-S-I-R-W-E-C-

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2-D Heat Transfer Model of A Horizontal U-Tube

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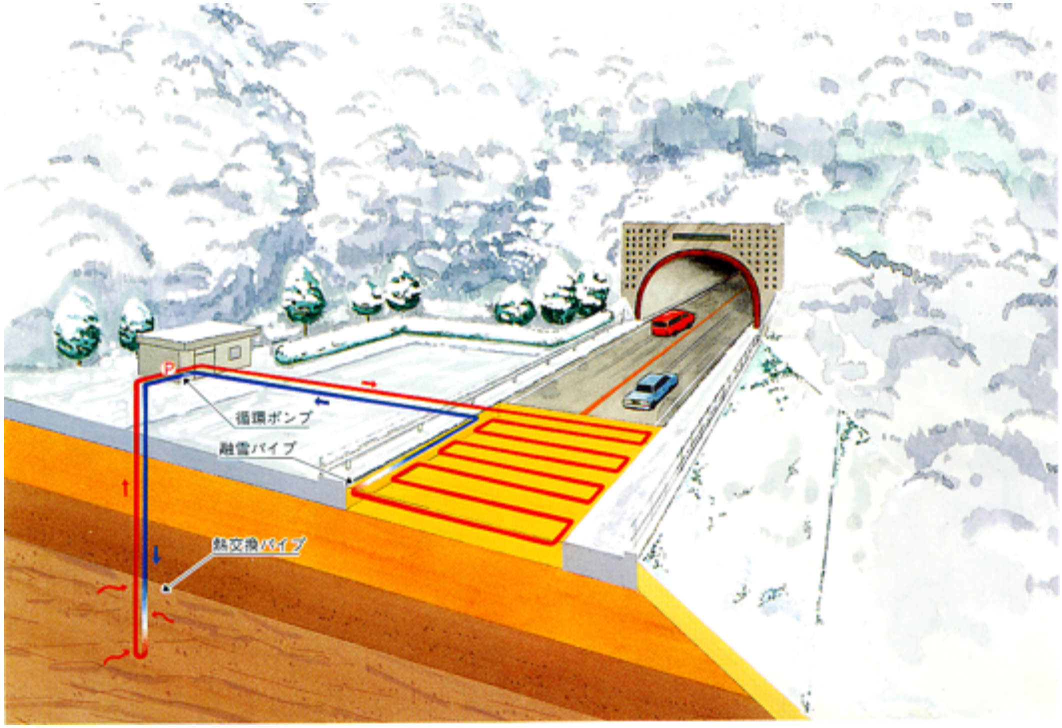
Introduction

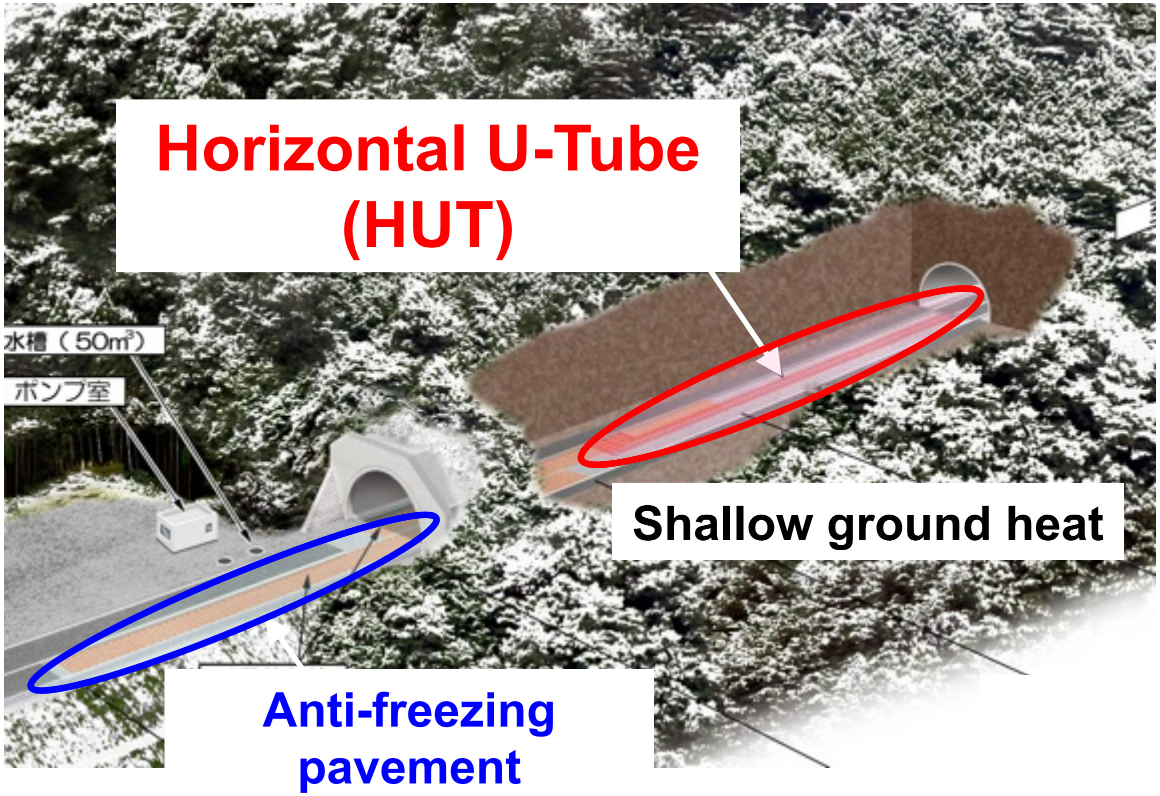
A slip accident at specific places such as intersections, bridges, tunnel mouths occurs frequently in winter. because the road surface conditions are remarkably changeable

Introduction



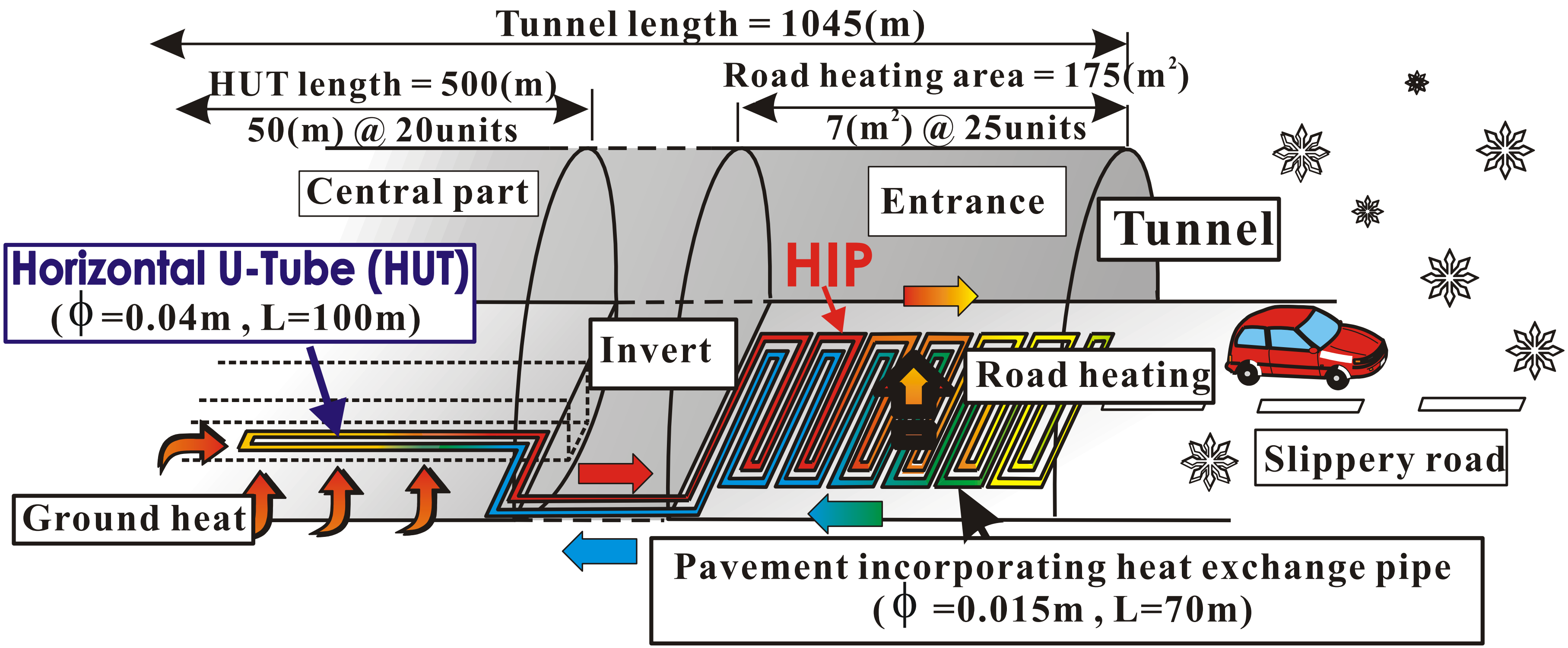
Road heating system has a significant requirement for reducing winter traffic accidents at the specific places

Introduction



Paying attention to the use of shallow ground heat inside the tunnel, we have been developing Horizontal U-Tube (HUT) road heating system in order to prevent road freezing at tunnel mouth.

