

Evaluation of Energy Efficiency of Room Air Conditioner under Various condition

Takao Sawachi

National Inst. for Land &Infrastructure Management
(NILIM)

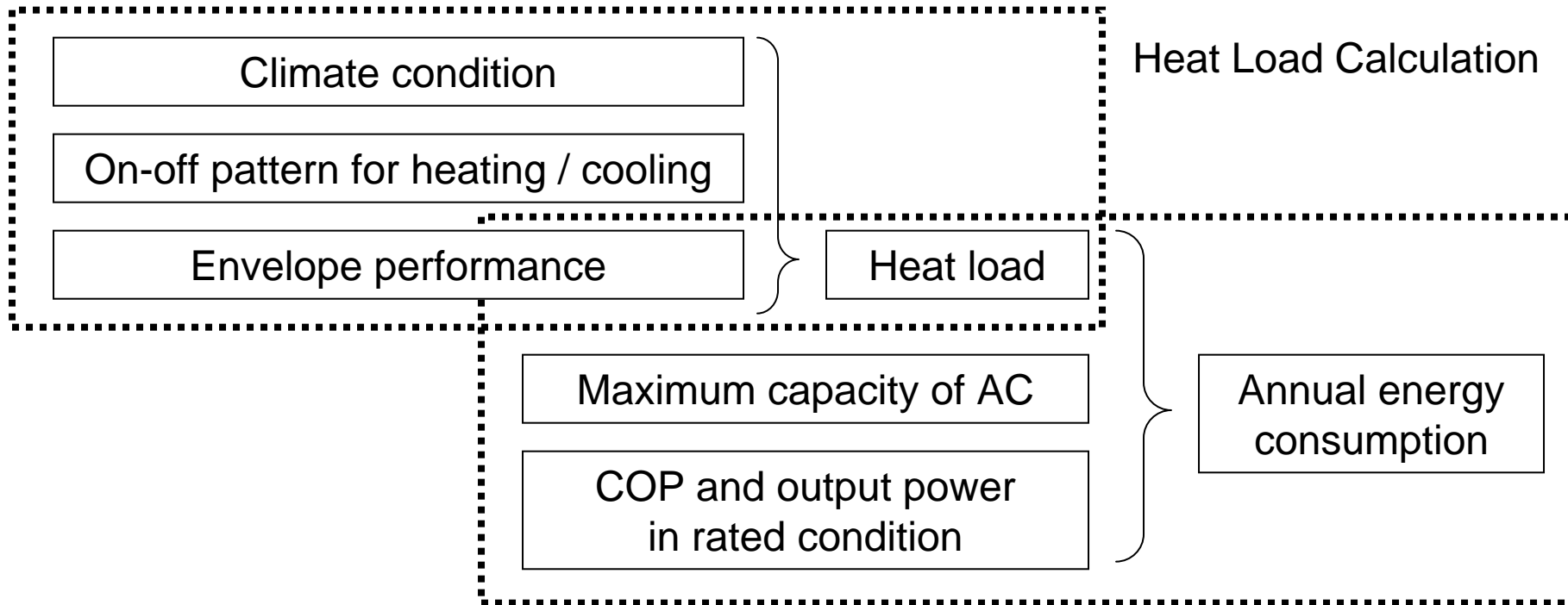
Part I Background

- Room air conditioner is used commonly for heating and cooling in Japan.
- Energy efficiency is represented by a method under rated conditions defined by ISO and JIS (Japanese Industrial Standard).
- However, rated energy efficiency given by the method above is inadequate to evaluate the energy consumption of room air conditioner for heating/cooling because the efficiency generally depends on the external and internal temperature and humidity and also heat load.

