

# Performance Prediction and Feasibility Study of Heat Pump Systems for an Actual Low Energy House

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# Today's Topics

We introduce performance prediction and feasibility study of two types of ground source heat pump (GSHP) systems for space heating (SH), space cooling (SC), and domestic hot water supply (DHW) of an actual low energy house



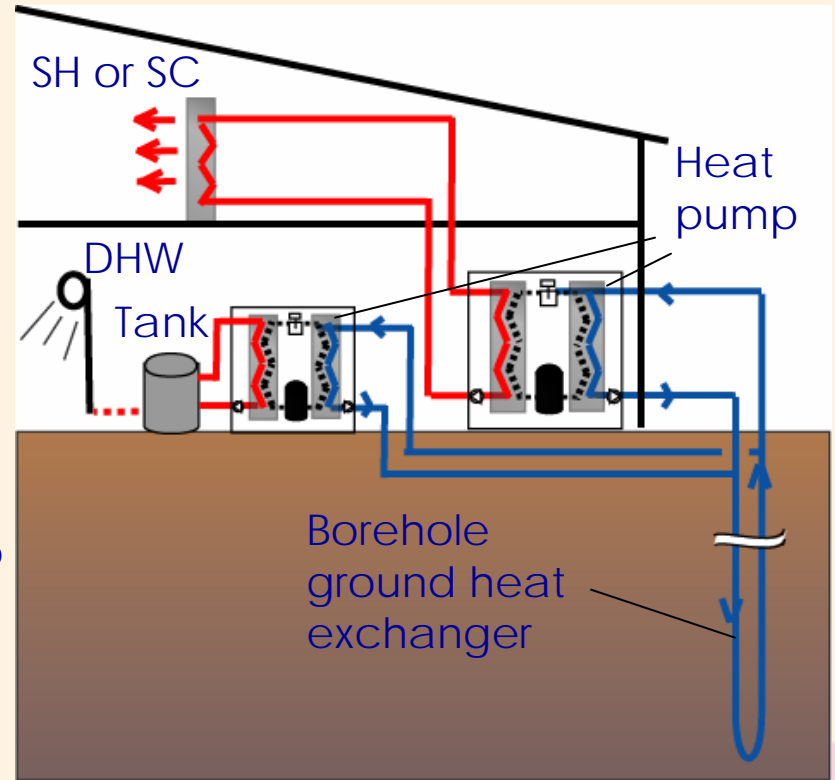
# Today's Topics

## Calculated GSHP systems

### 1. Twin compressor type GSHP system (Actually installed in the low energy house)

Heat pumps and hot water tank

System diagram

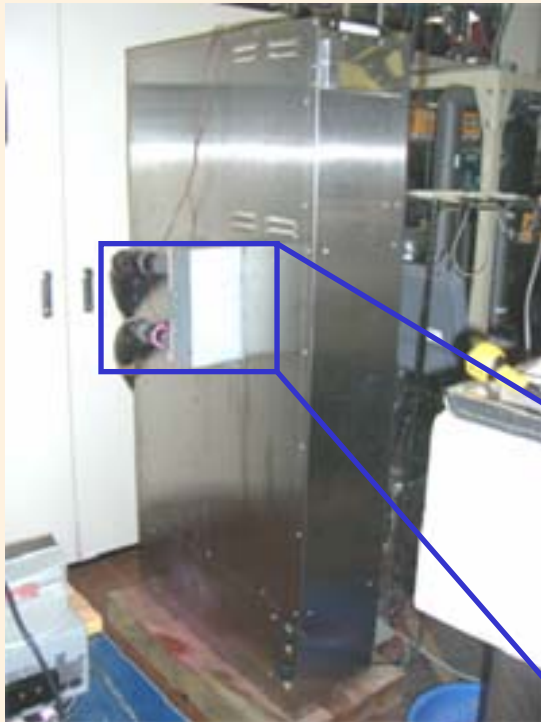


# Today's Topics

## Calculated GSHP systems

## 2. Integrated GSHP system with a de-superheater

Heat pump\*

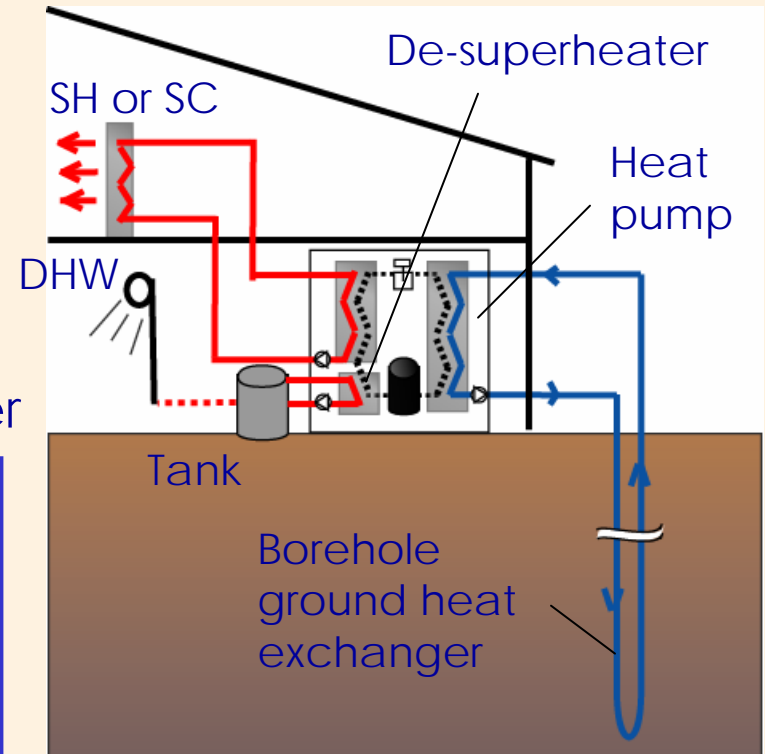


\*This is the same as the one for SH and SC, which is shown in previous slide

De-superheater



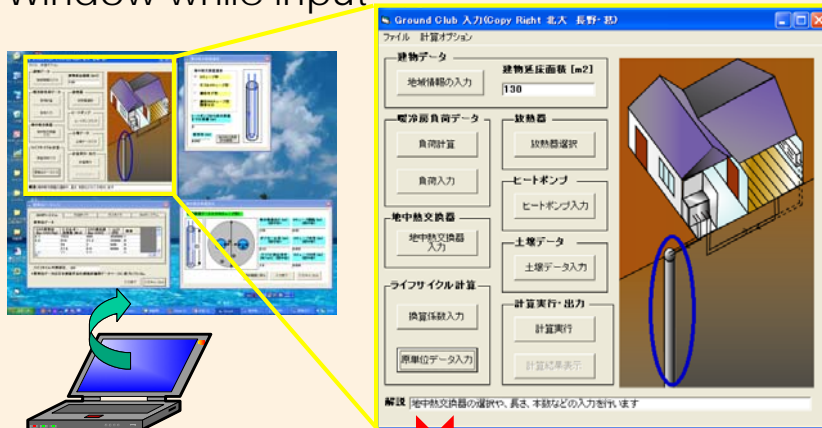
System diagram



# Outlines of heat pump system simulation

Calculation soft : Computer aided design and performance prediction tool for GSHP systems 'Ground club'

Window while input

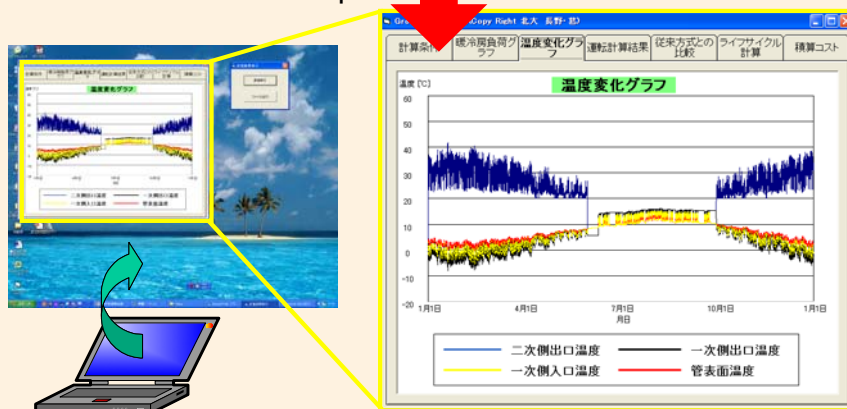


## Input items

- Building data
- Region and climate
- Radiator
- Spec of heat pump unit
- Spec of ground heat exchangers
- Number of ground heat exchangers
- Soil condition
- LCA data etc

Calculation

Window while output



## Output items

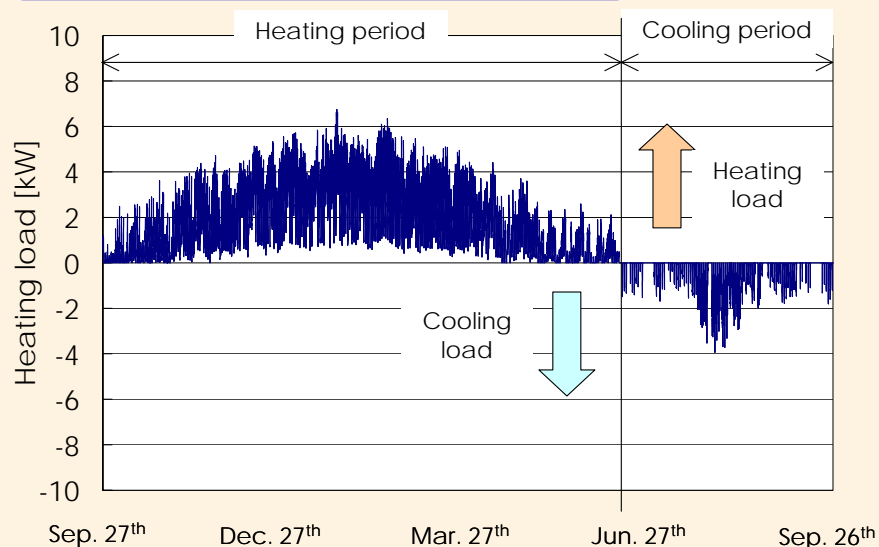
- Temperature variation of each part
- Performance of the GHP system
- Annual electric power consumption
- Annual energy consumption and CO<sub>2</sub> emission
- Running cost
- Result of LCA

# Outlines of heat pump system simulation

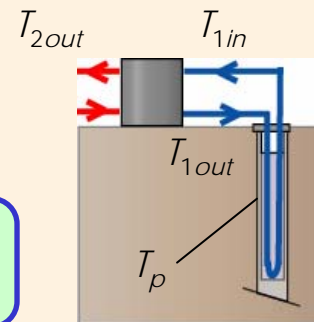
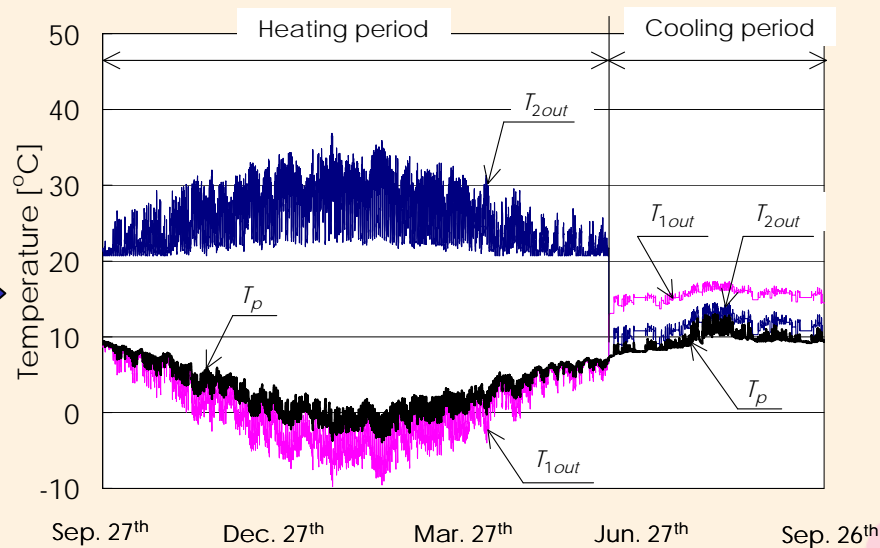
## Advantage of design tool