HUT Road Heating System



Since the shallow ground heat has a low energy density, the reliable HUT heat transfer model is required to calculate the extracted ground heat for different tunnel lengths and the ground temperatures.

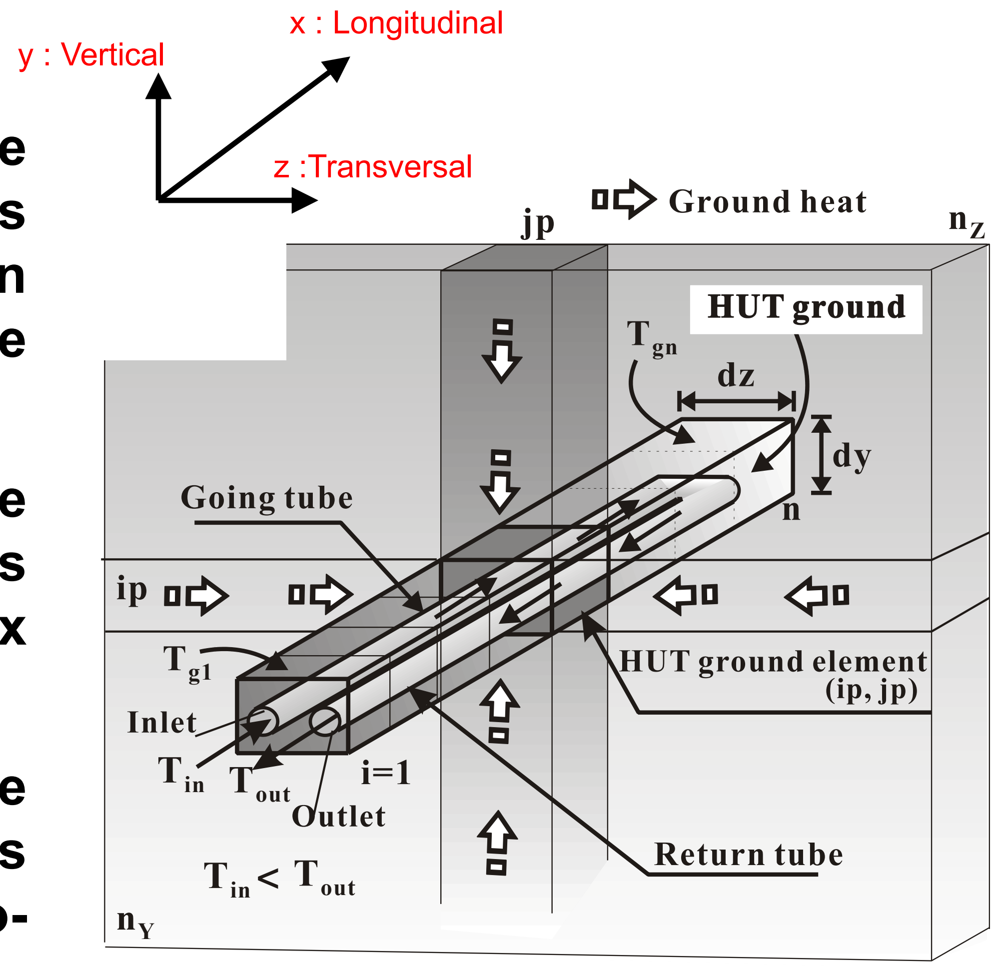
In winter, the HUT fluid is warmed associated with the extraction of the shallow ground heat, while it passes through the HUT and then the extracted heat is supplied to the pavement surface via the HIP.

Specific Aims

- **To develop heat transfer models of HUT system.**
- **To examine the validity of the proposed models by indoor experiments.**

Model Assumptions

1. The temperature gradient of the HUT fluid in the x direction is negligibly small in comparison with the ground temperature gradient in the y or z direction.
2. From the assumption 1), the HUT ground temperature, T_g, is assumed to be uniform in the x direction.
3. From the assumption 2), the heat transfer in ground is applicable in the y-z two-dimensional plane.



Energy Balance Equations

Ground surrounding HUT

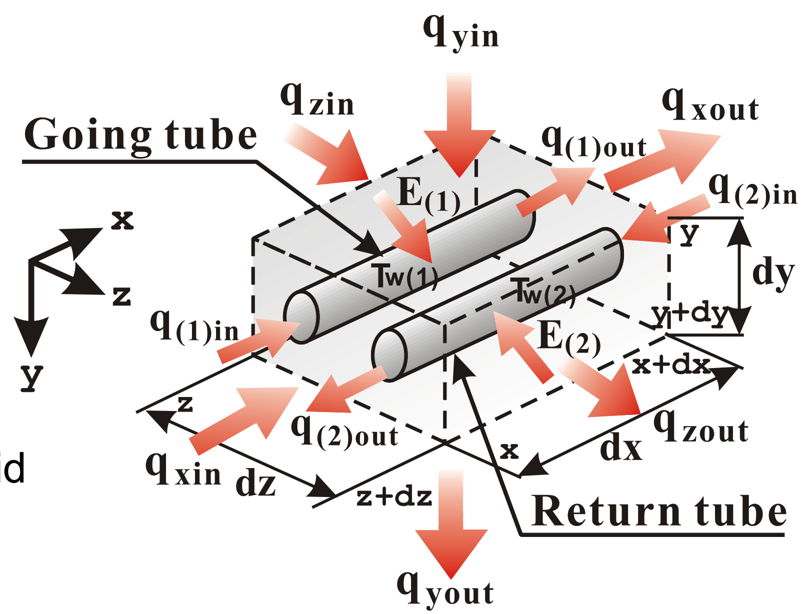
$$(\rho C)_g \frac{\partial T_g}{\partial t} = \frac{\partial}{\partial y}\left(\lambda_g \frac{\partial T_g}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda_g \frac{\partial T_g}{\partial z}\right) - \sum_{m=1}^{2} E_{(m)}.\eta_g$$

- T_g : ground temperature
- $(\rho C)_g$: heat capacity of ground
- λ_g : thermal conductivity of ground
- $E_{(m)}$: extracted heat flux per unit circumference-surface area of HUT
  [m=1: for going tube, m= 2: for return tube]
- η_g : the ratio of the circumference-surface area of HUT to the volume of HUT ground element

Extracted Heat Flux

$$E_{(m)} = \alpha\left(T_g - T_{w(m)}\right) \quad [m=1 \text{ or } 2]$$

- α : heat transfer coefficient between HUT fluid and HUT ground.
- T_w : HUT fluid temperature