Objective

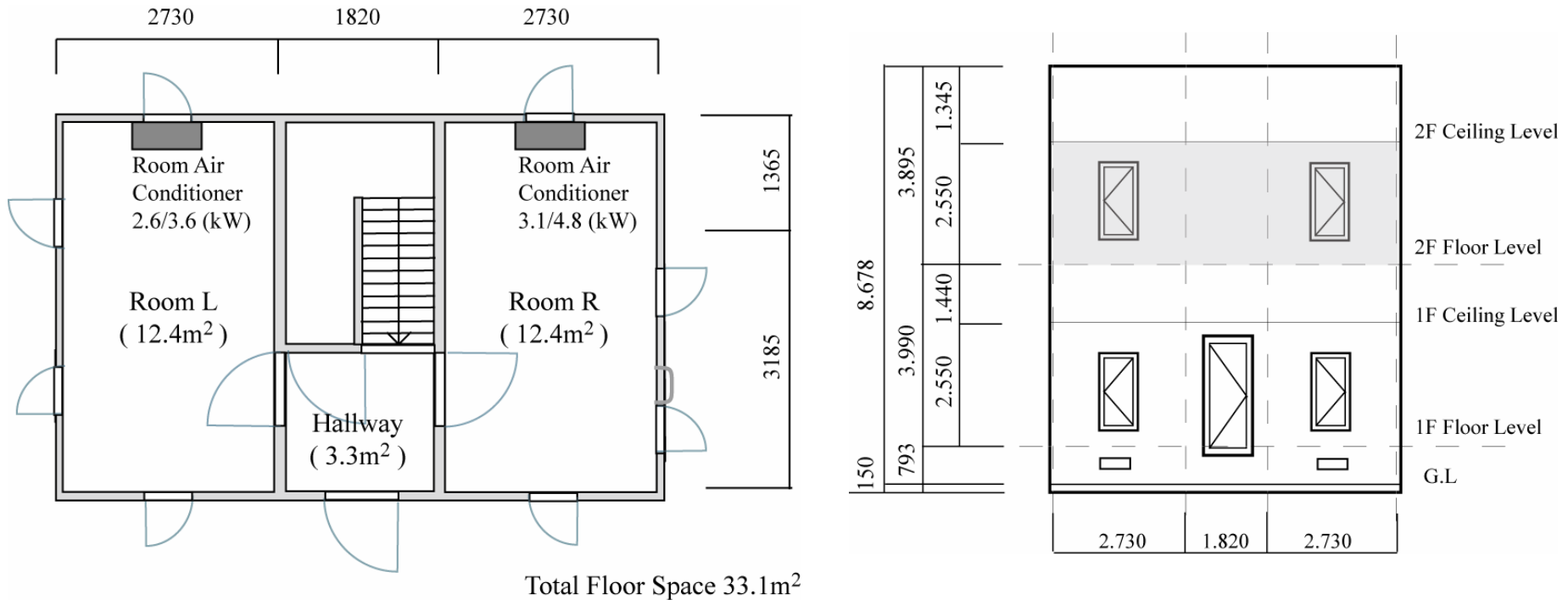
- Grasp the change of the energy efficiency under not only rated condition but also various condition by experiments
- Develop a method by which we can calculate energy efficiency under given condition and also calculate energy consumption.

Necessary Input Information for Calculation



Calculation of energy consumption of room air conditioner mentioned in this presentation

Experiment – Experimental House



Two room air conditioners were installed at the 2nd floor of a two-story wooden house in a chamber which temperature and humidity could be controlled. This wooden house is equipped with central ventilation system by which air supply and exhaust rate can be controlled. Thickness of the insulation at the floor and the wall can be changed.

Experienced Room Air Conditioner

	Cooling				Heating			
	COP	Capacity			COP	Capacity		
		Minimum kW	Rated kW	Maximum kW		Minimum kW	Rated kW	Maximum kW
RoomR	4.8	0.8	2.2	2.6	5.4	0.8	2.5	3.6
RoomL	4.7	0.8	2.8	3.1	5.1	0.8	3.6	4.8



Parameters Changed in Experiments

Operating Mode	External Condition		Internal Condition	Changed Parameters
	Temp. °C	RH %	Temp. °C	
Cooling (Dehumidified Mode)	35	40	27	External Temperature
	30	40	27	
	25	40	27	
	35	80	27	*Internal Humidity
	35	60	27	
	35	40	30	Internal temperature
	35	40	24	
(Dehumidified Mode)	35	40	27	
Heating	-3	87	20	External Temperature
	2	87	20	
	7	87	20	
	12	87	20	External Humidity
	7	50	20	
	7	87	22	Internal temperature
	7	87	24	

*Internal humidity was changed by changing external humidity. Internal humidity depends on external humidity because internal air was exhausted by ventilation system and external air flows into the room through the slit.

Change of Cooling/Heating Load

- Heat loads were given by changing exhaust air rate and if necessary, we use electric heater in the room.

$$L = KA\Delta T + Qc\rho\Delta T + H$$

K : Heat loss coefficient (W/m²K)

A : Area of Walls (m²)

ΔT : Difference between external temperature and internal temperature (°C)

Q : Ventilation rate, which was changed in the experiments (m³/s)

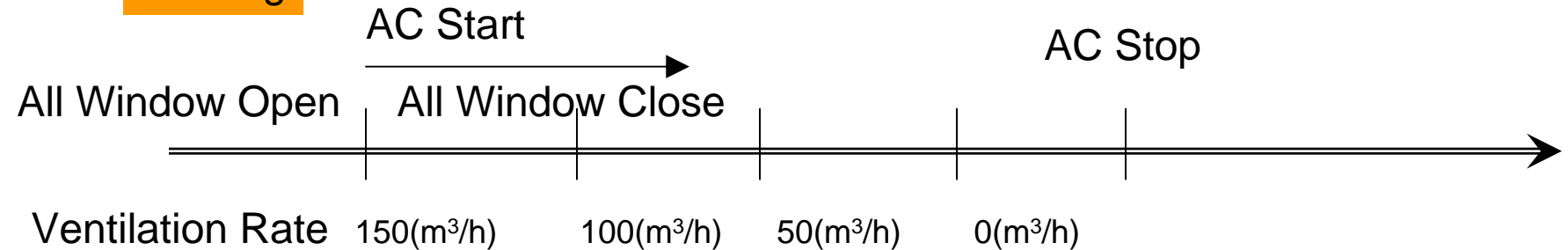
$c\rho$: Volumetric heat capacity of air (J/m³K)