Short time calculation according to hourly heating and cooling demand

### Hourly heating demand



### Hourly temperature variations of each part



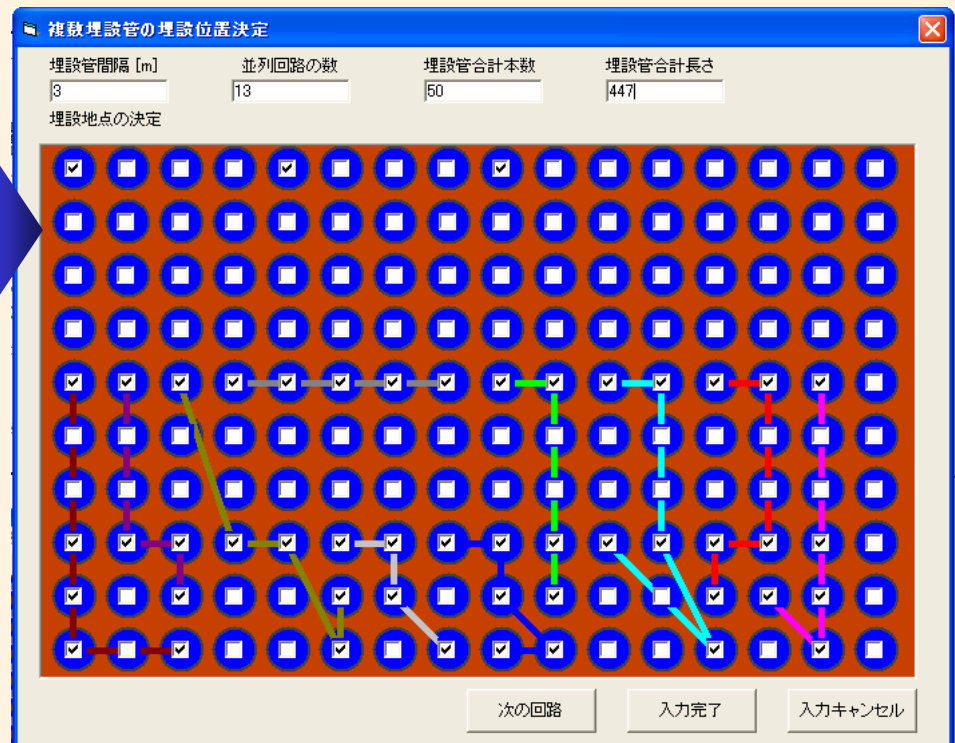
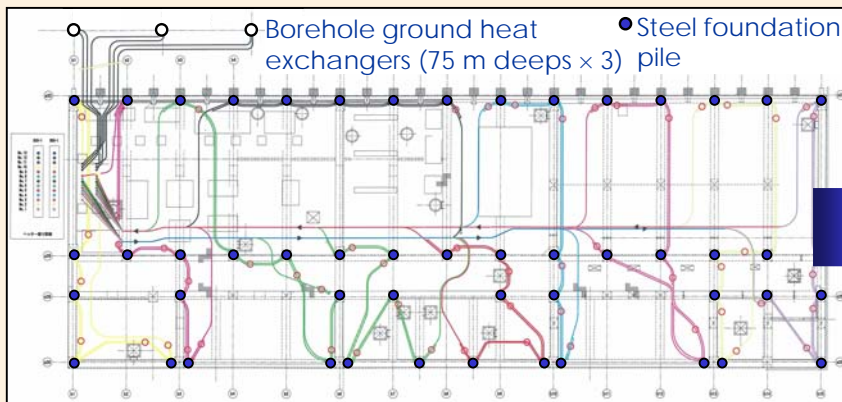
Computation time is approx.  
1min for 2 year's operation

# Outlines of heat pump system simulation

## Advantage of design tool

High speed calculation algorithm for multiple ground heat exchangers buried in random layout

Input of pipe arrangement of multiple ground heat exchangers

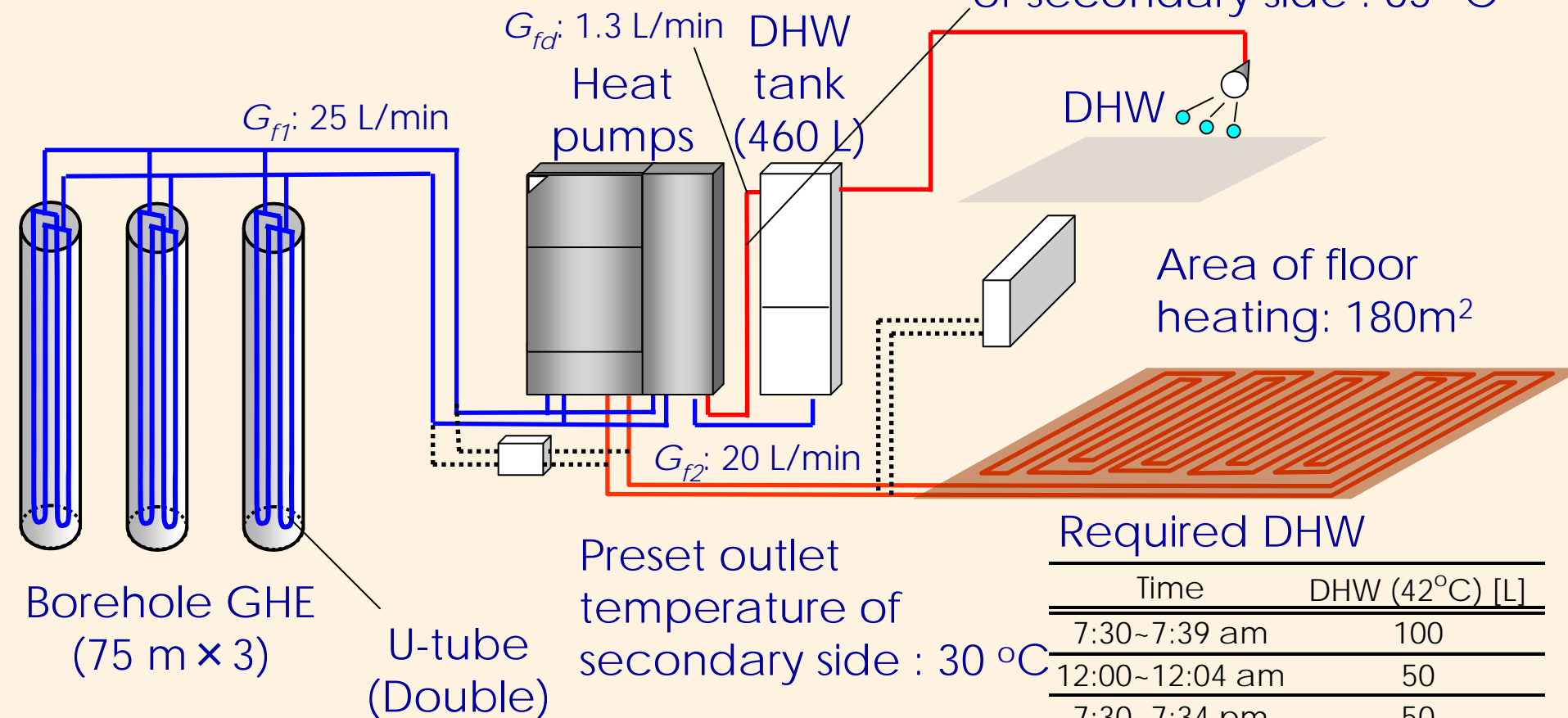


# Outlines of heat pump system simulation

## System description of twin compressor GSHP system

Schematic diagram (Heating and DHW)

Preset outlet temperature of secondary side : 65 °C



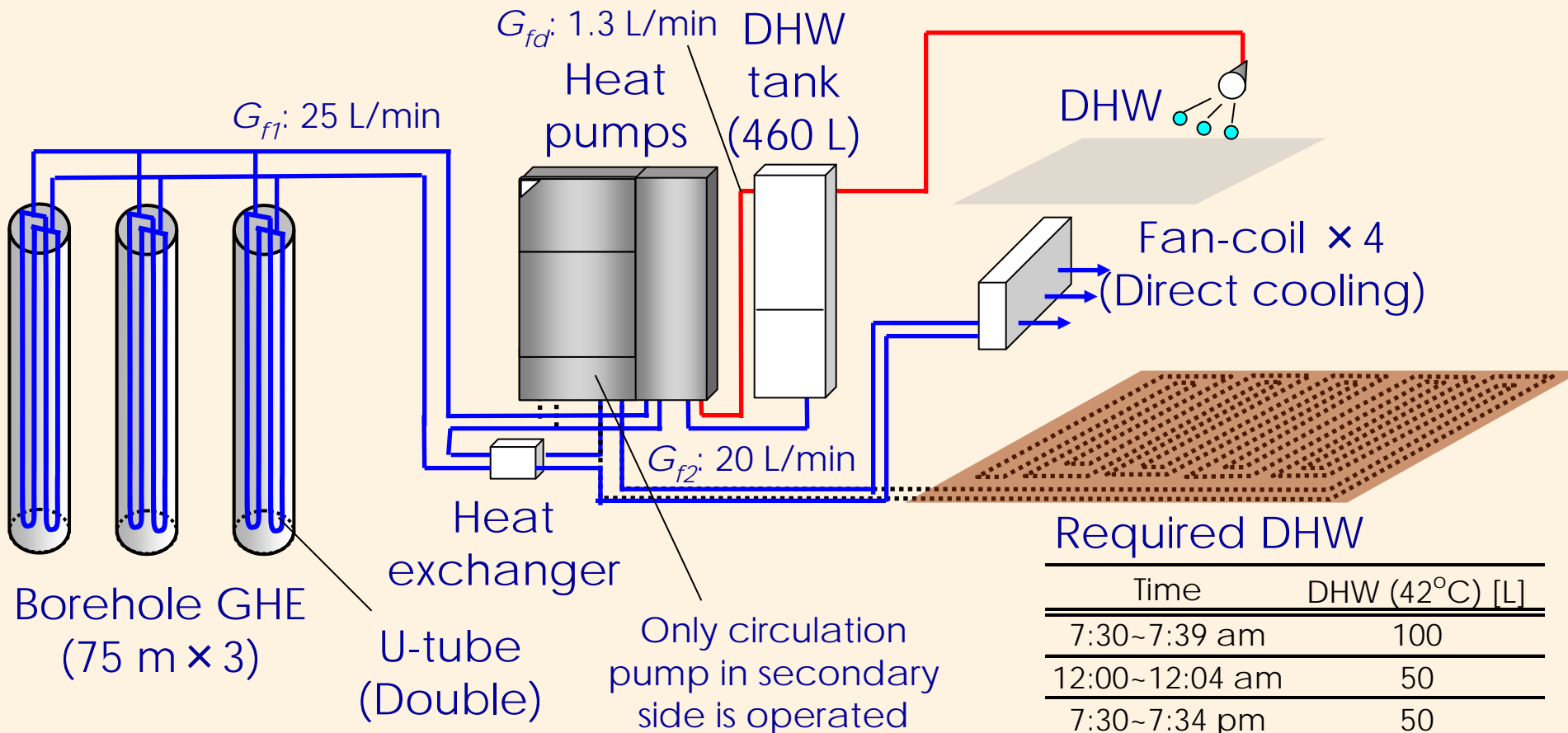
### Required DHW

Time	DHW (42°C) [L]
7:30~7:39 am	100
12:00~12:04 am	50
7:30~7:34 pm	50
9:00~9:29 pm	300
Total	500

# Outlines of heat pump system simulation

## System description of twin compressor GSHP system

Schematic diagram (Direct (passive) cooling and DHW)



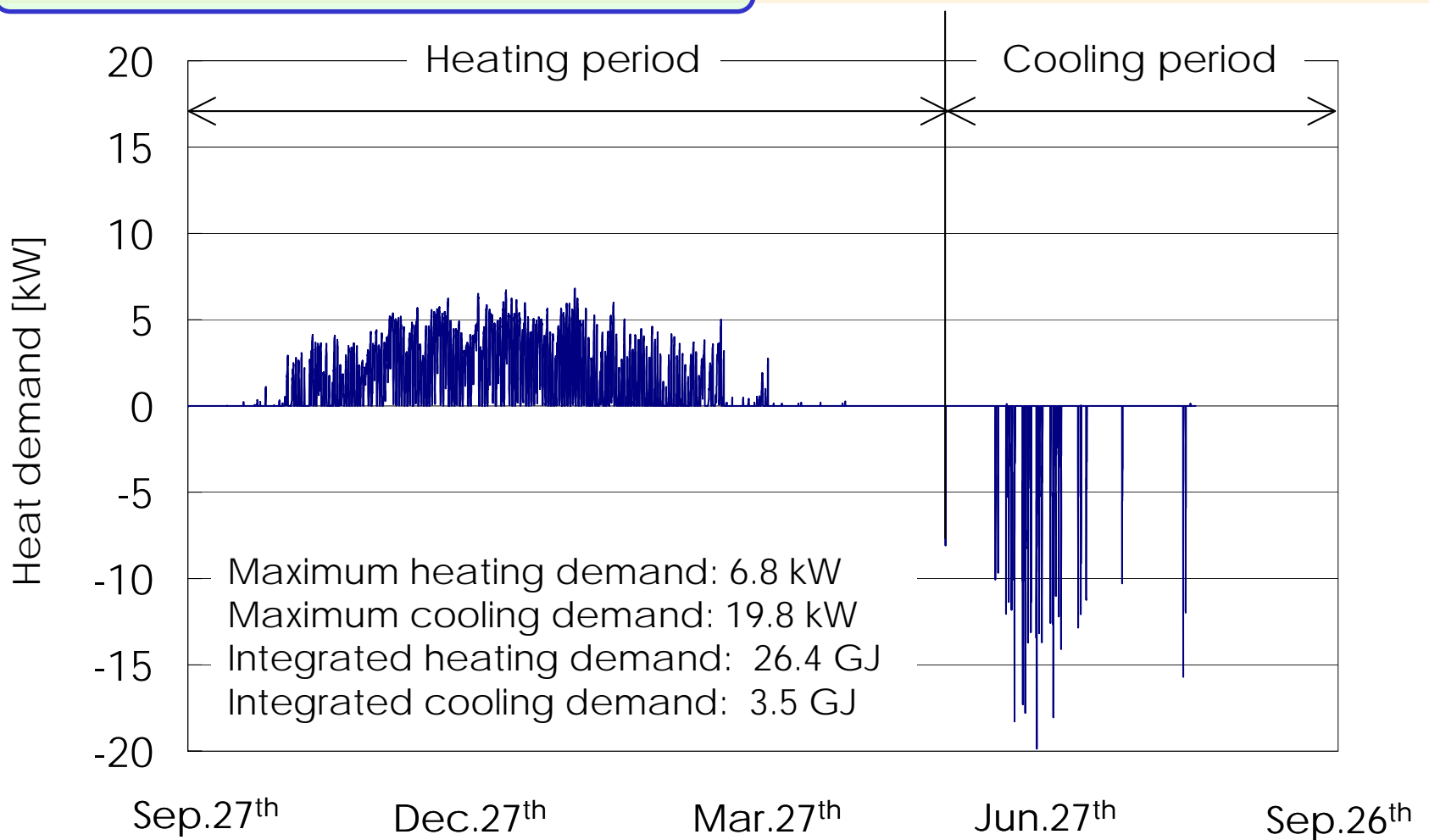
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# Outlines of heat pump system simulation