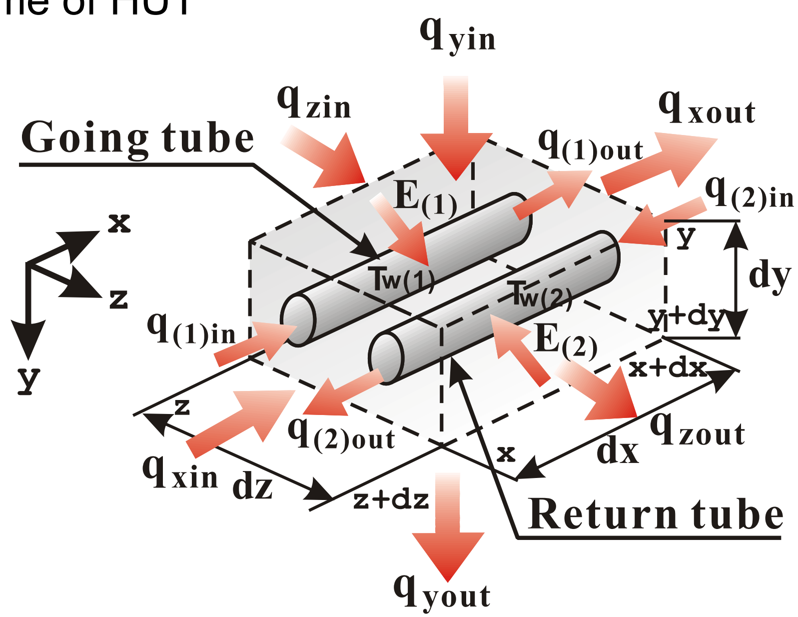


Energy Balance Equations

Heat Carrier Fluid of HUT (HUT fluid)

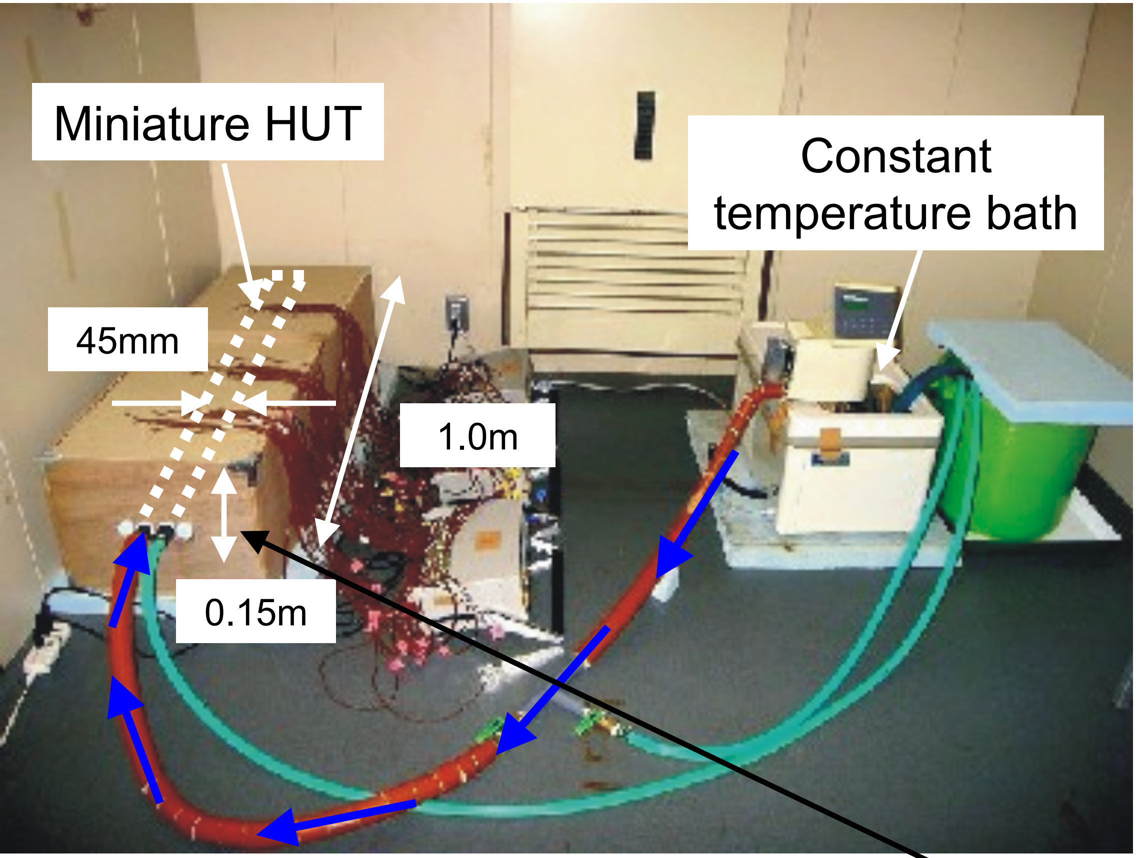
$$(\rho C)_w \frac{\partial T_{w(m)}}{\partial t} = \frac{\partial}{\partial x}\left(\lambda_w \frac{\partial T_{w(m)}}{\partial x}\right) - (\rho C)_w V \frac{\partial T_{w(m)}}{\partial x} + \sum_{m=1}^{2} E_{(m)}.\eta_p$$

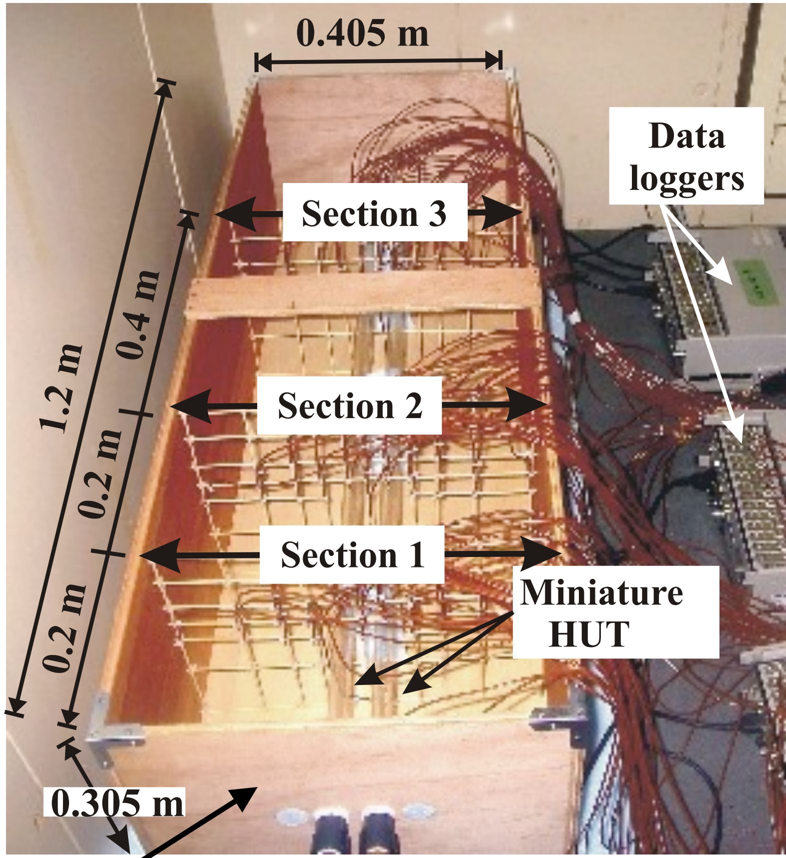
$(\rho C)_w$: heat capacity of HUT fluid
λ_w : thermal conductivity of HUT fluid
V : velocity of HUT fluid
H_p : ratio of circumference-surface area to volume of HUT