H : Heat generation given by electric heater, which was used if necessary (W)

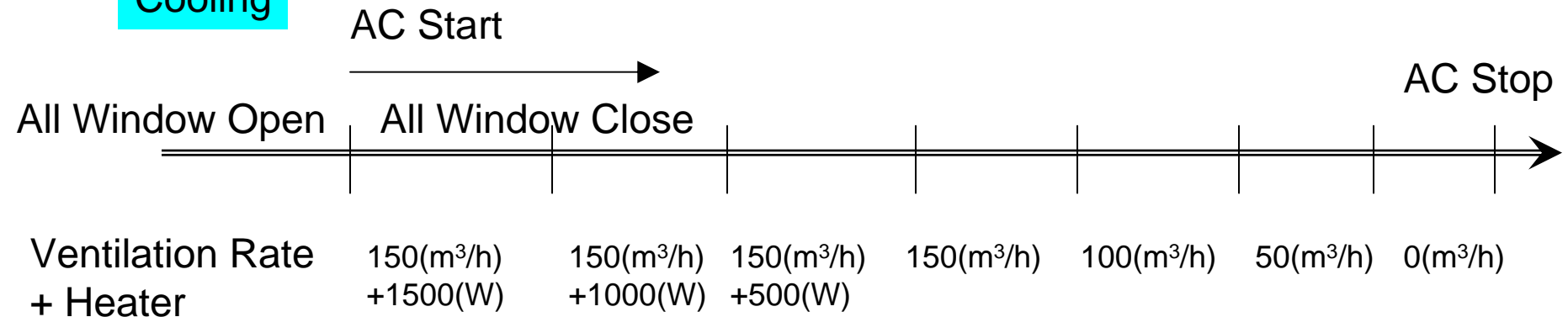
Set ventilation rate was 150, 100, 50 and 0 (m³/h).