## Heat demand for SH and SC

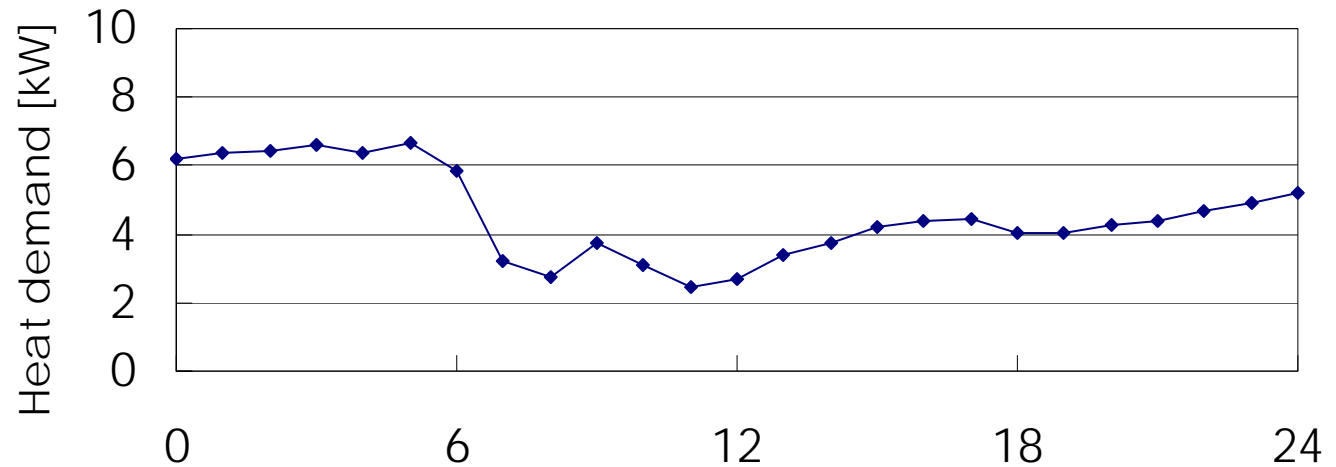
### Variation of heat demand in annual



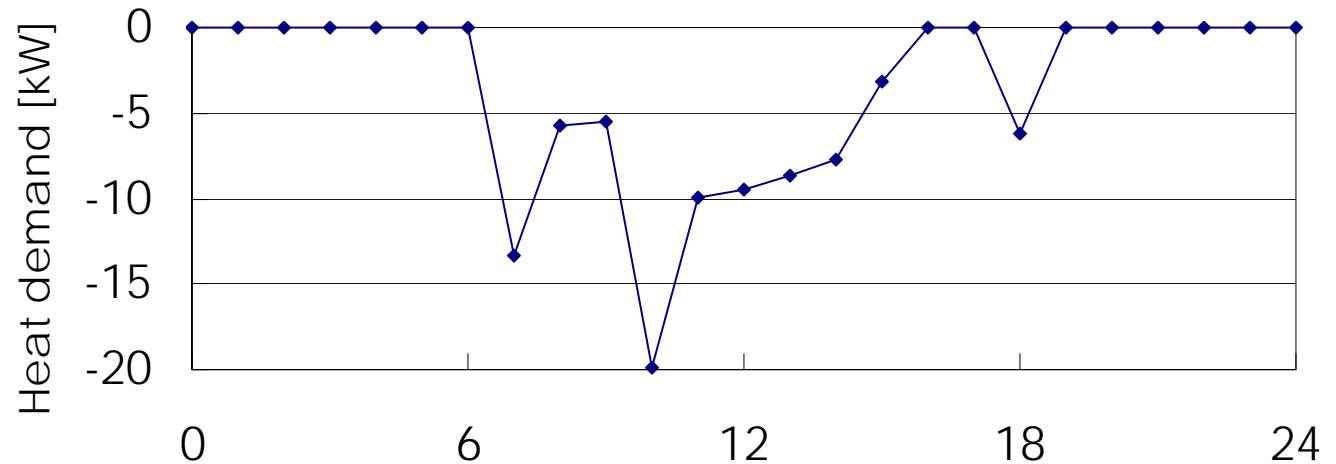
# Outlines of heat pump system simulation

## Heat demand for SH and SC

Daily variation of heat demand in peak day of heating demand (Jan. 20<sup>th</sup>)



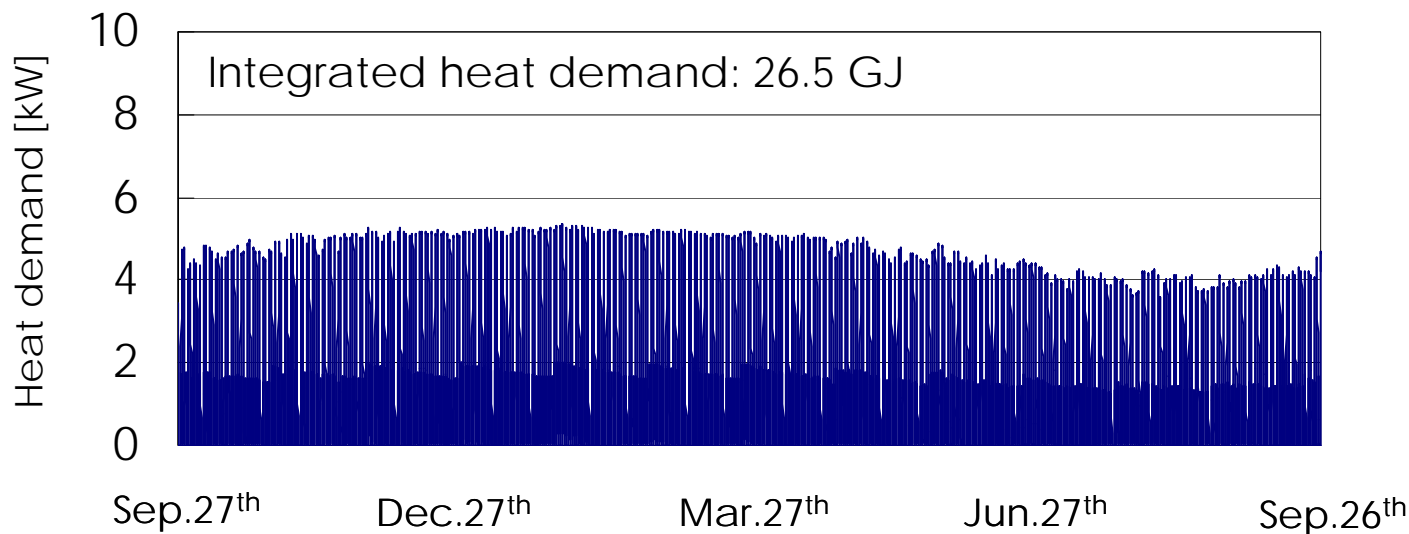
Daily variation of heat demand in peak day of cooling demand (Jul. 31<sup>st</sup>)



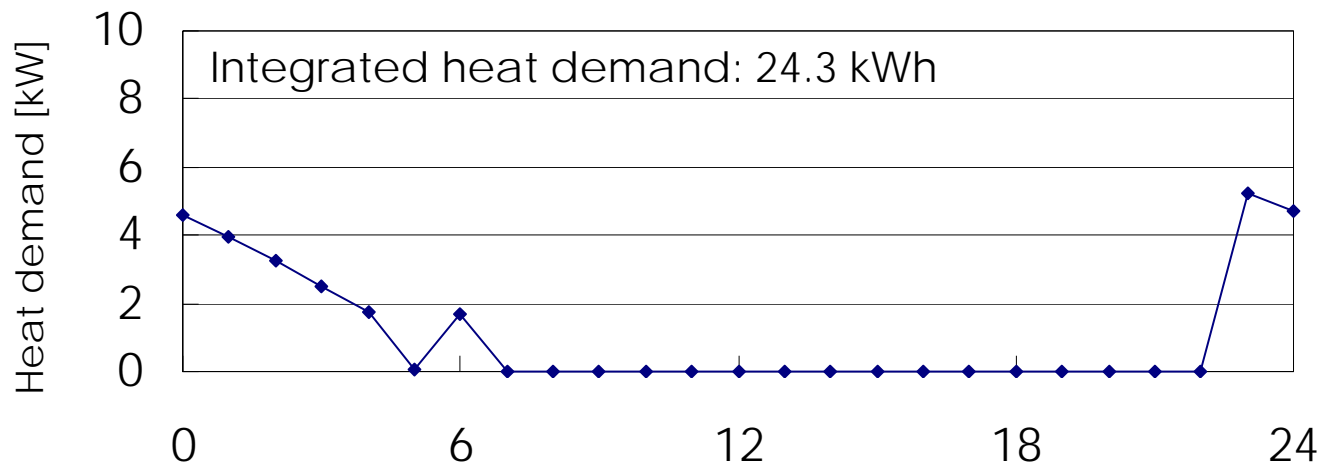
# Outlines of heat pump system simulation

## Heat demand for DHW

Variation of heat demand in annual

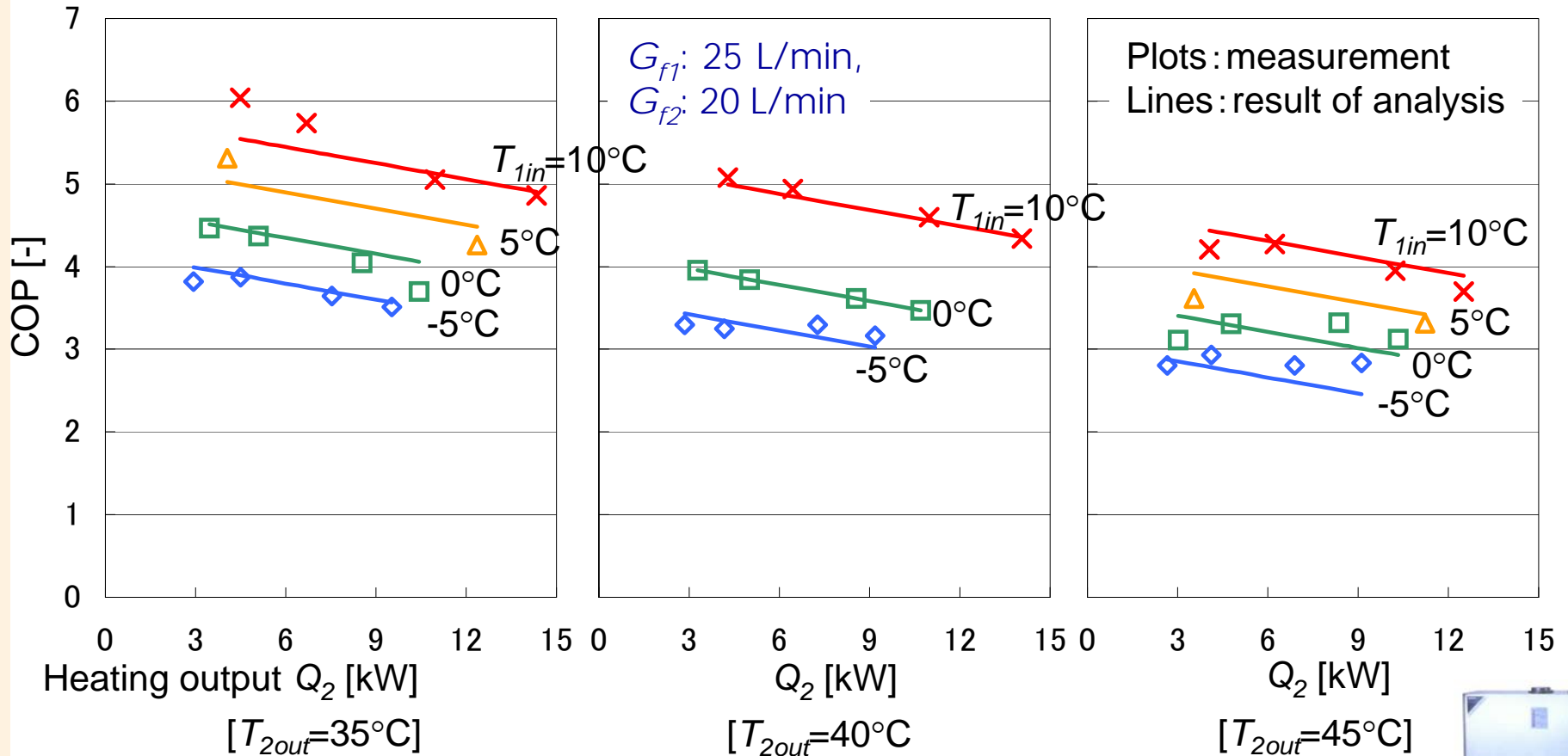


Daily variation of heat demand in peak day (Jan. 20<sup>th</sup>)