Indoor Experiments

Air temperature : 25ºC

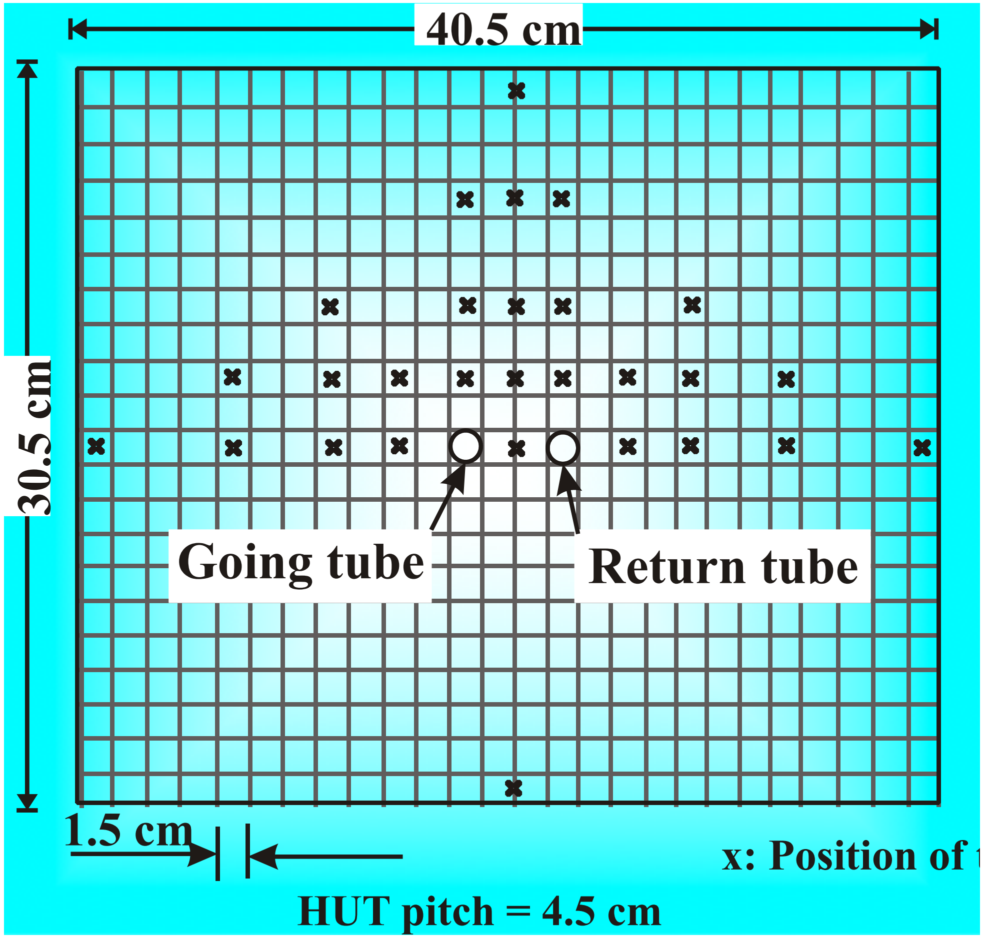




HUT fluid temperature : 10ºC

Soil box

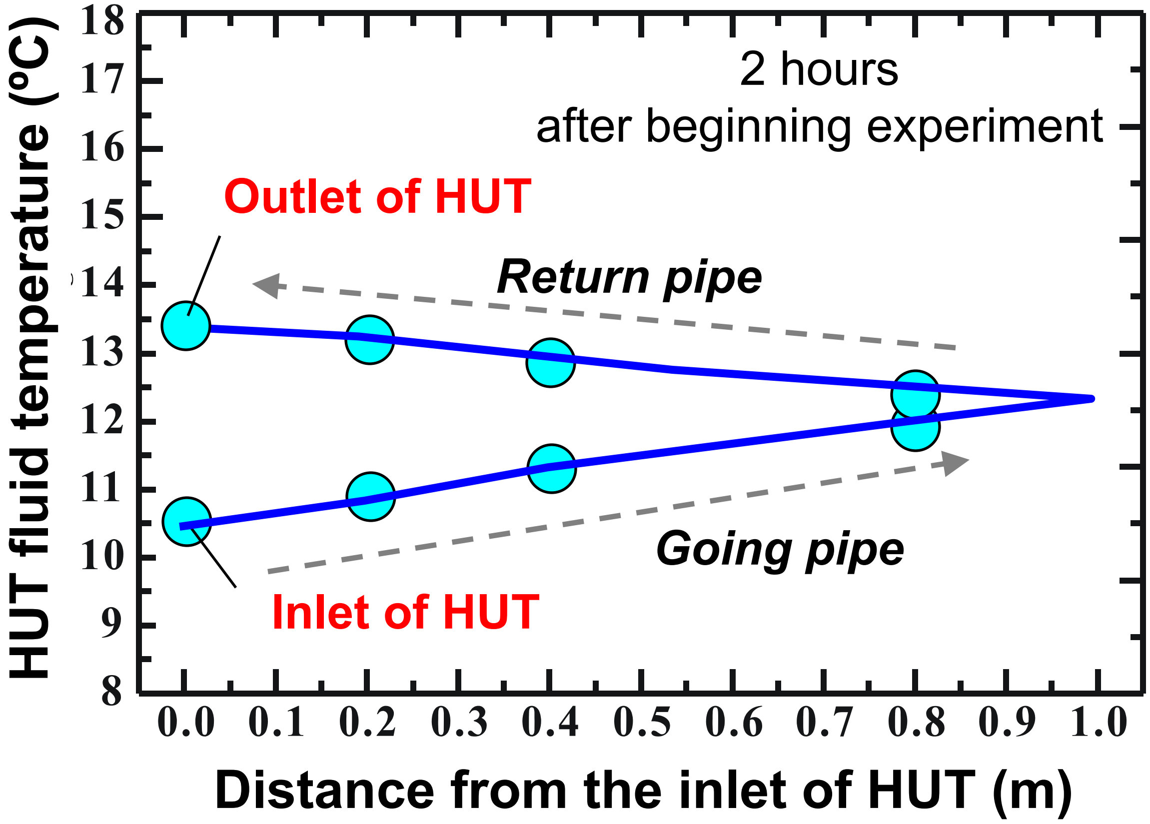
Thermo-couples position



Experimental Conditions

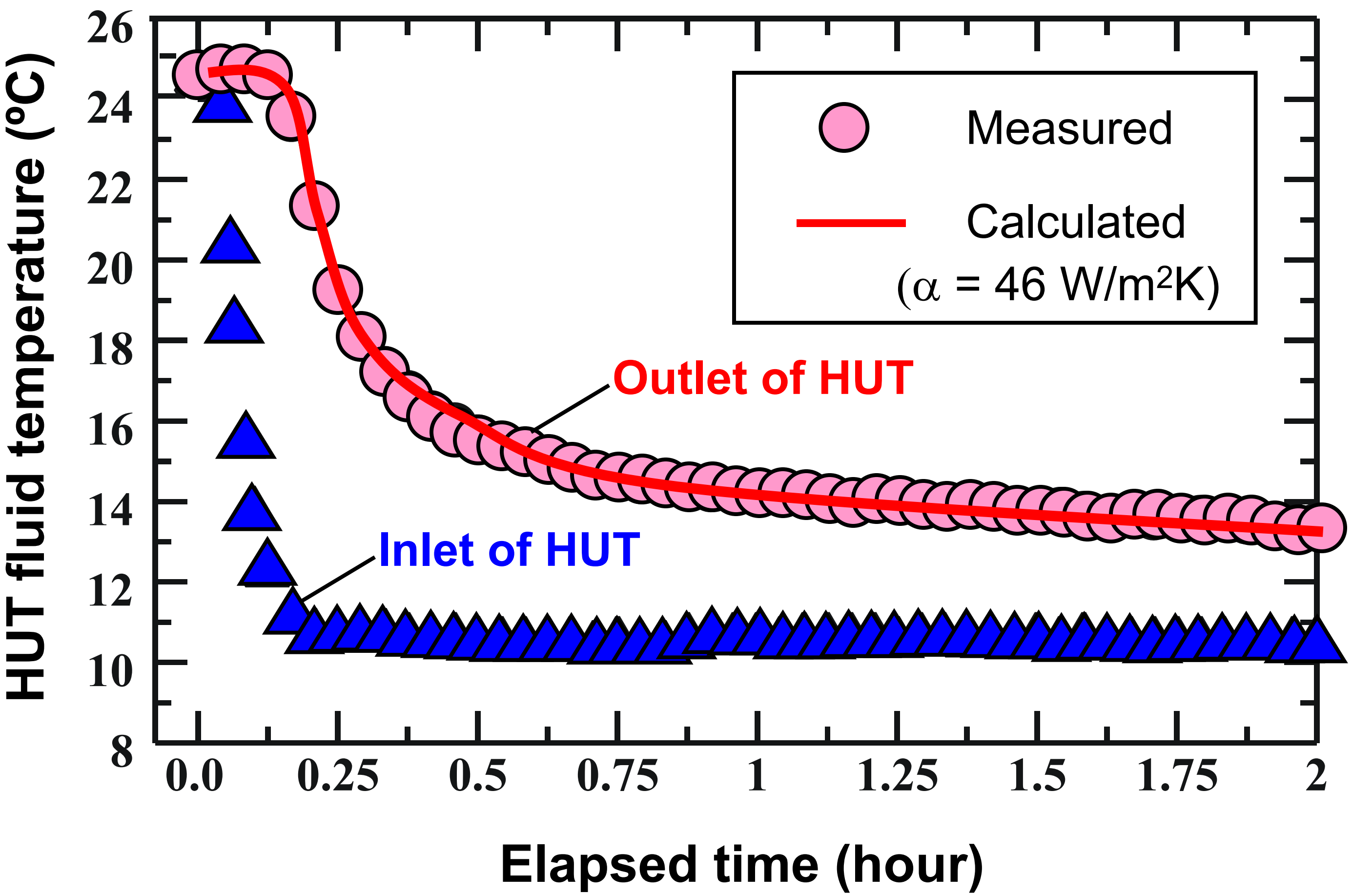
Case No.	Room conditions		Flow rate ($m^3/sec \times 10^{-7}$)
	T_a (°C)	RH_a (%)	
1	25	50	7.0
2			12.4
3			20.8
4			25.7
5			47.6

