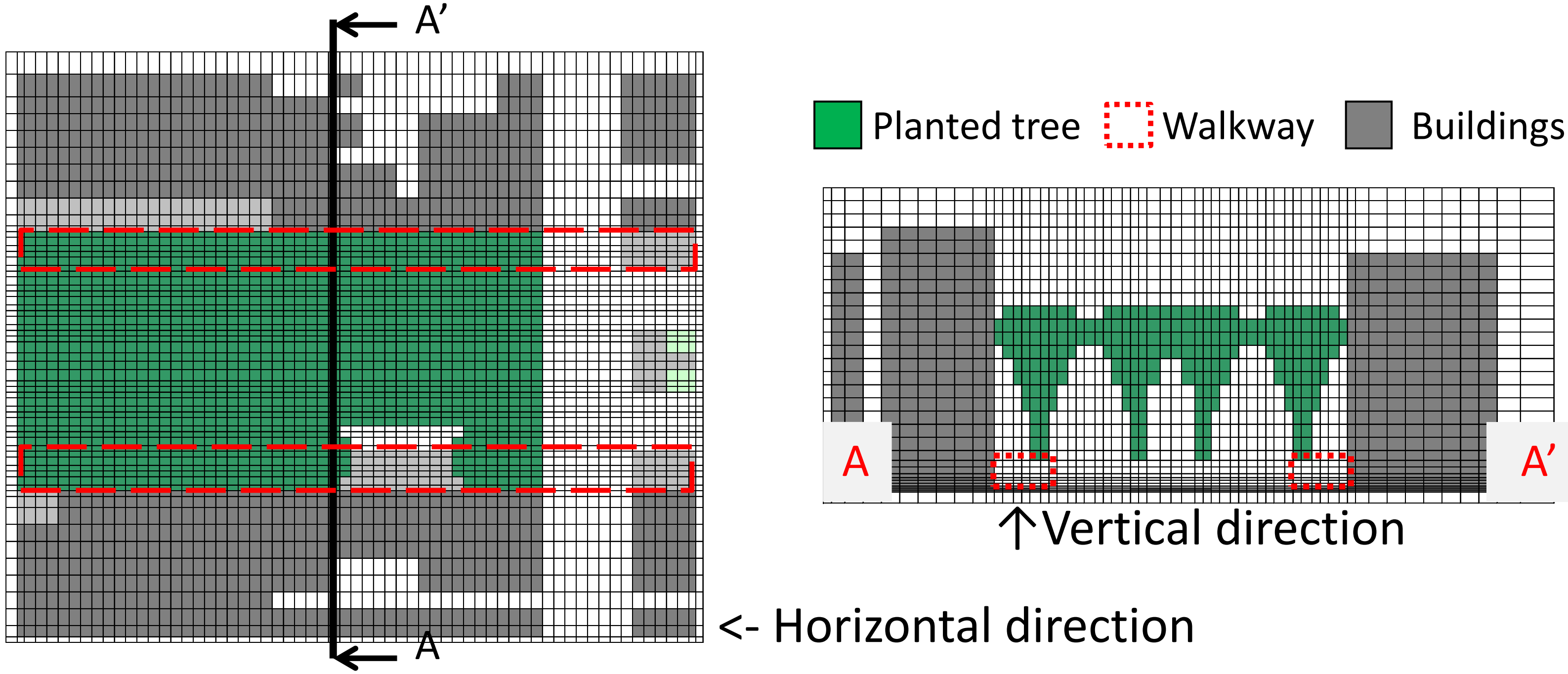
Calculation conditions for the microscale climate analysis

- **Calculation time**: 12 p.m. on July 16, 2011.
- **Simulation target**: Jozenji Street
- In Jozenji street, Zelkova trees that were about 15 m high are planted on the sides of the roads for over 700 m.
- Two situations were simulated to investigate the effect of the roadside trees: (1) the case with roadside trees, and (2) the case without roadside trees.