# Outlines of heat pump system simulation

## Performance of heat pump unit for SH and SC



COP function obtained by multi-regression analysis:

$$\text{COP} = -0.0650 Q_2 + 0.1101 T_{1in} - 0.1135 T_{2out}$$

$G_f$ : Flow rate [L/min],  $T$ : Temperature [ $^\circ\text{C}$ ]

Subscripts 1: Primary side, 2: Secondary side for SH or SC,  $d$ : Secondary side for DHW,  $in$ : inlet,  $out$ : outlet



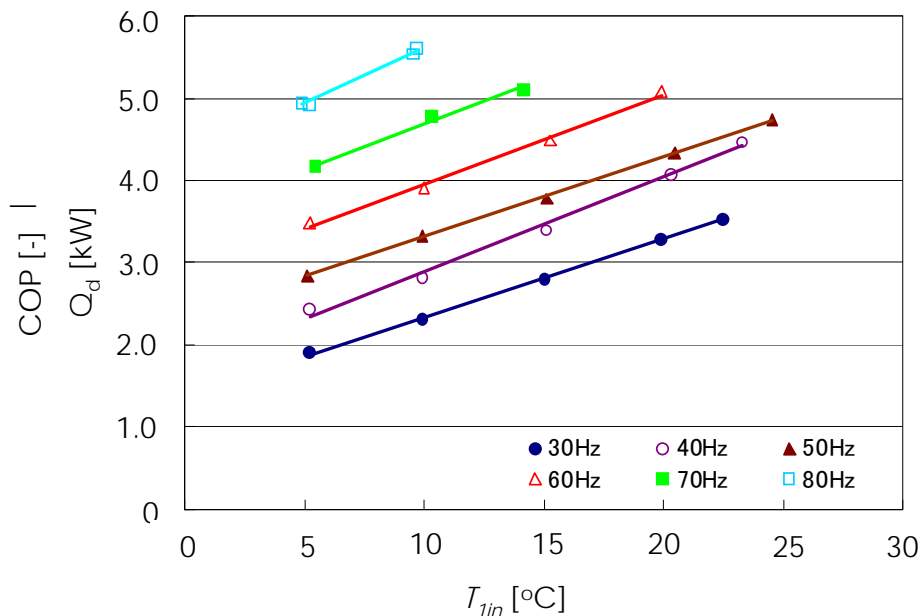
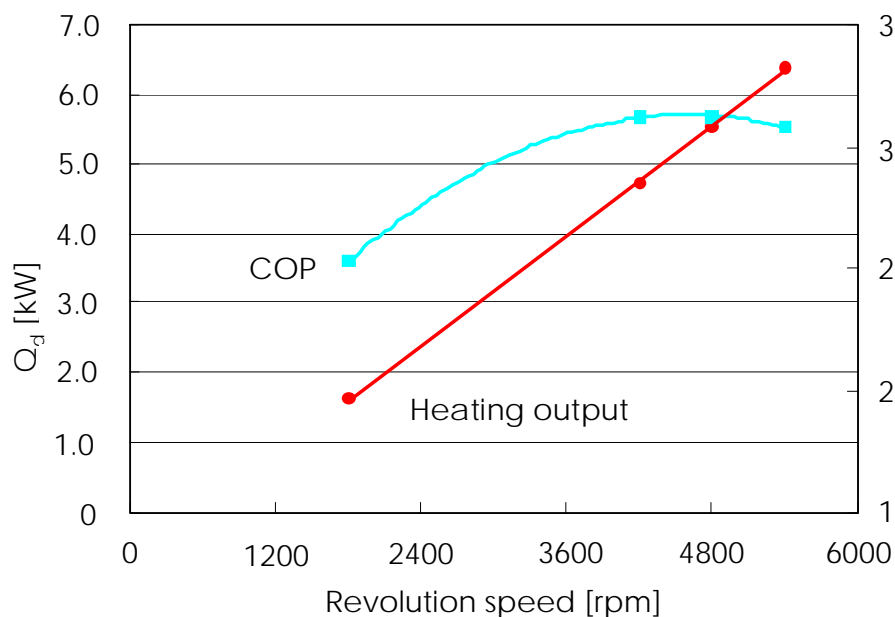
# Outlines of heat pump system simulation

## Performance of heat pump unit for DHW

$Q_d$  and COP according to revolution speed

$Q_d$  according to  $T_{1in}$

Conditions  $G_{f1}$ : 25 L/min,  $G_{fd}$ : 1.3 L/min,  $T_{din}$ : 17 °C,  $T_{dout}$ : 65 °C



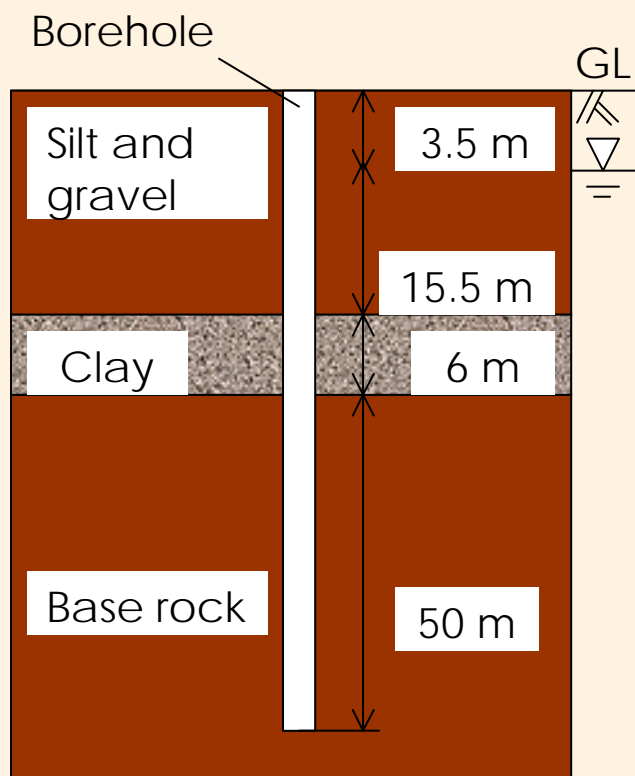
COP function obtained by multi-regression analysis:

$$\text{COP} = 0.5997 Q_d + 0.0898 T_{1in} + 4.7368$$

# Outlines of heat pump system simulation

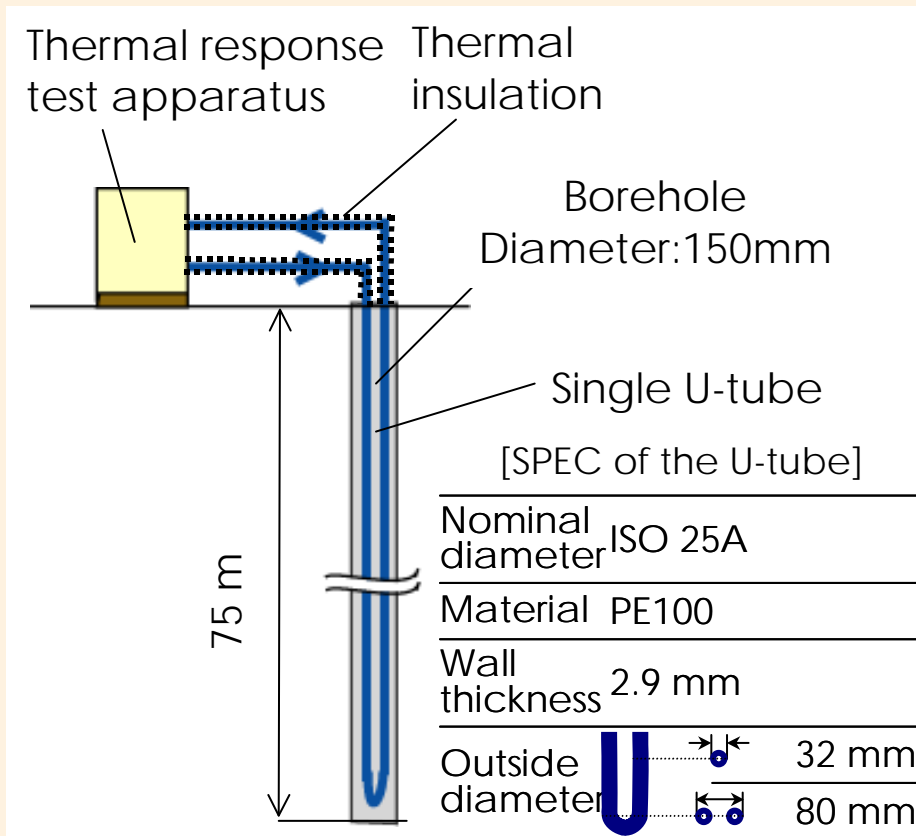
## Geological conditions

### Geological condition



Average ground temperature:  $11.0\text{ }^{\circ}\text{C}$

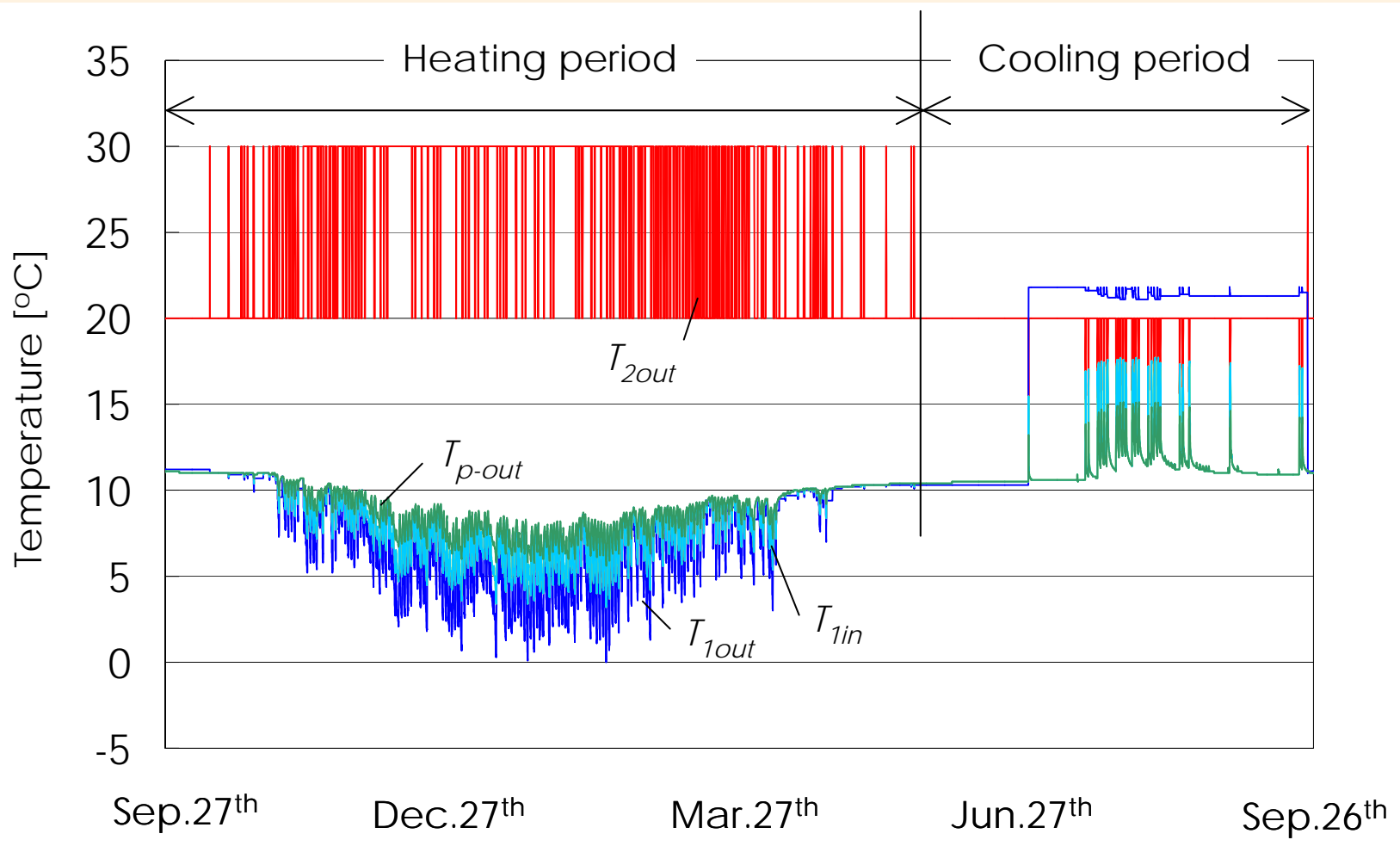
### Schematic diagram of thermal response test