Set of Experimental Condition

Heating

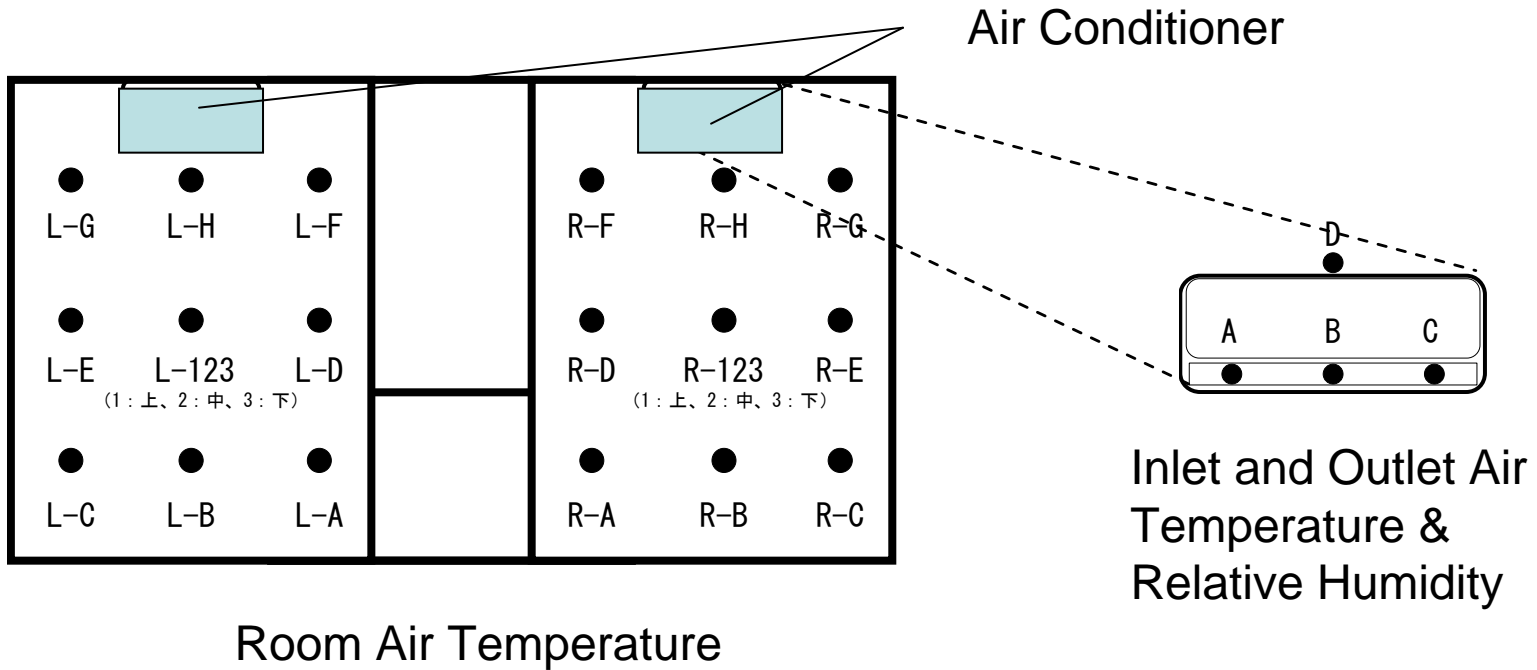


Cooling



Points of Measurements

- Temperature & Humidity



Points of Measurements

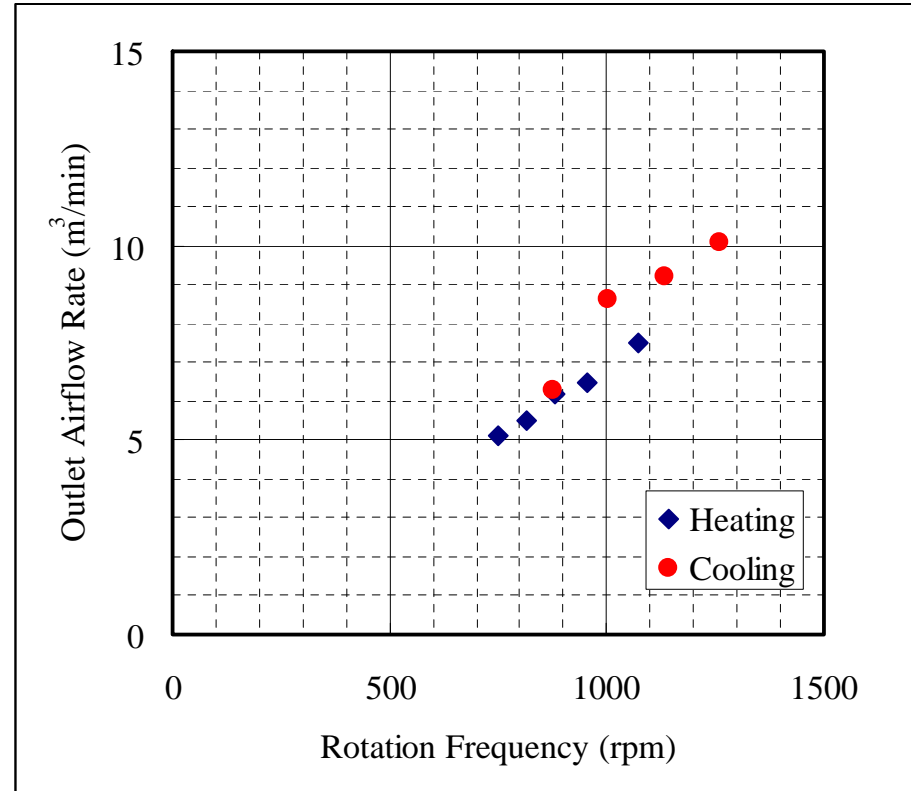
- Outlet Air Flow Rate of Internal Unit
 - Rotation frequency of the fan in the internal unit was measured instead of measuring outlet air velocity.
 - Relation between the rotation frequency and air flow rate was measure additionally.
 - Air flow rate was calculated using this relational expression.