Longitudinal profile of HUT fluid temperature



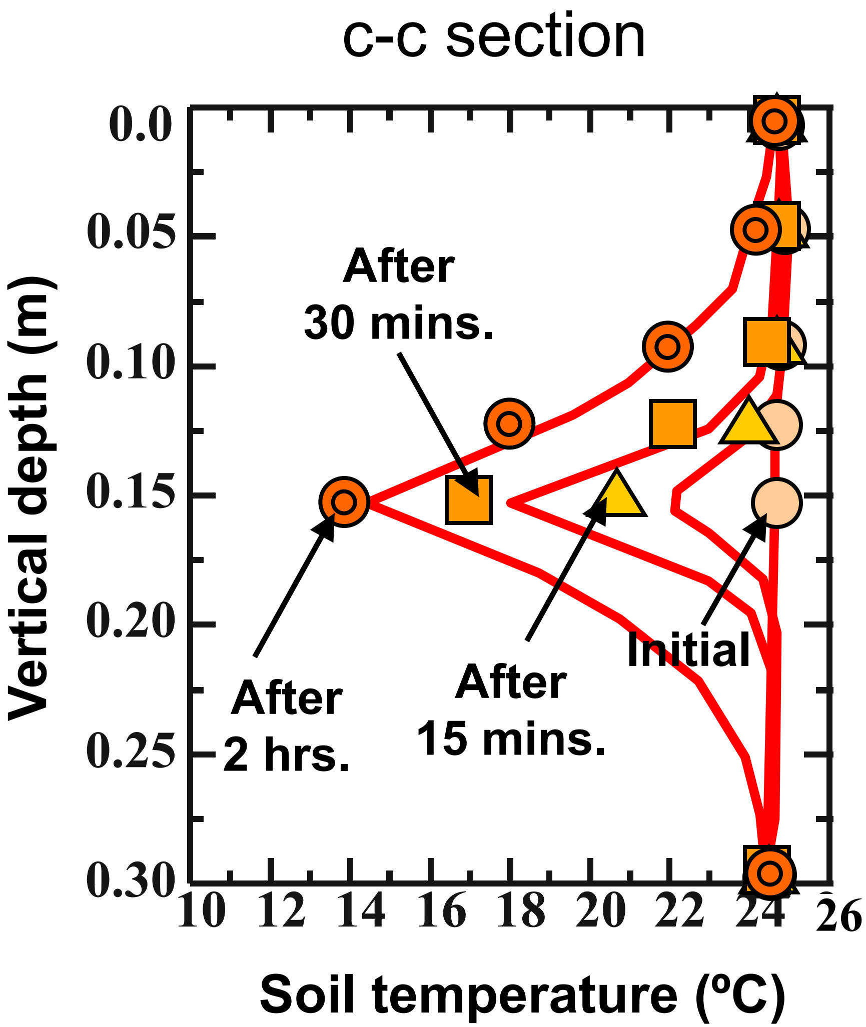
Flow rate: 47.6×10^{-7} m^3/sec

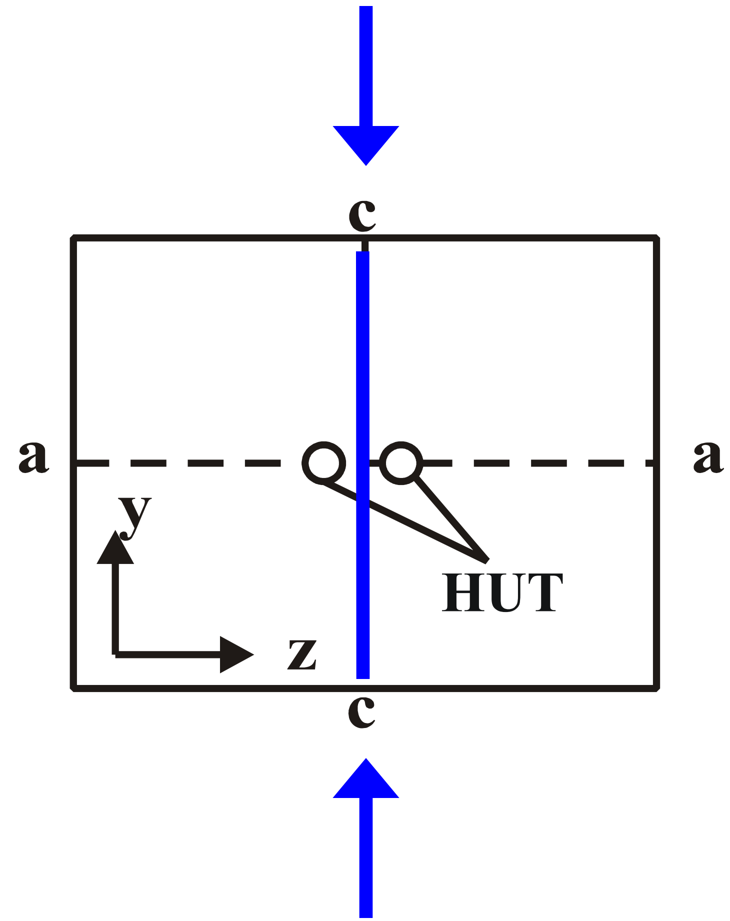
Time change of HUT fluid temperature



Flow rate: 12.4×10^{-7} m^3/sec

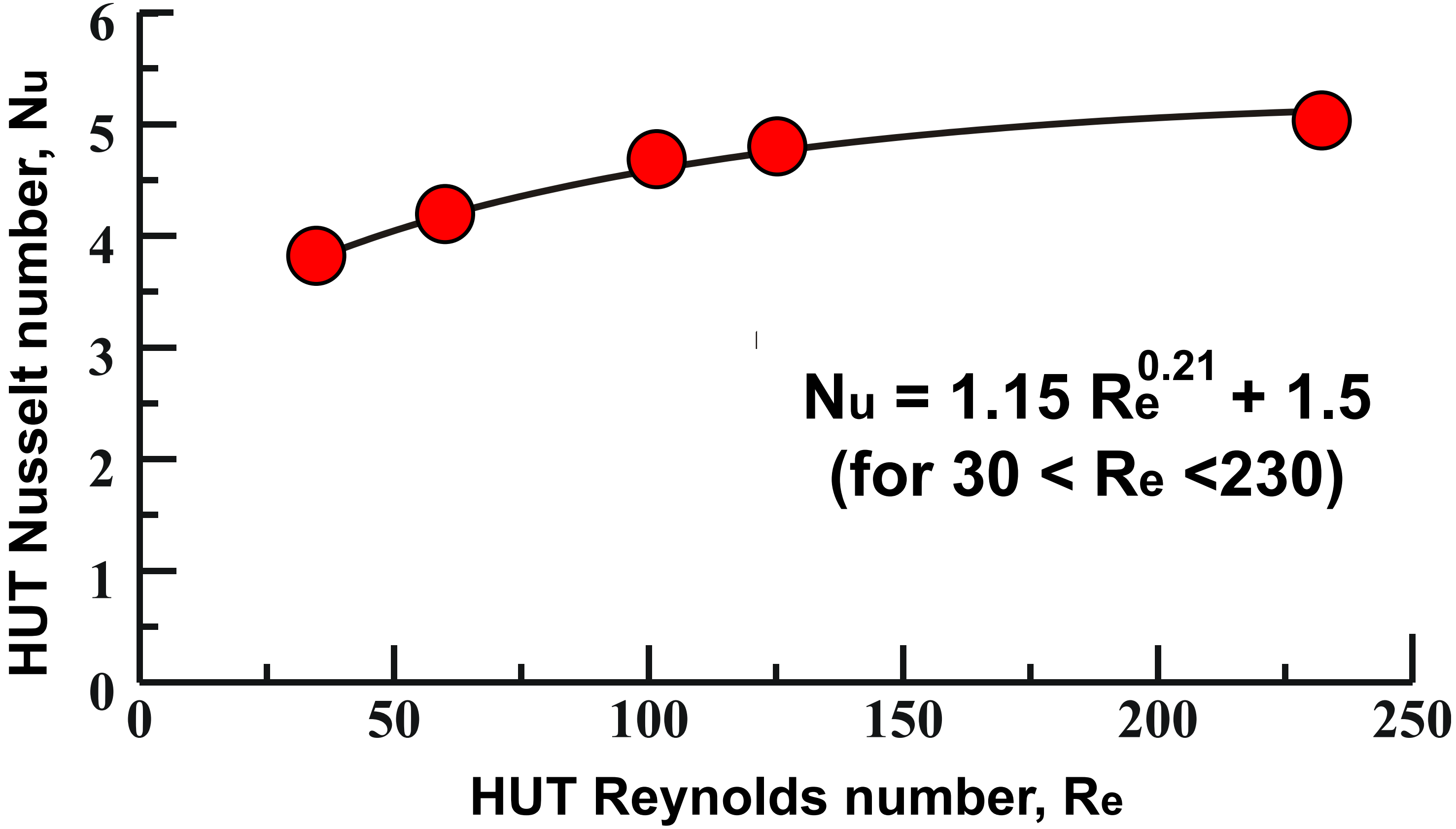
Vertical ground temperature





α = 46 W/m^{2}K

Relation between Nu and Re



$$Nu = 1.15\, Re^{0.21} + 1.5$$

(for $30 < Re < 230$)

Conclusions

A simplified heat transfer theory of a Horizontal U-Tube (HUT) is proposed and the applicability of the proposed model was discussed in comparison with experimental results using a miniature HUT

1. The relation between the HUT Nusselt number and the HUT Reynolds number is given by a power function and Nu increases with Re.