Effective thermal conductivity:  $\lambda_{es} = 2.49\text{ W/m/K}$

# Results of heat pump system simulation

Temperature variation in primary side

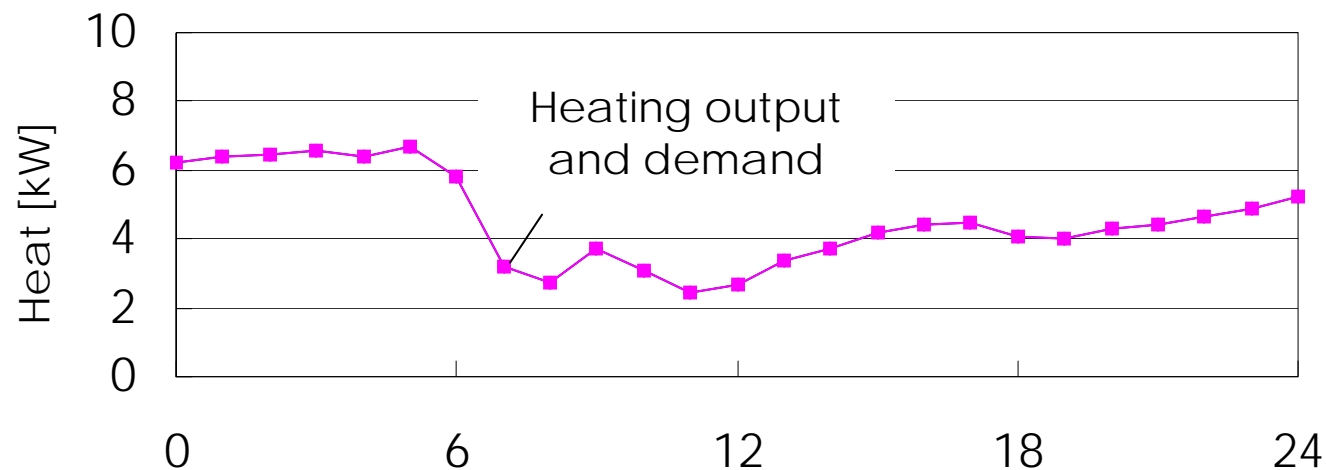


$T_{p-out}$ : Borehole surface temperature [°C]

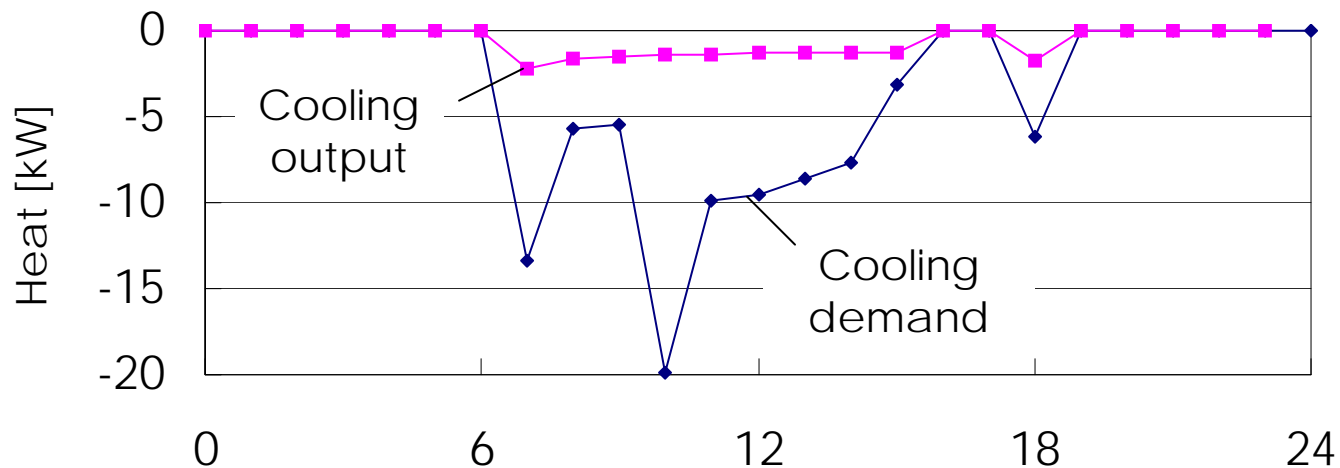
# Results of heat pump system simulation

## Heating output and cooling output

Daily variation of heating output in peak day of heating demand (Jan. 20<sup>th</sup>)



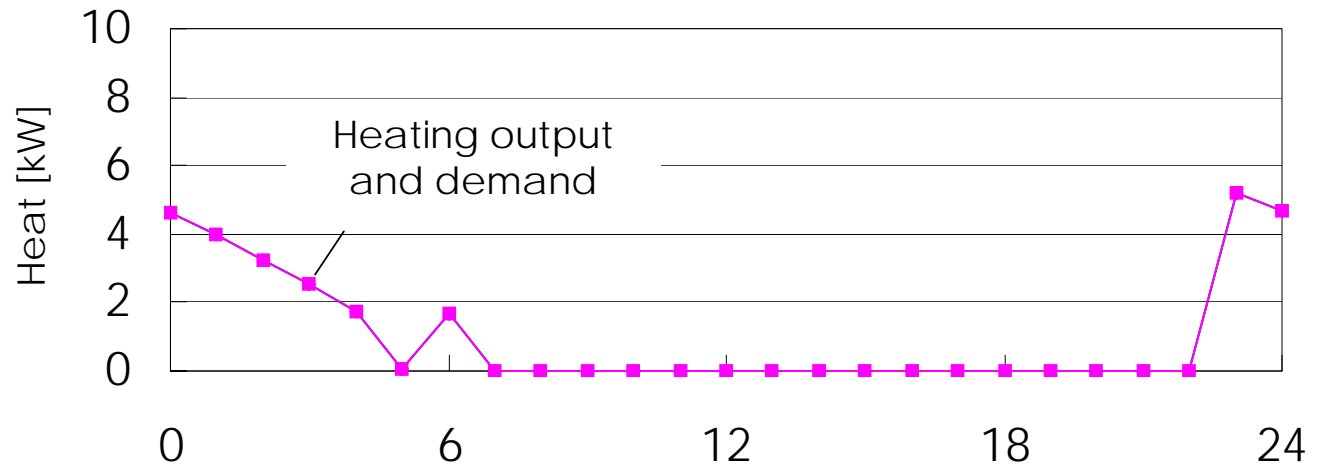
Daily variation of cooling output in peak day of cooling demand (Jul. 31<sup>st</sup>)



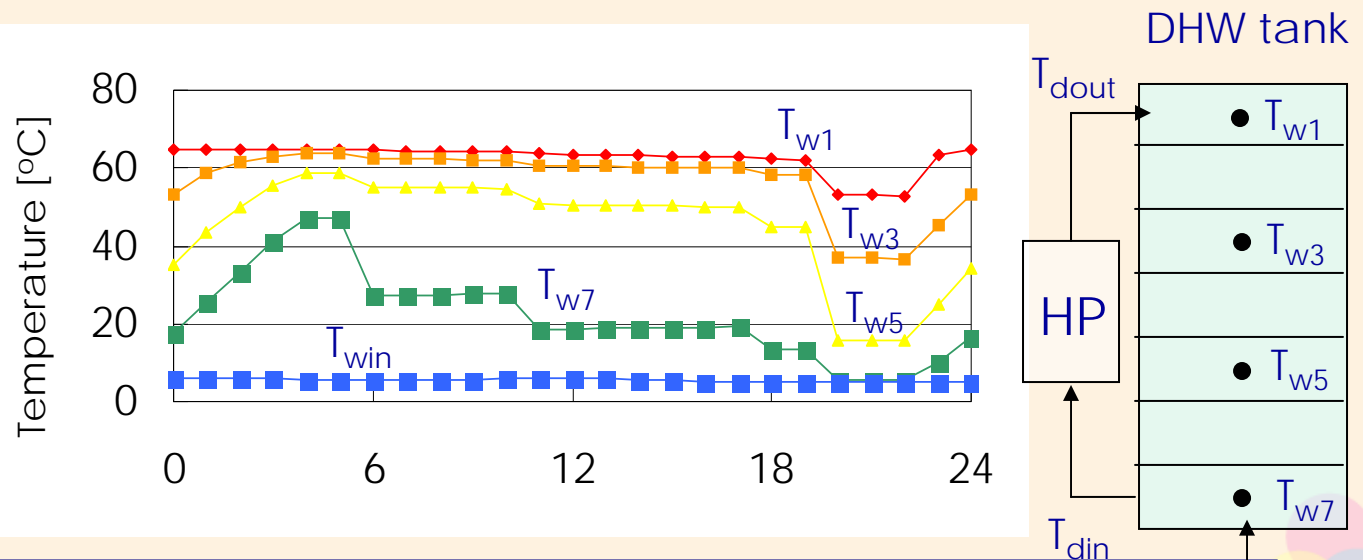
# Results of heat pump system simulation

## Heating output for DHW

Daily variation of heating output in peak day (Jan. 20<sup>th</sup>)



Daily variation of temperature in DHW tank in peak day (Jan. 20<sup>th</sup>)



# Results of heat pump system simulation

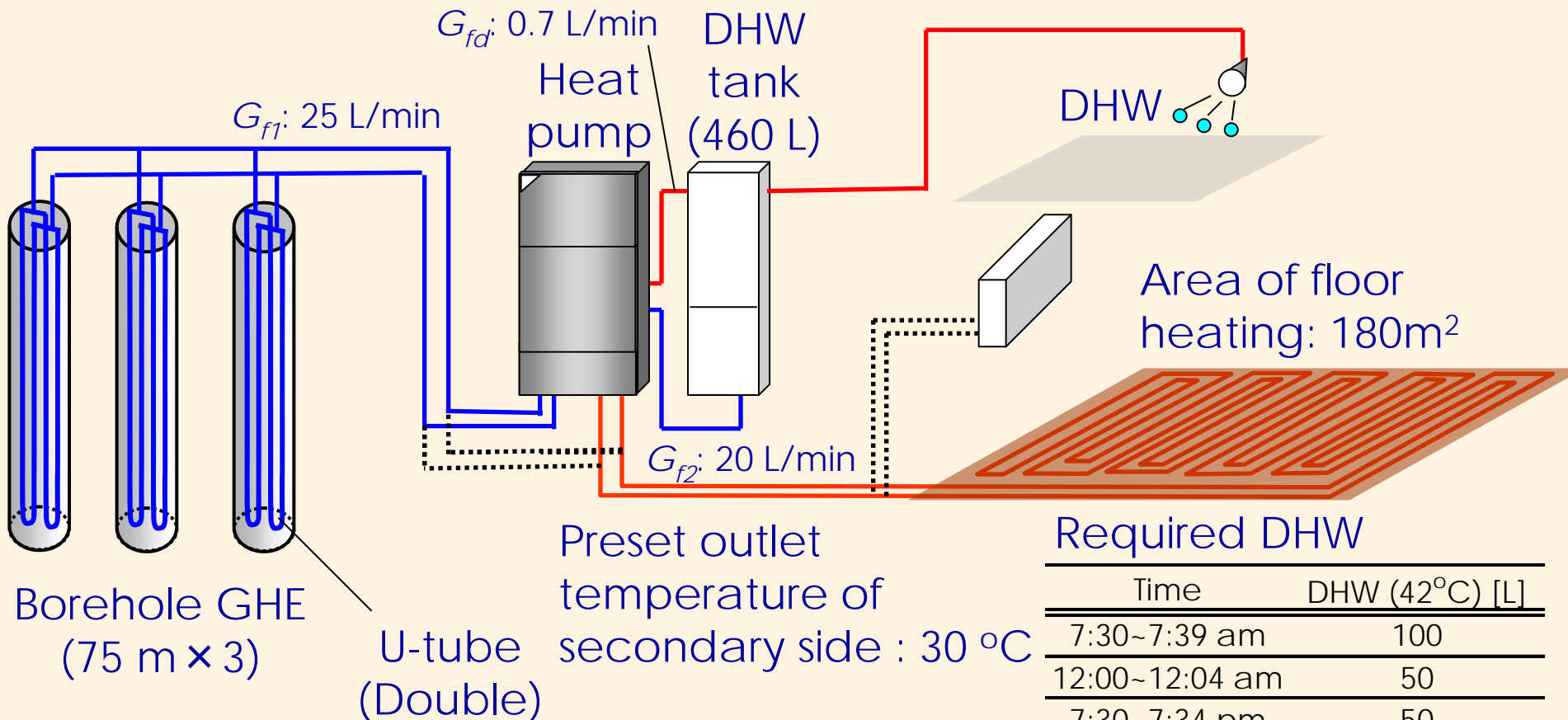
## Annual performance of heat pump system