Additional Measurements

Relation between Outlet Air Flow Rate and Rotation Frequency

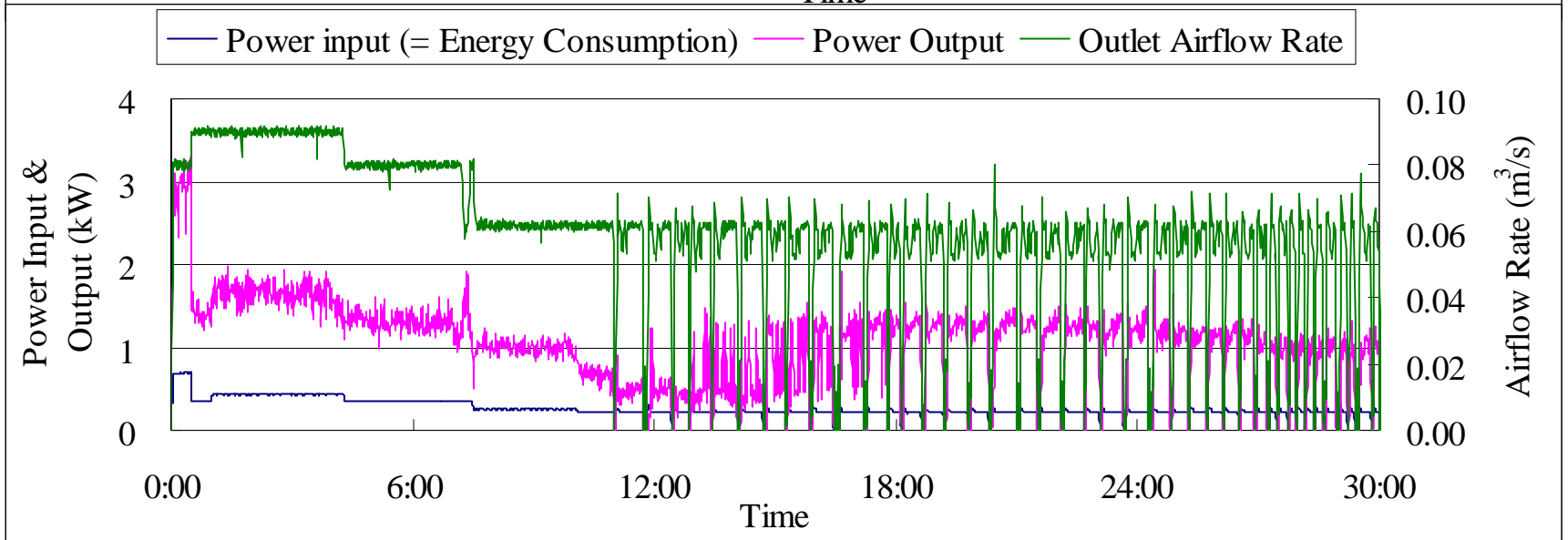
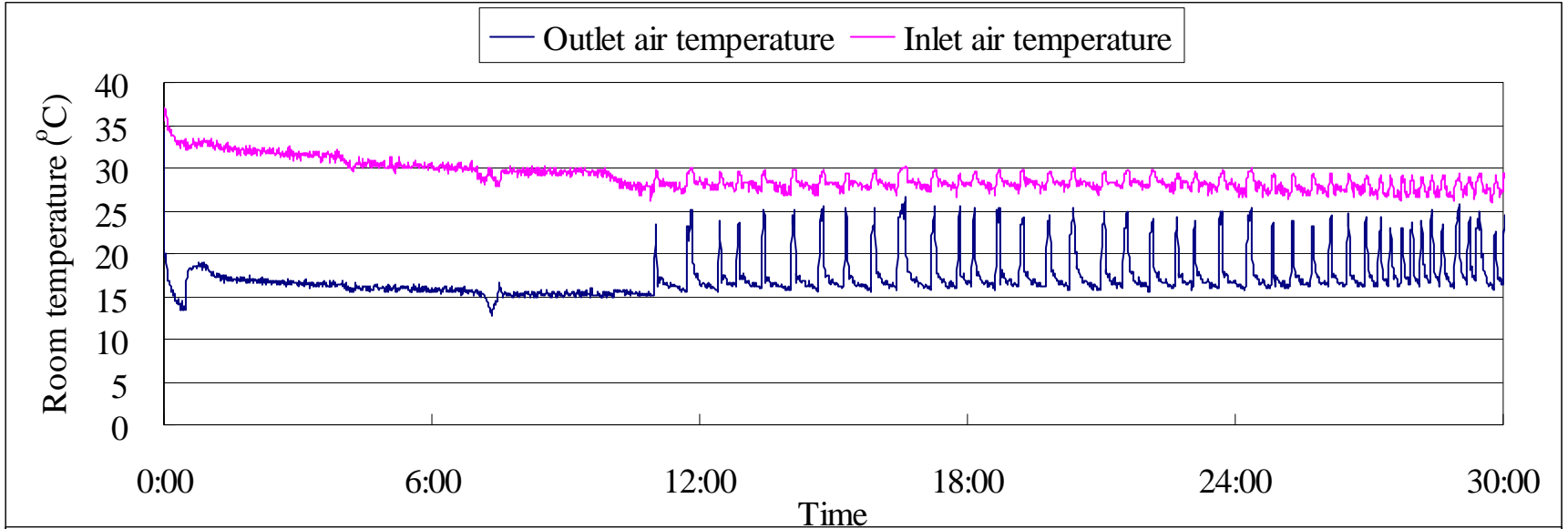