2. The indoor experimental results allowed the proposed model to reasonably predict the extracted ground heat.

Thank You

2.3 Initial & Boundary Conditions for Indoor Examination

Initial Conditions

- Horizontal and vertical soil temperature
- Fluid temperature at the inlet of HUT

Boundary Conditions

- Room temperature = 25 °C
- Relative Humidity = 50 %
- Time variations of the boundary soil temperatures were interpolated from the observed data obtained at an interval of 30 seconds.

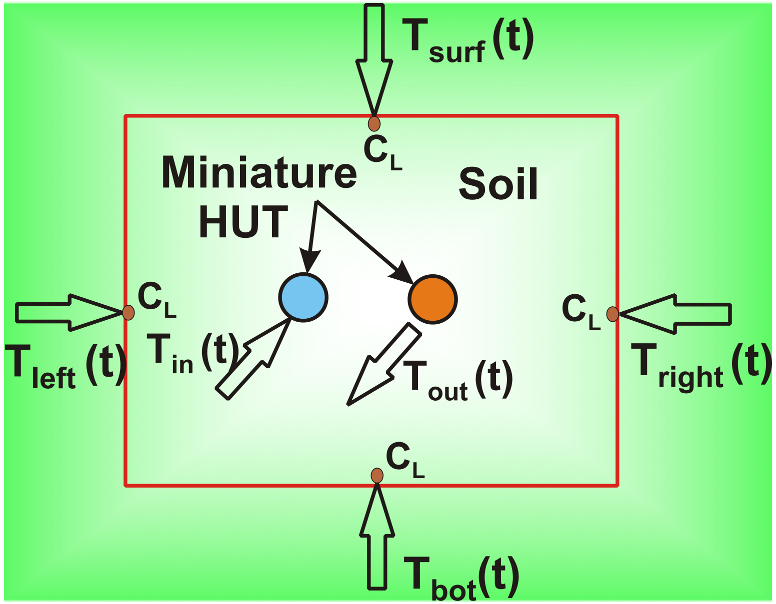


Fig. 9 Boundary conditions for indoor examination

3.2 Results of Indoor Experiments

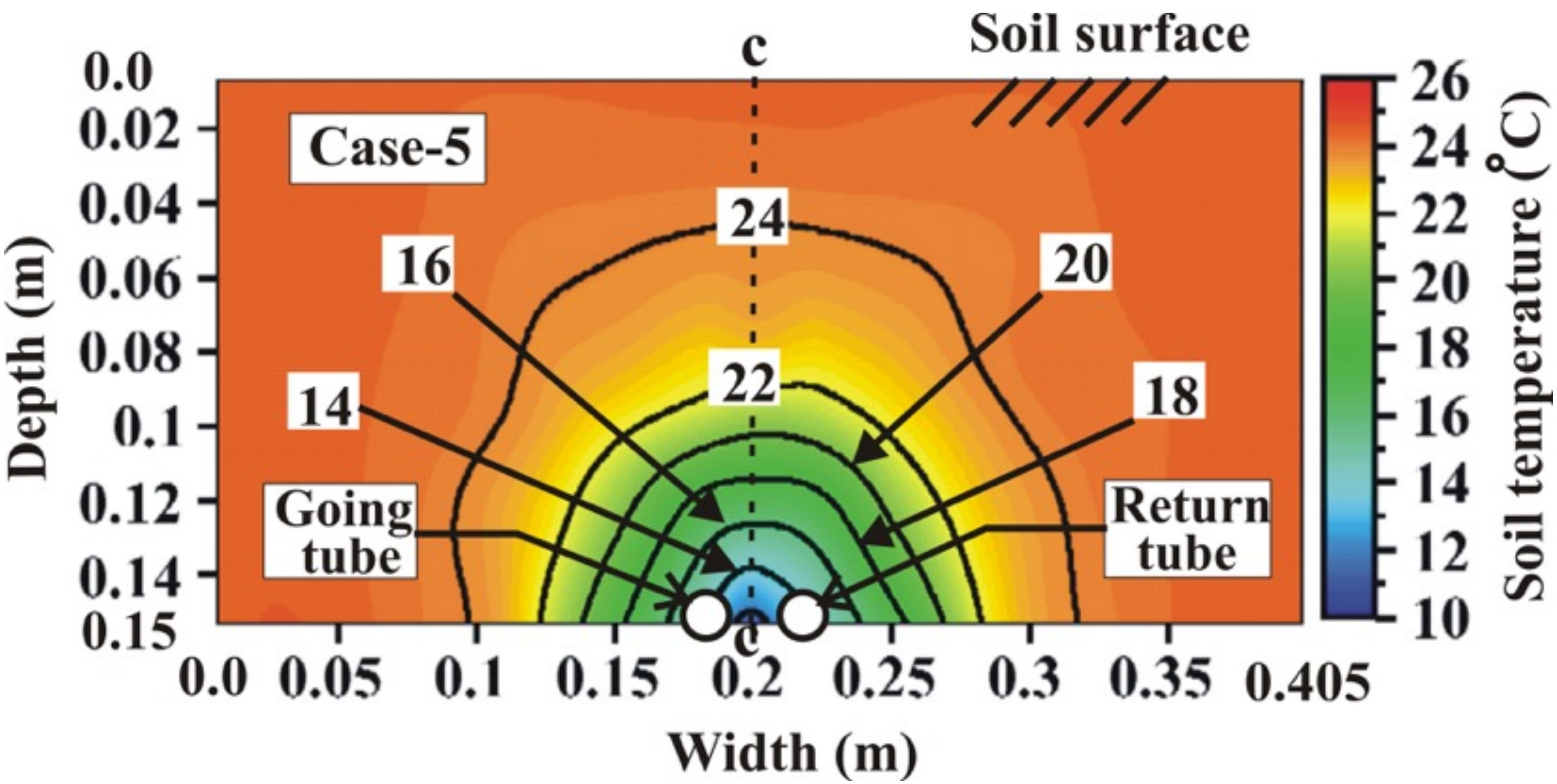
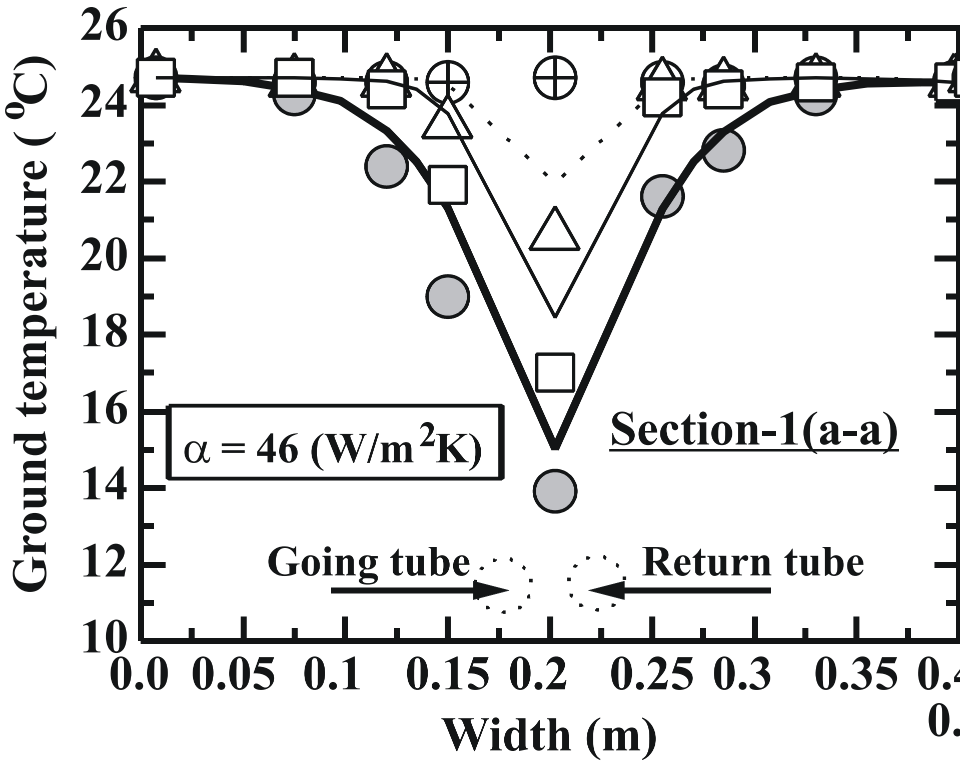
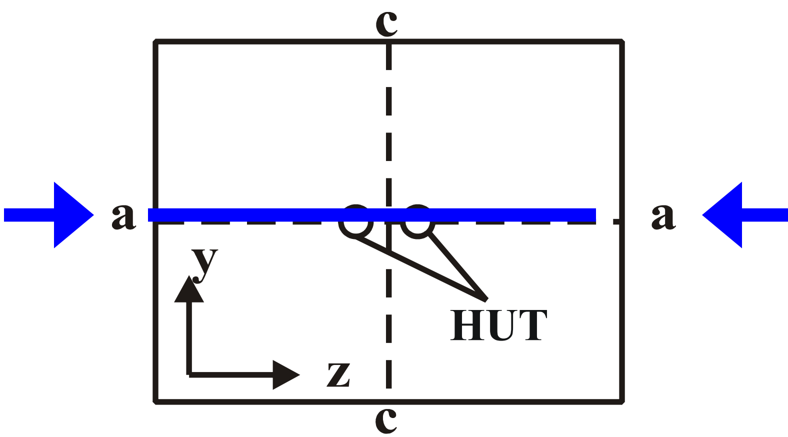