SH	H1. Heating output for SH [kWh]	7333
	H2. Electric power consumption of compressor for SH [kWh]	1330
	H3. Electric power consumption of circulation pumps [kWh]	432
	H4. Average COP of heat pump unit during operation for SH (=H1/H3)	5.51
	H5. Seasonal performance factor (=H1/(H2+H3))	4.16
SC	C1. Cooling output for SC [kWh]	226
	C2. Electric power consumption of compressor [kWh]	0
	C3. Electric power consumption of circulation pump [kWh]	22
	C4. Average COP of heat pump unit during operation for SC (=C1/C2)	-
	C5. Seasonal performance factor (=C1/(C2+C3))	10.32
DHW	D1. Heating output for DHW [kWh]	7387
	D2. Electric power consumption of compressor for DHW [kWh]	2442
	D3. Electric power consumption of circulation pumps [kWh]	308
	D4. Average COP of heat pump unit during operation (=D1/D2)	3.02
	D5. Annual performance factor (=C1/(C2+C3))	2.69

# Outlines of heat pump system simulation

## System description of integrated GSHP system

### Schematic diagram (Heating and DHW)



### Required DHW

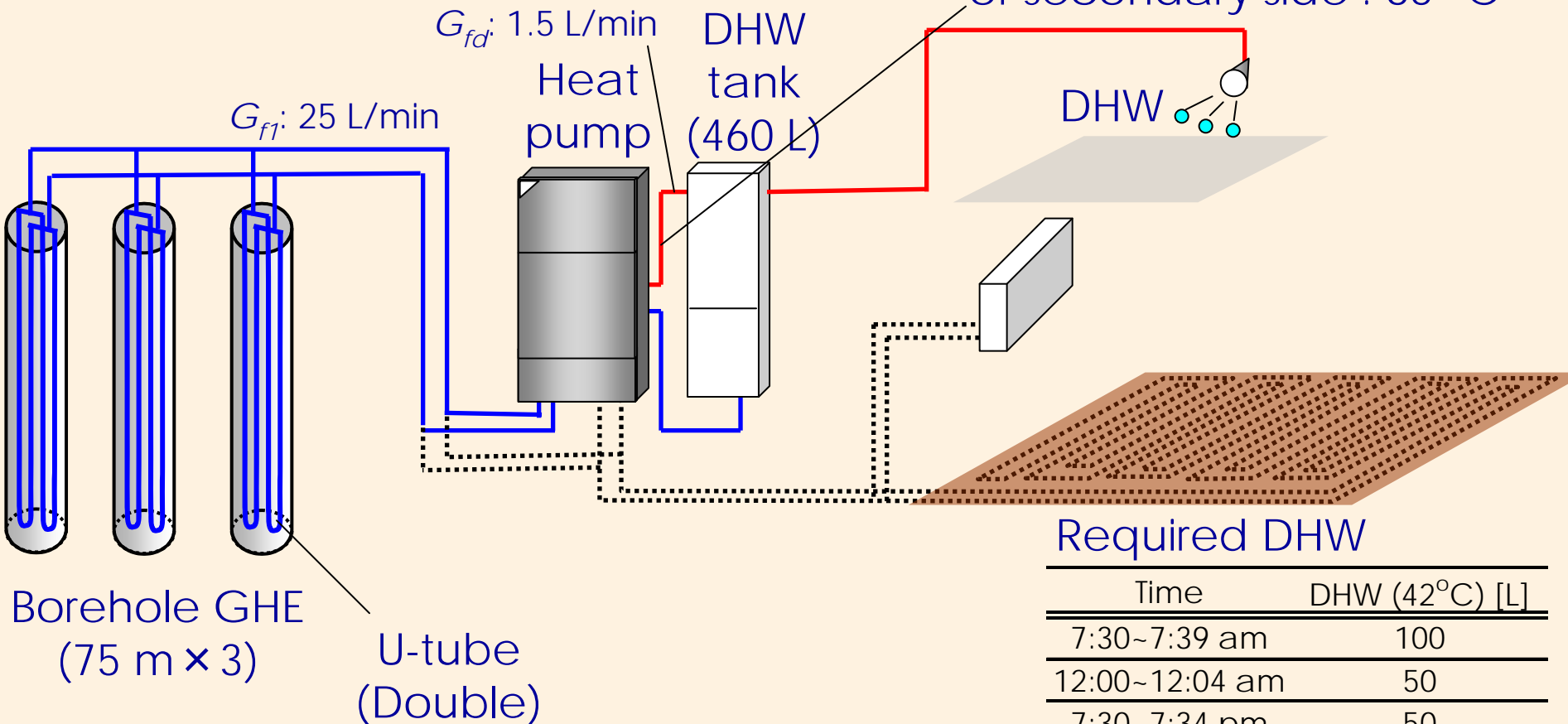
Time	DHW (42°C) [L]
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Total	500

# Outlines of heat pump system simulation

## System description of integrated GSHP system

### Schematic diagram (DHW)

Preset outlet temperature of secondary side : 65 °C



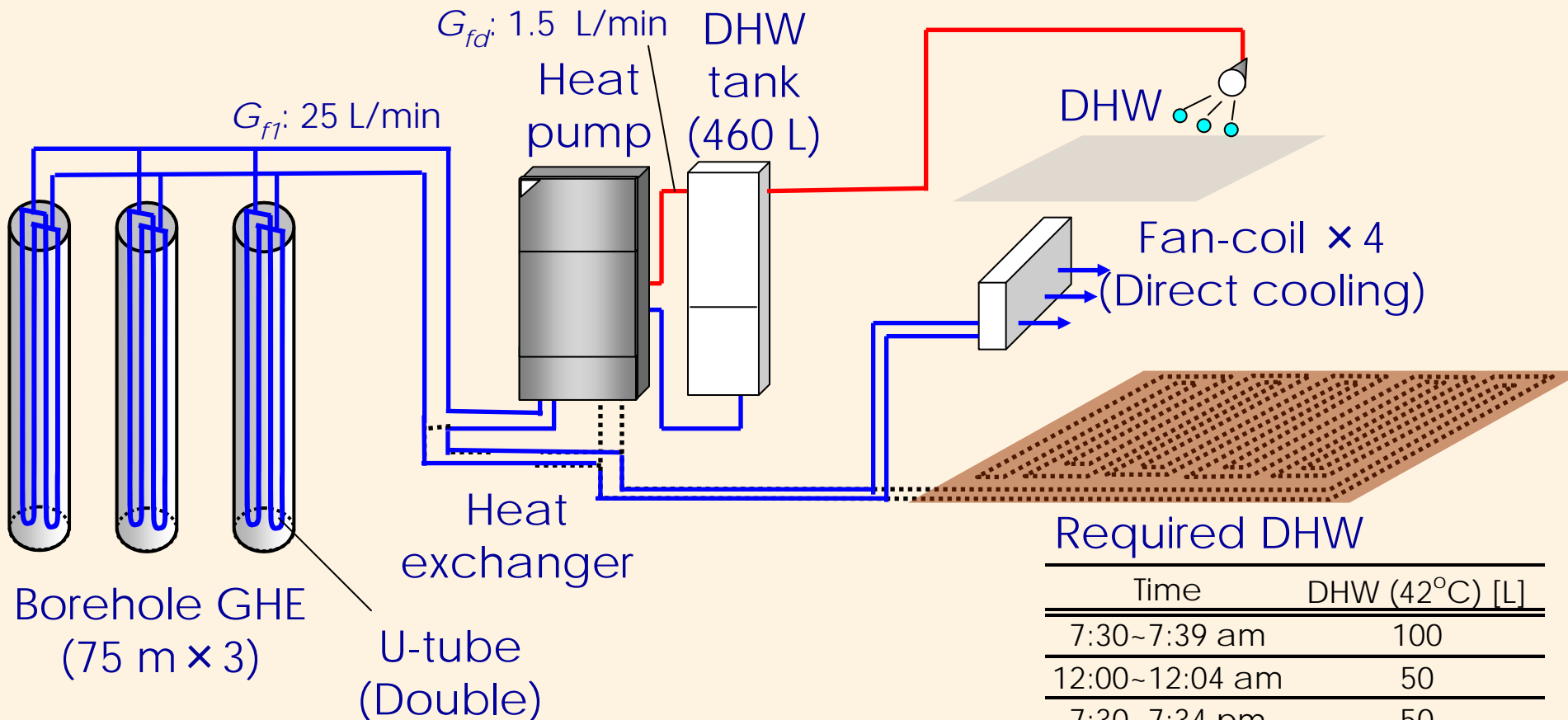
### Required DHW

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# Outlines of heat pump system simulation

## System description of integrated GSHP system

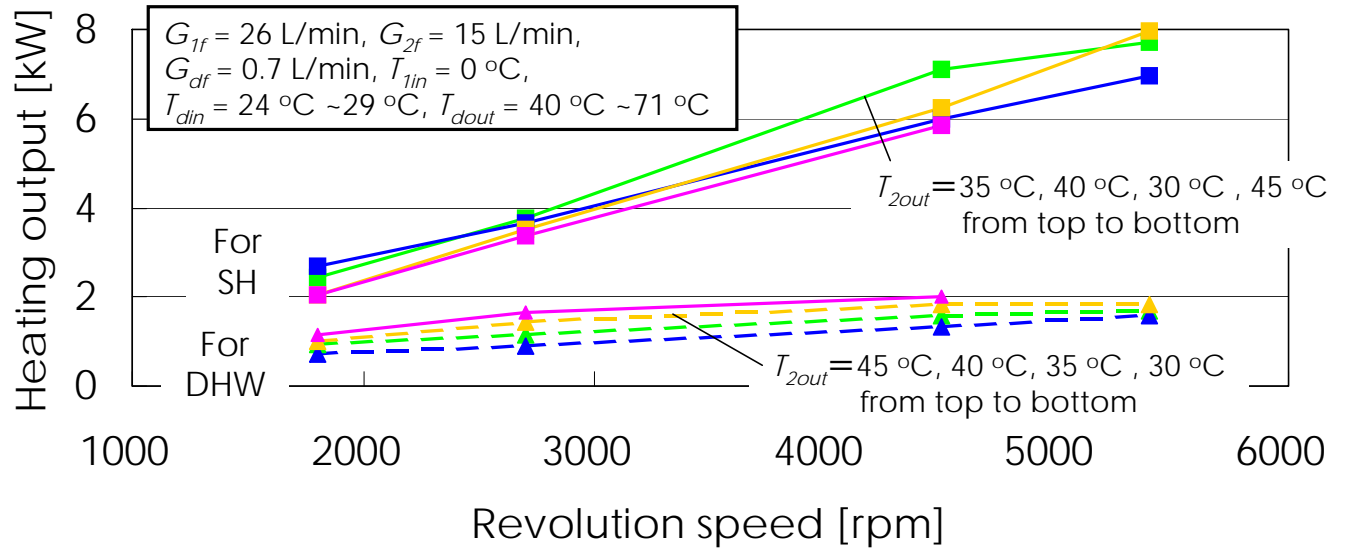
Schematic diagram (Direct (passive) cooling and DHW)