Measurement of Outlet Air Flow Rate

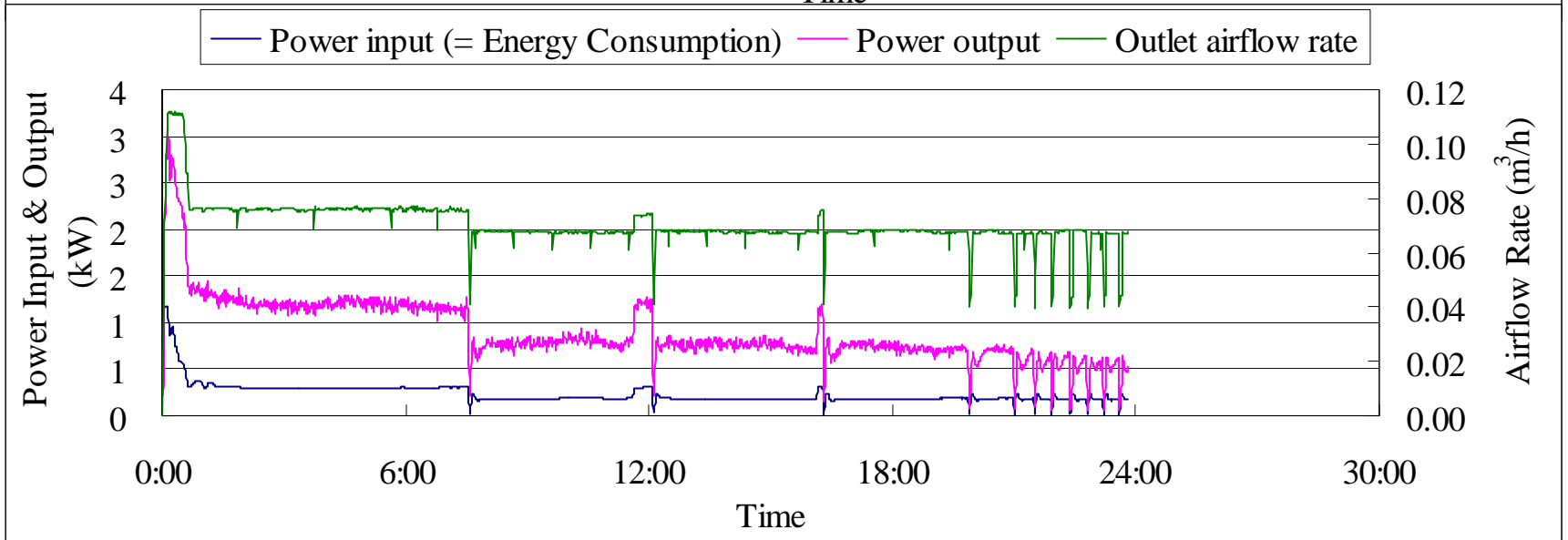
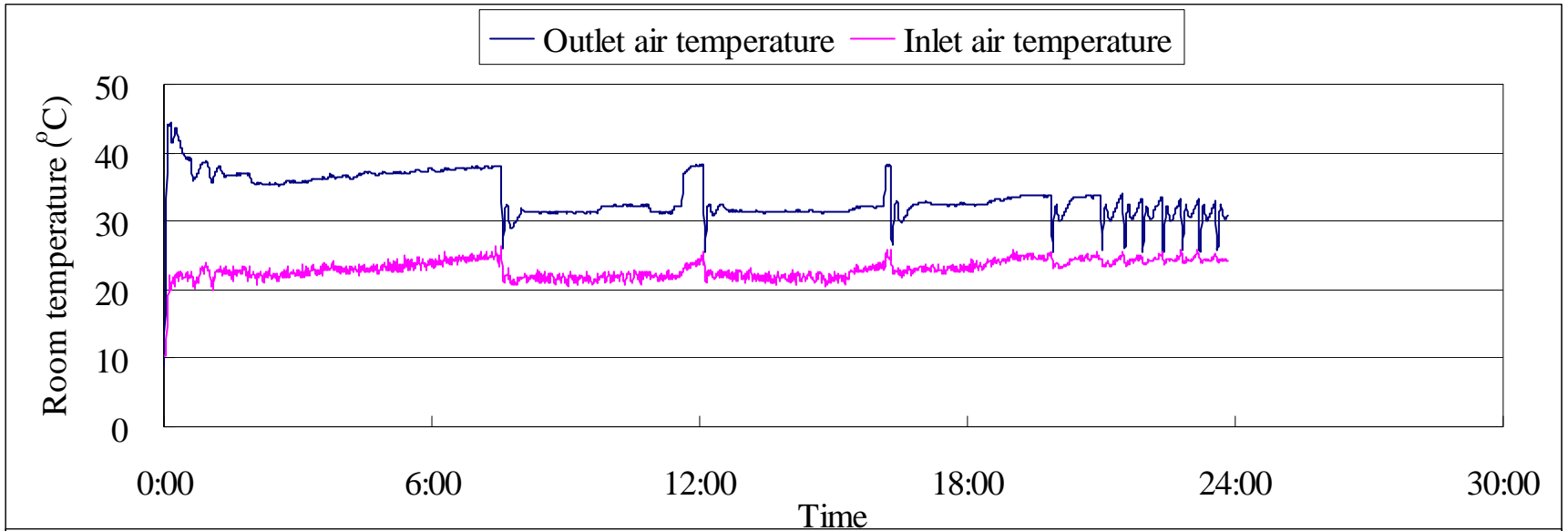