Fig. 18 Observed and calculated isothermal contours after 1.5 hours system operation (Case-5)

Horizontal ground temperature

a-a section





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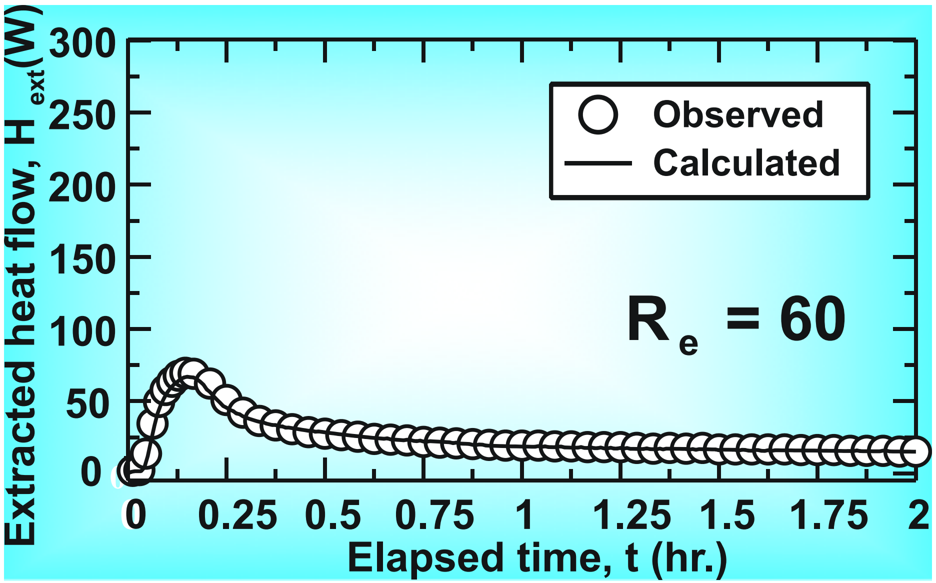
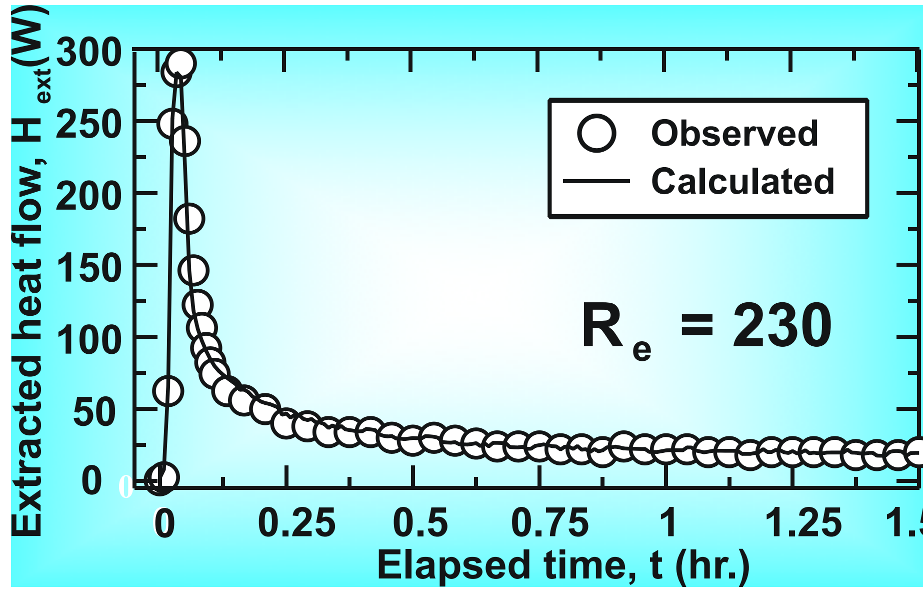