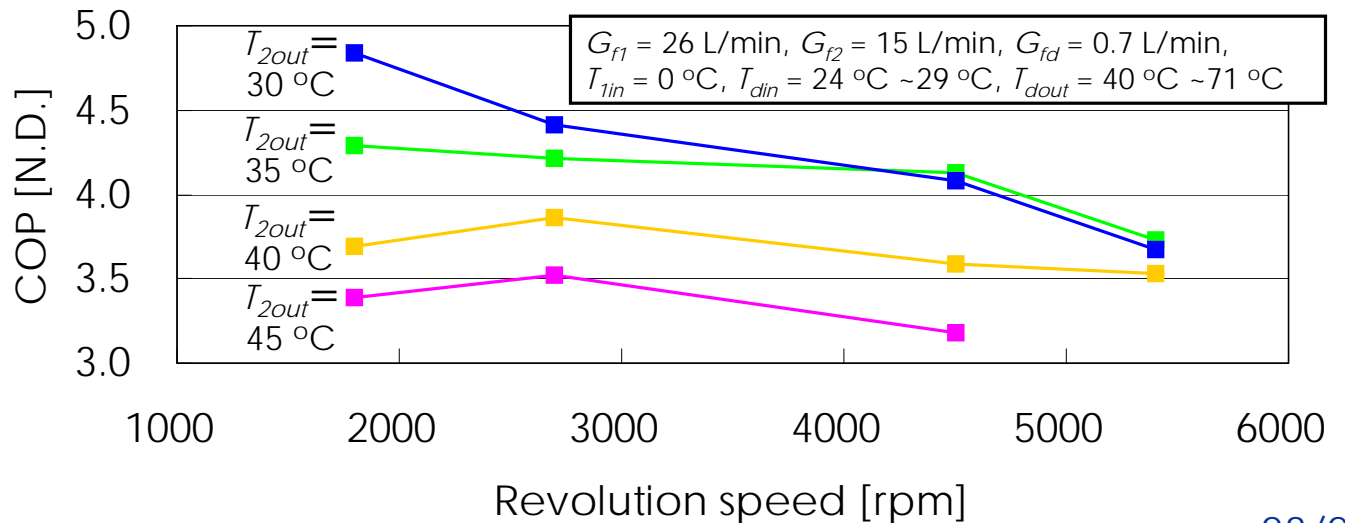
# Outlines of heat pump system simulation

## Performance of integrated heat pump unit

Q according to revolution speed

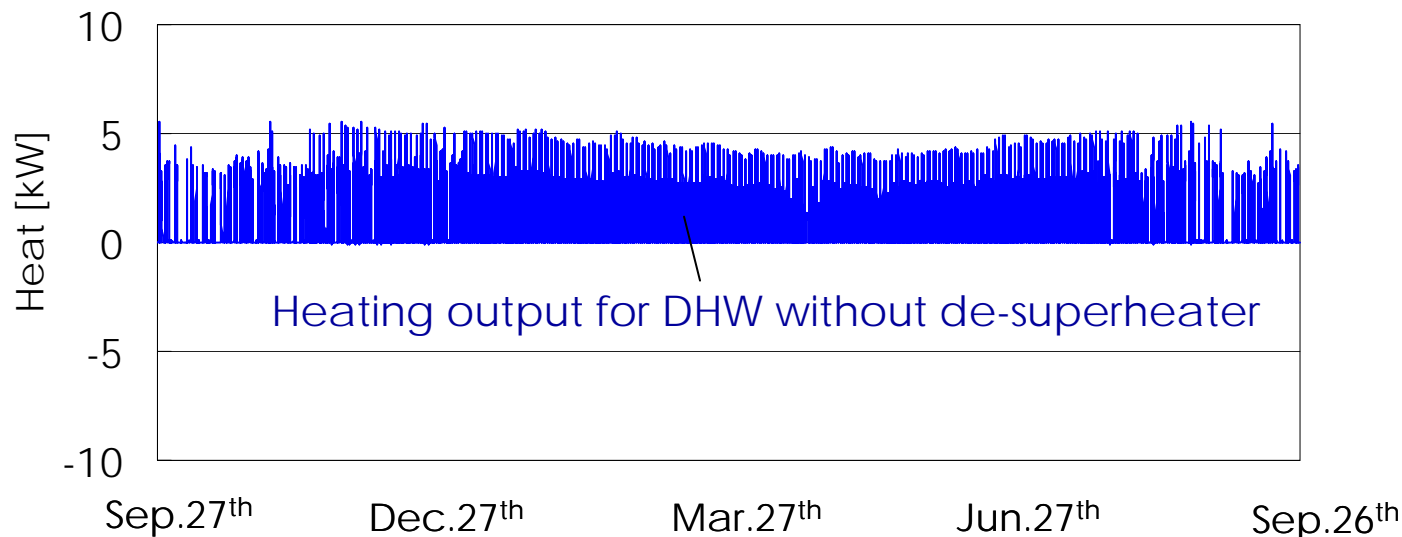
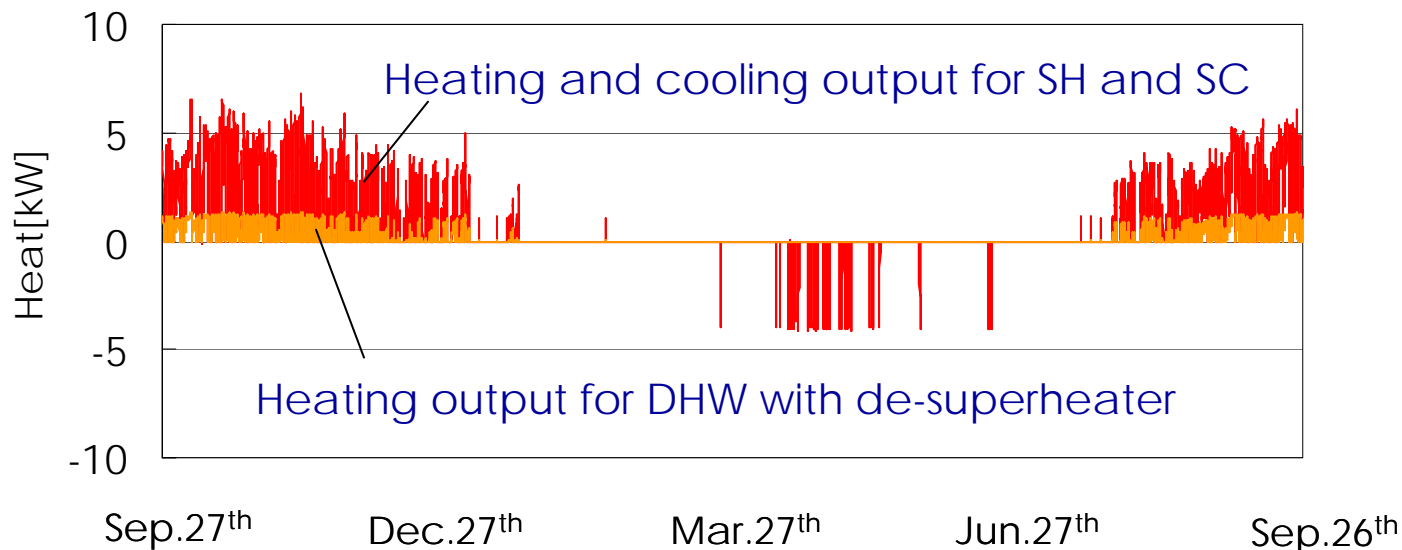


COP according to revolution speed



# Results of heat pump system simulation

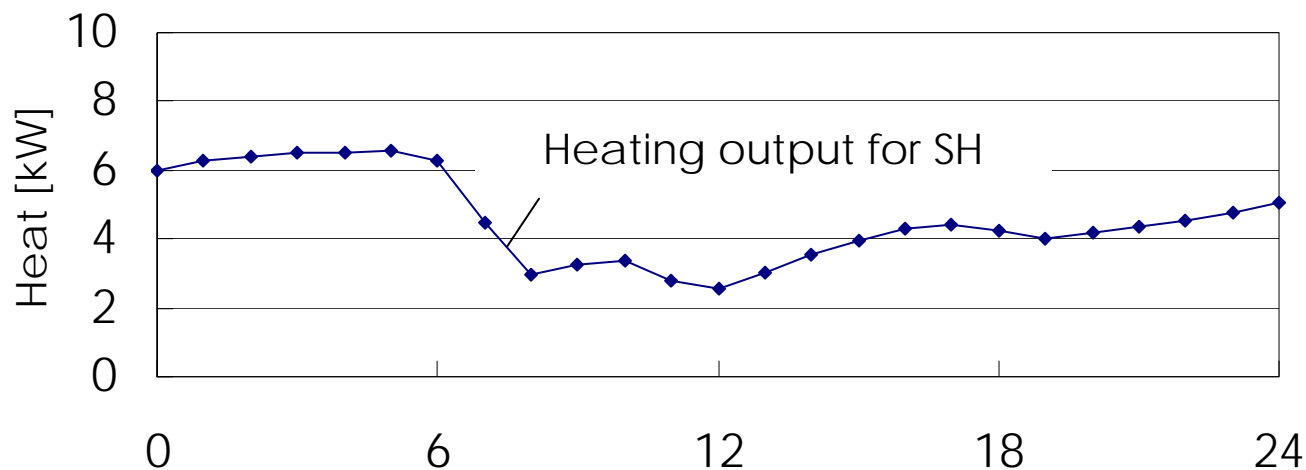
Variations of heating and cooling output in annual



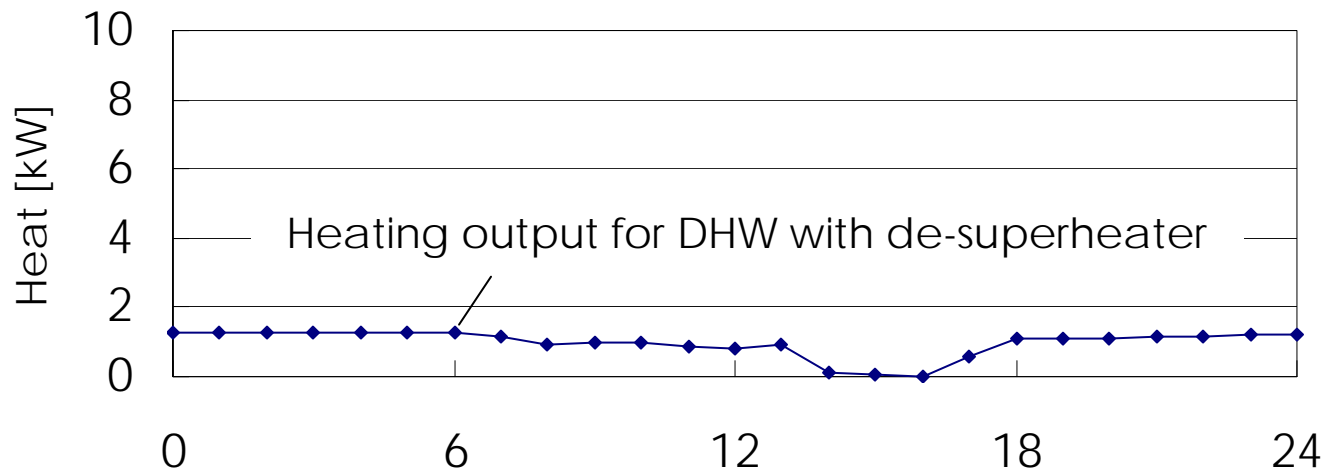
# Results of heat pump system simulation

## Heating output for SH and DHW

Daily variation of heating output for SH in peak day (Jan. 20<sup>th</sup>)



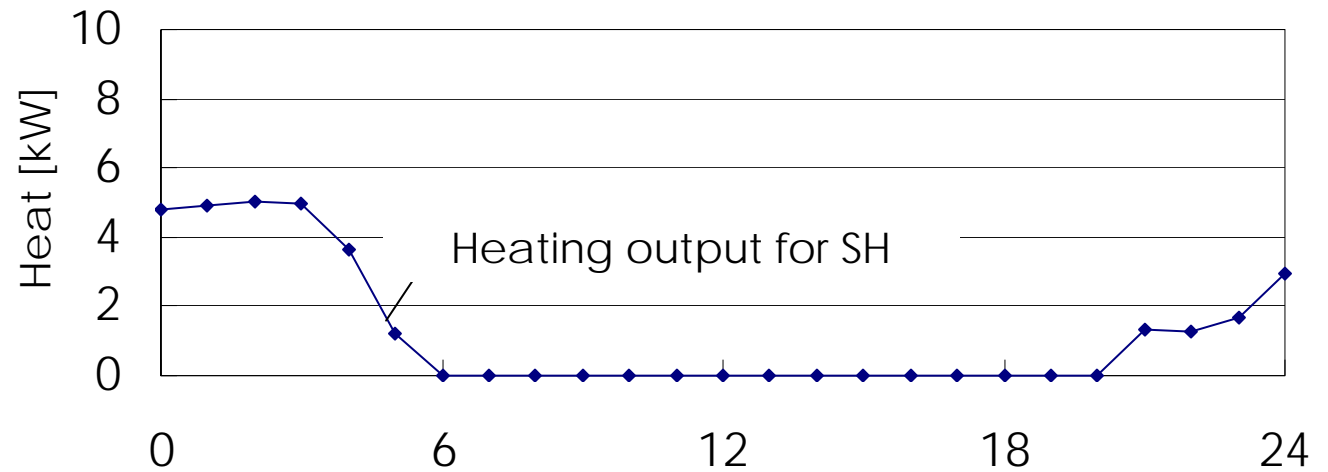
Daily variation of heating output for DHW in peak day (Jan. 20<sup>th</sup>)