Relational Expression

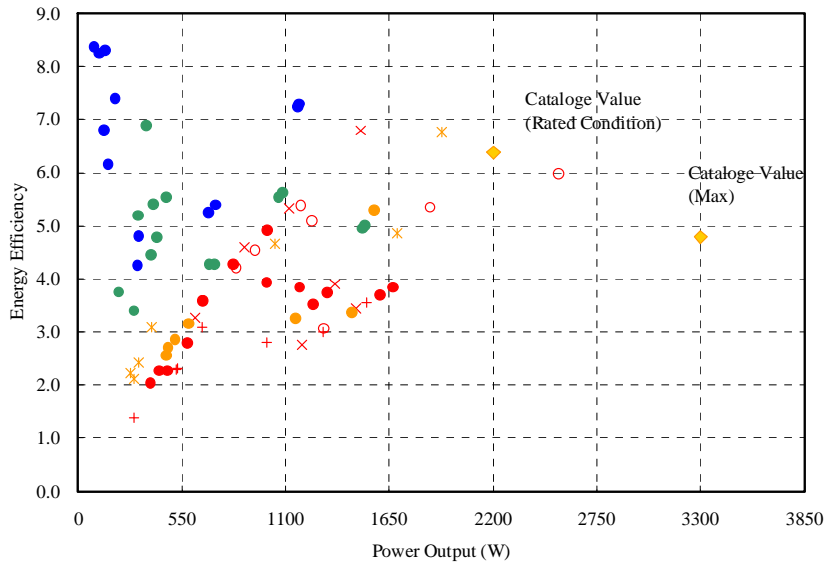
Results (Cooling)



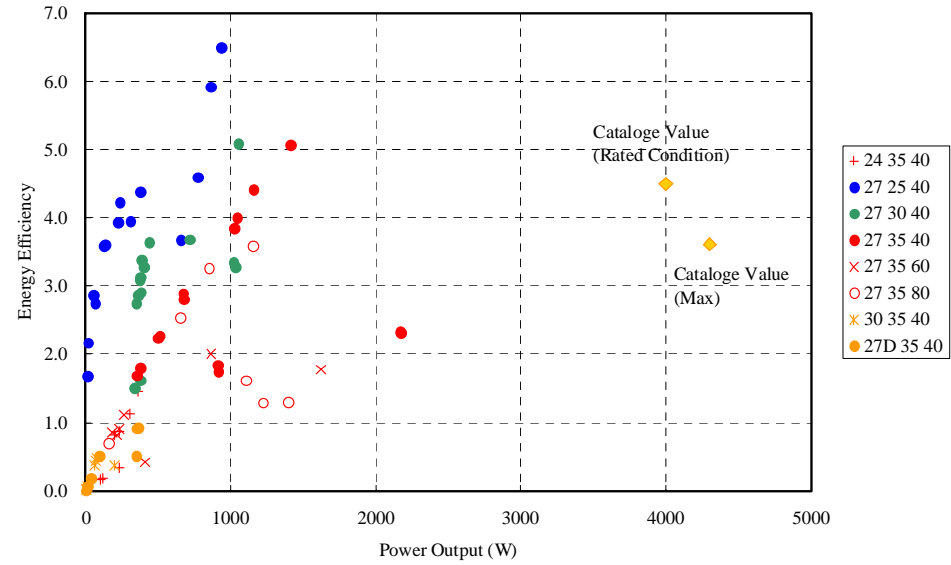
Results (Heating)