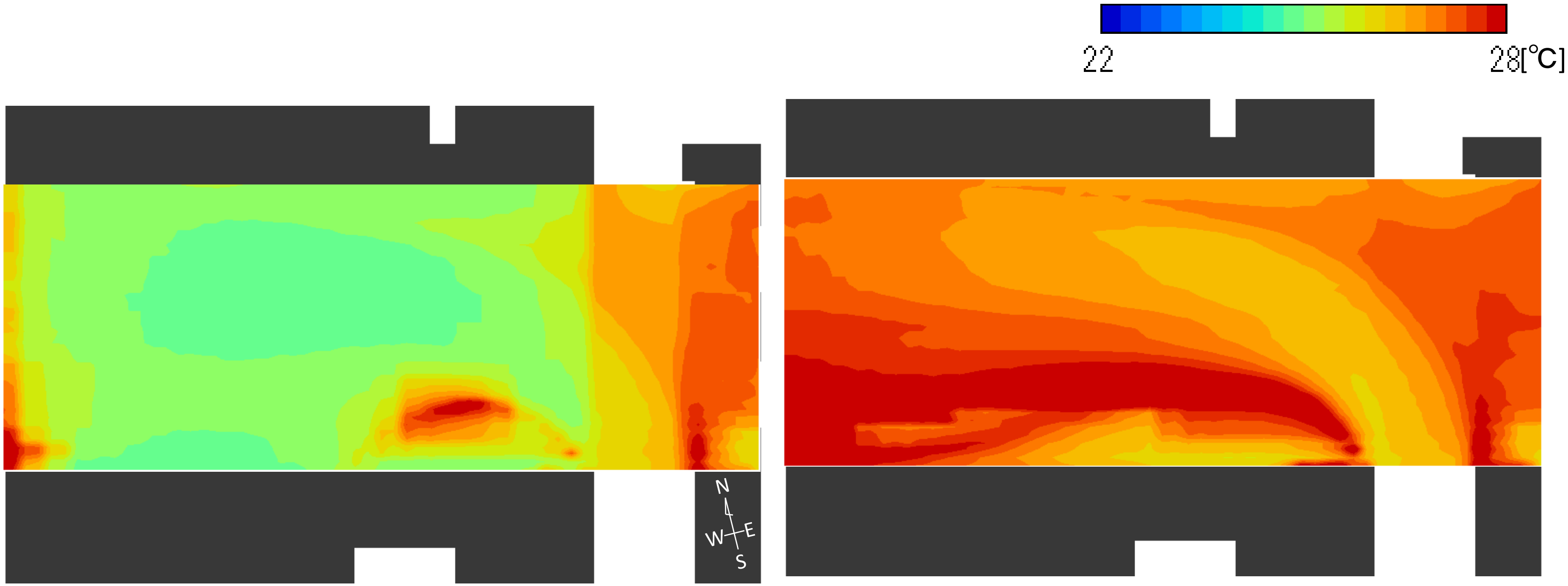
Mesh division

	Coupled simulation of radiation and conduction	Isothermal CFD simulation
Computational domain (X[m]×Y[m]×Z[m])	32×27×18	69×65×52
Grid arrangement (I×J×K)	340×300×200	171×151×550
Mesh number	15552	233220



Computational domain of CFD simulation in case with roadside trees

WBGT (h=1.15m)



With roadside tree

Without roadside tree

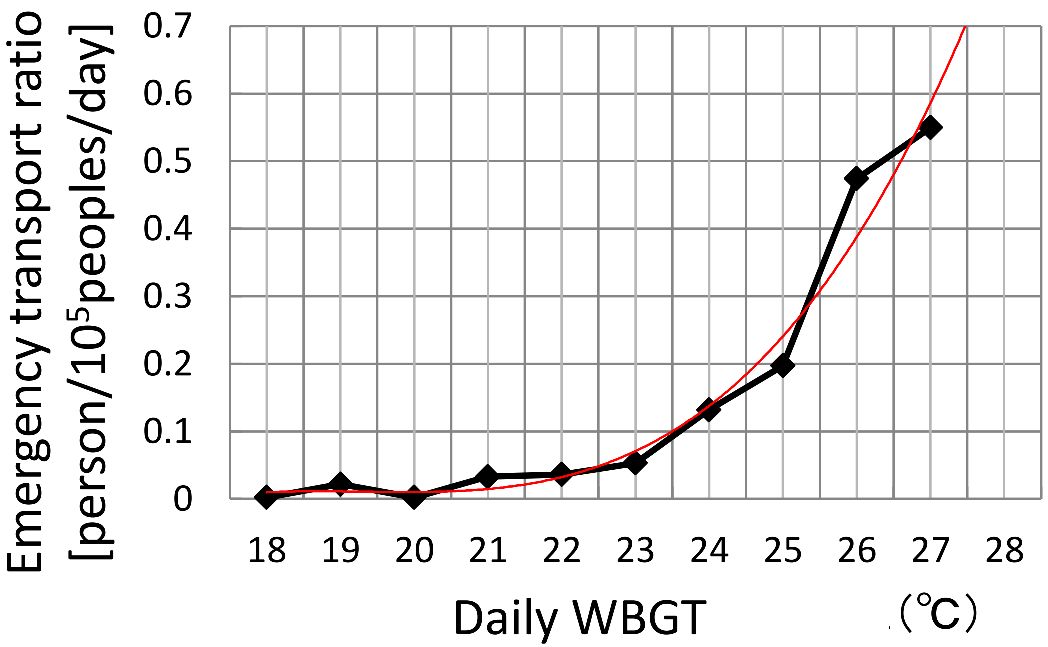
- WBGT in the case with roadside trees was lower than that in the case without roadside trees because of the shade provided by roadside tree

Application of the risk evaluation method

Risk evaluation results

Risk evaluation

- Finally, from the emergency probability curve and the WBGT values derived from mesoscale and microscale climate analysis, the risk values and the risk amplification ratio were estimated.



The emergency transport probability curve for Sendai city

Risk evaluation results

	Natural Hazard WBGT above urban area [°C]	**Actual Hazard** Average WBGT over pedestrian space [°C]	**Hazard increment** Difference between Natural Hazard and Actual Hazard [°C]
With roadside trees	**26.5**	**25.6**	**- 0.9**
Without roadside trees		**26.9**	**+ 0.4**
	***f*(Natural Hazard)** Risk above the urban area [person/10^5people/day]	***f*(Actual Hazard)** Risk inside the urban area [person/10^5people/day]	**Risk amplification ratio** [-]
With roadside trees	**0.36**	**0.22**	**0.62**
Without roadside trees		**0.43**	**1.2**

The results indicated that roadside trees reduced the risk considerably due to the shade provided by roadside trees under the conditions assumed in this study.

Conclusion

- A new method for evaluating the outdoor thermal environment based on the concept of risk evaluation was developed.
- Emergency transport probability curves for nine cities were estimated based on a comparison between emergency transport data and meteorological data.
- The spatial distribution of actual hazard values inside urban areas and the health risk value were estimated for the central region of Sendai. <u>Roadside trees reduced the health risk by providing shade under the conditions assumed in this study.</u>
- The results obtained in this study are based on preliminary trials that introduce the concept of risk evaluation in urban planning. Further discussion is required to evaluate risks more effectively.