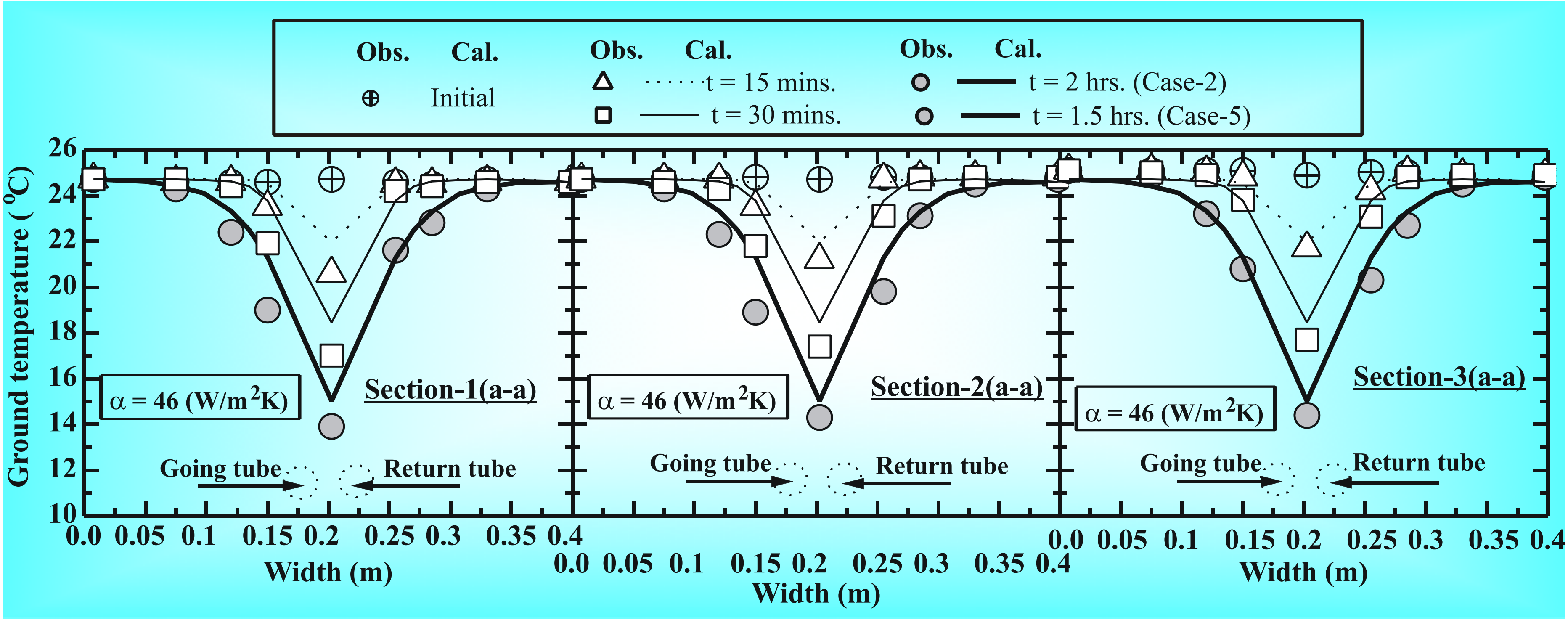
Case-2



Case-5

Fig. 20 Extracted heat flow with elapsed time

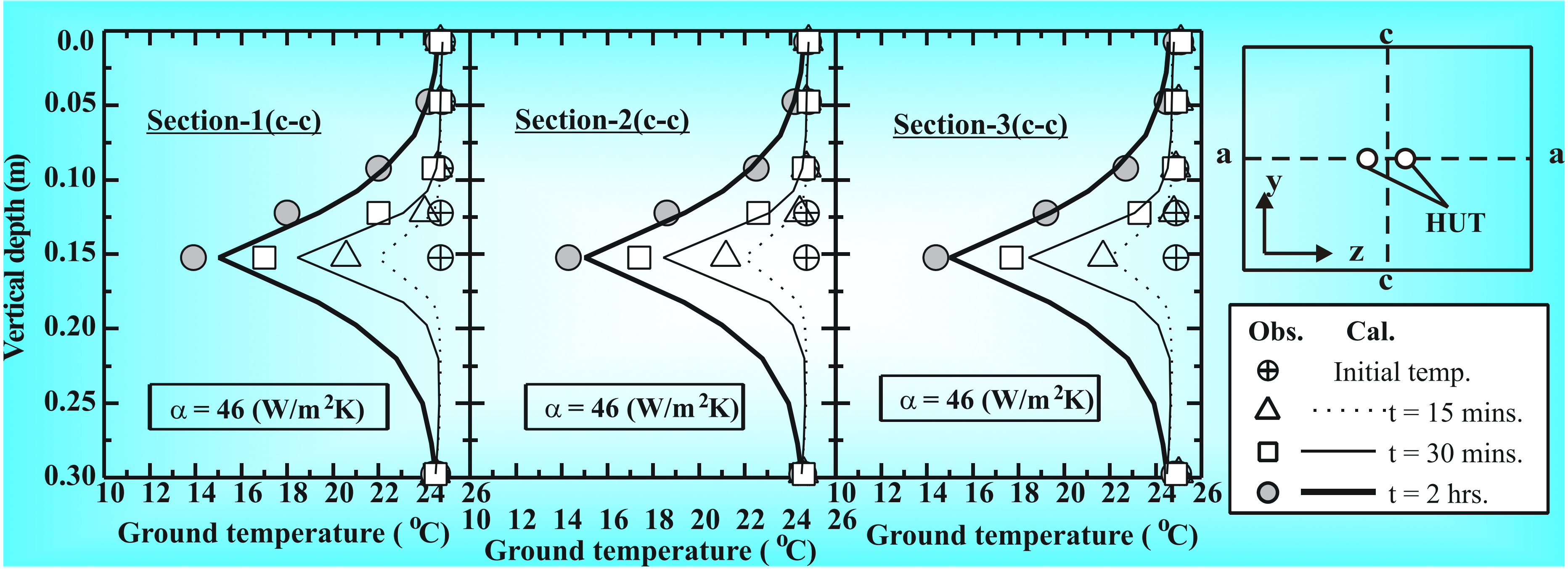
3.2 Results of Indoor Experiments



Case-2

Fig. 16 Model verification based on the horizontal ground temperature profile

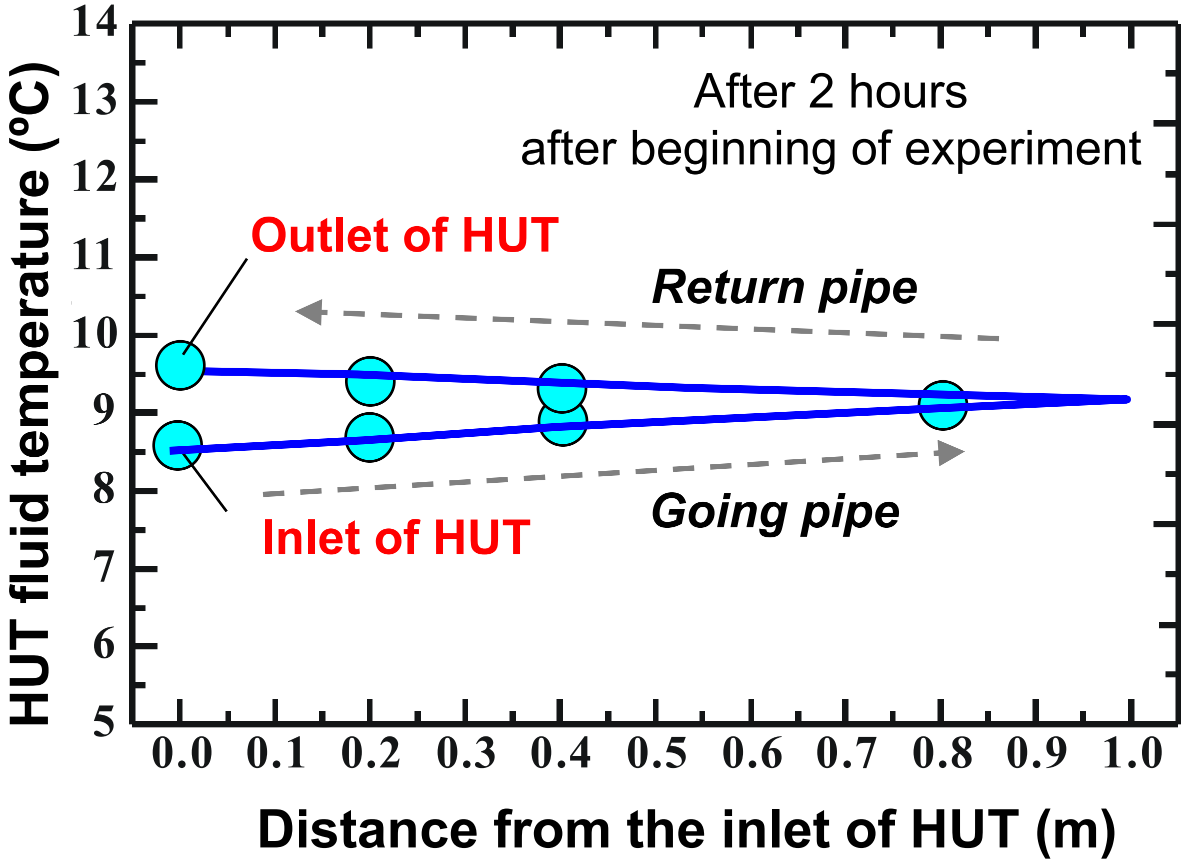
3.2 Results of Indoor Experiments



Case-2

Fig. 15 Model verification based on the vertical ground temperature profile

Longitudinal profile of HUT fluid temperature



Flow rate: 12.4×10^{-7} m^3/sec