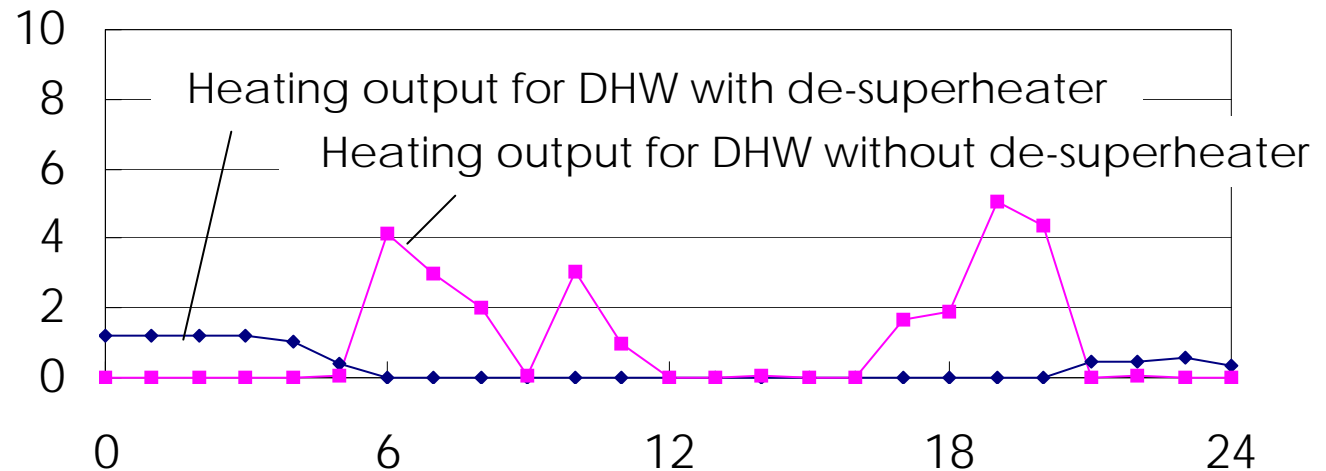
# Results of heat pump system simulation

## Heating output for SH and DHW

Daily variation of heating output for SH in one day in Intermedial stage (Apr. 8<sup>th</sup>)



Daily variation of heating output for DHW in one day in Intermedial stage (Apr. 8<sup>th</sup>)



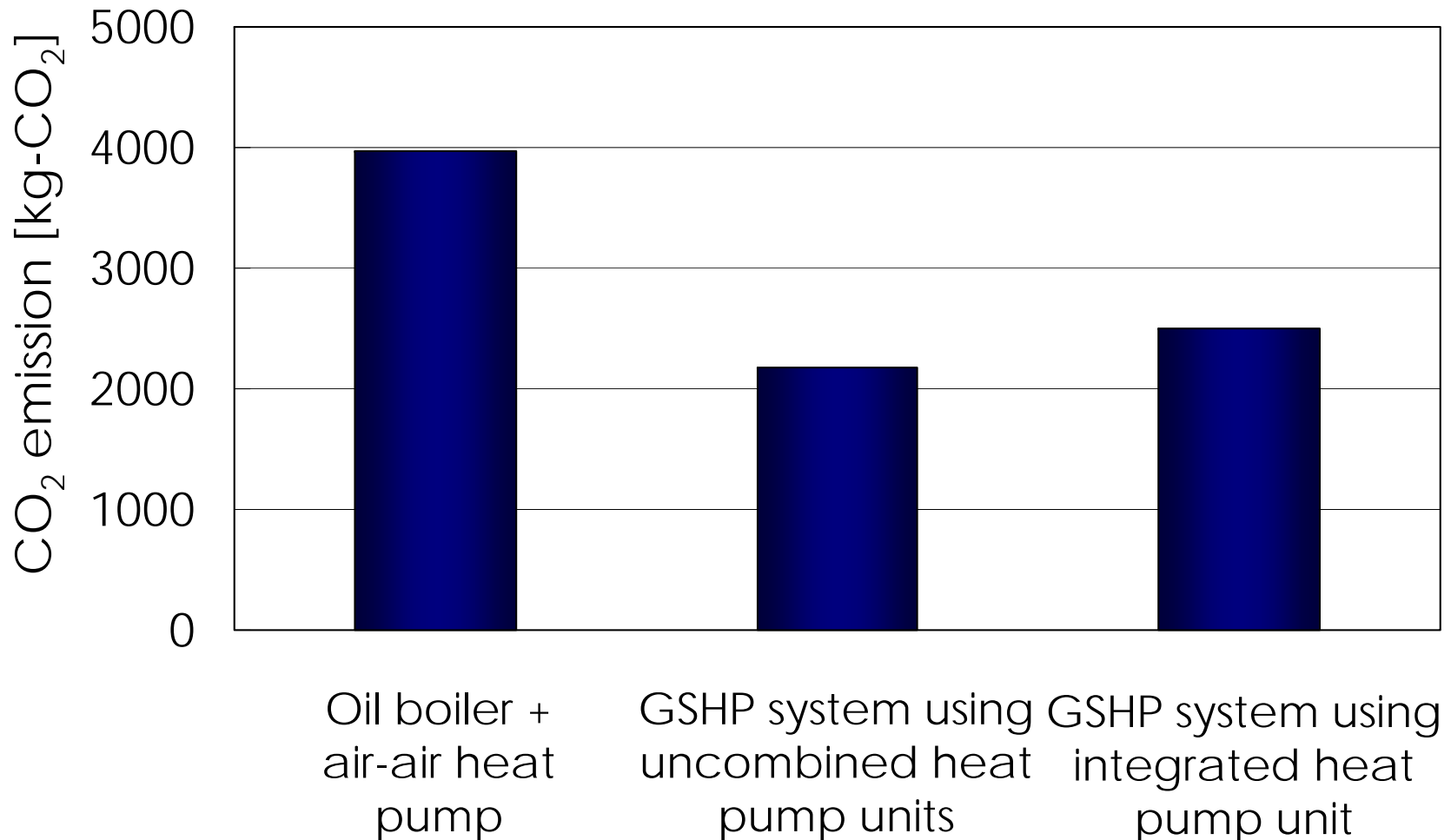
# Results of heat pump system simulation

## Annual performance of heat pump system

SH	H1. Heating output for SH [kWh]	7323
	H2. Heating output for DHW with SH [kWh]	1755
	H3. Electric power consumption of compressor for SH [kWh]	1669
	H4. Electric power consumption of circulation pumps [kWh]	432
	H5. Average COP of heat pump unit during operation for SH (=H1/H3)	5.44
	H6. Seasonal performance factor (=H1/(H2+H3))	4.32
SC	C1. Cooling output for SC [kWh]	538
	C2. Electric power consumption of compressor [kWh]	0
	C3. Electric power consumption of circulation pump [kWh]	14
	C4. Average COP of heat pump unit during operation for SC (=C1/C2)	-
	C5. Seasonal performance factor (=C1/(C2+C3))	38.43
DHW without SH	D1. Heating output for DHW [kWh]	6544
	D2. Electric power consumption of compressor for DHW [kWh]	2884
	D3. Electric power consumption of circulation pumps [kWh]	210
	D4. Average COP of heat pump unit during operation (=D1/D2)	2.27
	D5. Annual performance factor (=C1/(C2+C3))	2.12

# Results of heat pump system simulation

## Comparison of CO<sub>2</sub> emissions



# Summary

1. Calculation result of a twin compressor type GSHP system shows that heating output can satisfy the heating demand, even in when the outlet temperature in secondary side is 30 °C.
2. Predicted average COP during heating period is around 5.5 and very high.
3. It is predicted that the GSHP system which has only one heat pump is enough to cover both of heating demand for SH and DHW.
4. These GSHP systems can reduce 40 ~ 50 % of CO<sub>2</sub> emissions compared to conventional oil boiler system.

# Outlines of heat demand calculation

Calculation soft: SMASH (Japanese computer aided simulation program for calculation of heating and cooling demand)

## Calculated conditions

Air conditioning temperature / humidity : 27 °C / 60%

Heating temperature : 22 °C

Thermal conductivity of insulation material : 0.034 W/m/K

Efficiency of total heat exchanger : 93 %

Overall heat transfer coefficient of window: 1.2 W/m<sup>2</sup>/K

## Composition of roof, floor, wall

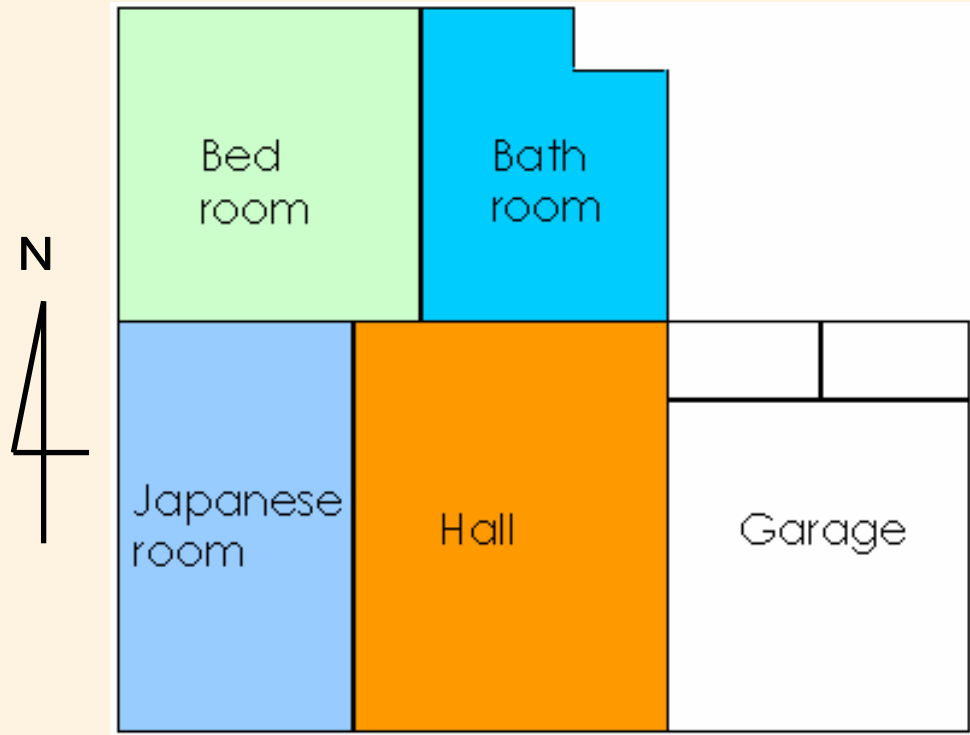
	Main constructed material
Roof	Insulation material (Thickness : 300 mm)
Floor	Insulation material (Thickness : 200 mm) Concrete (Thickness : 150 mm)
Wall (1F)	Insulation material (Thickness : 150 mm) Concrete (Thickness : 100 mm)
Wall (2F)	Insulation material (Thickness : 250 mm)

Calculated heat loss coefficient (Q value) : 0.96 W/m<sup>2</sup>/K

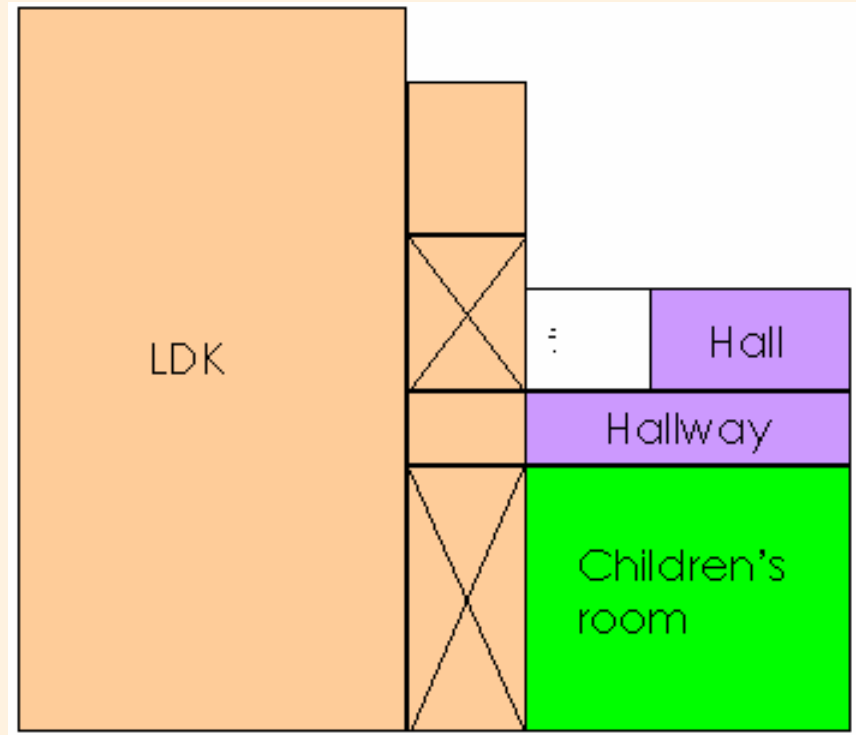
# Outlines of heat demand calculation

## Plane view

Total floor area : 217.9 m<sup>2</sup>



1st floor



2nd floor