Power Output vs. Energy Efficiency



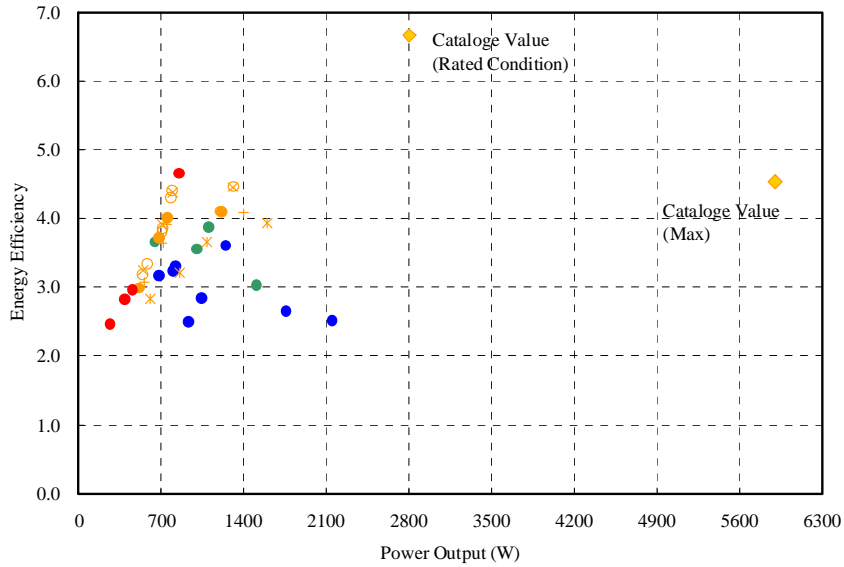
2.2kW



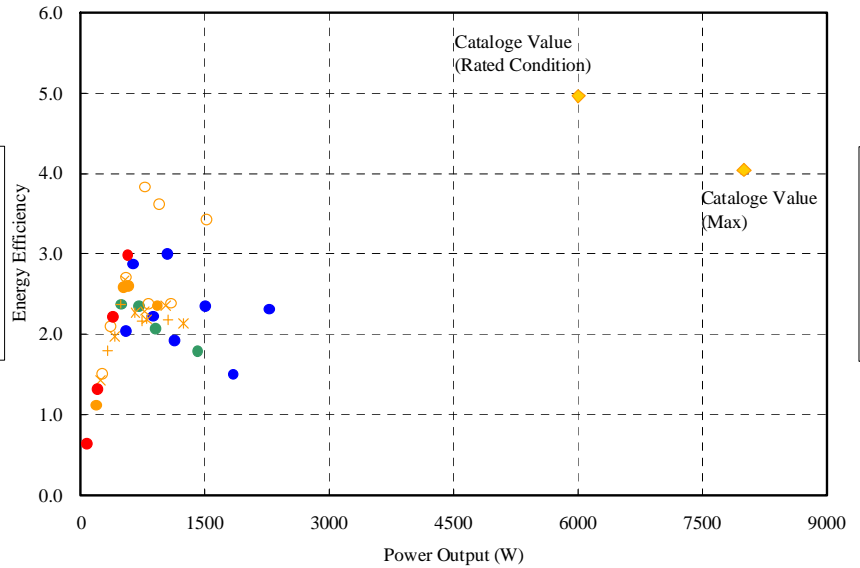
4.0kW

Cooling

Power Output vs. Energy Efficiency



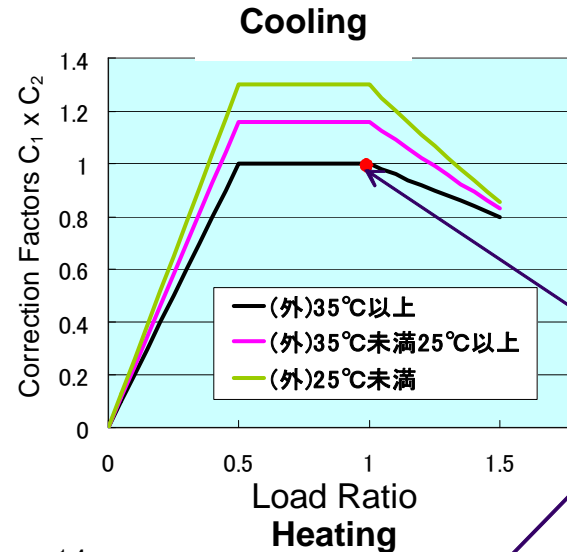
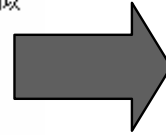
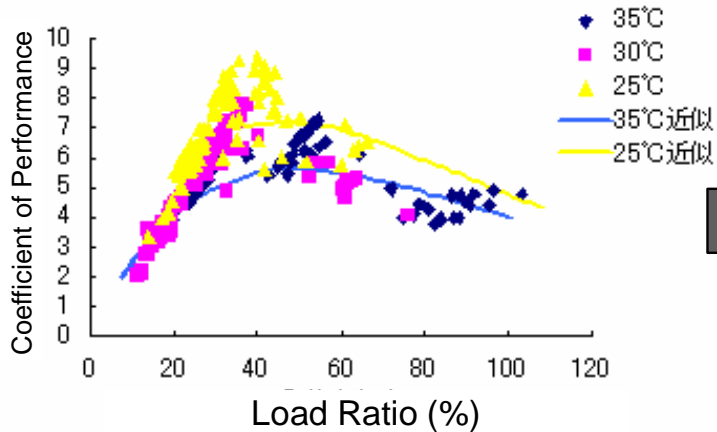
2.2kW



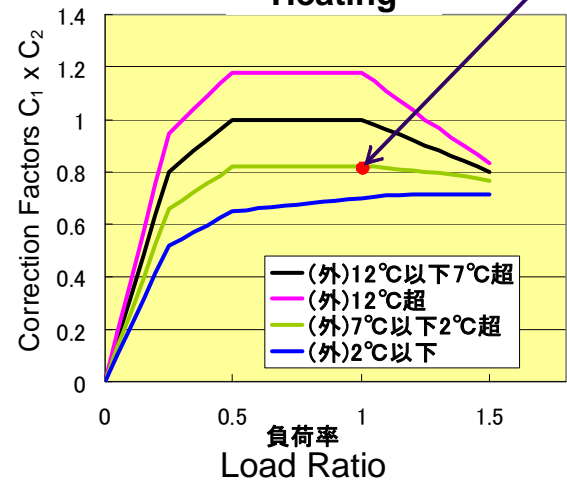
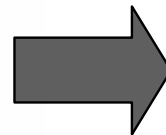
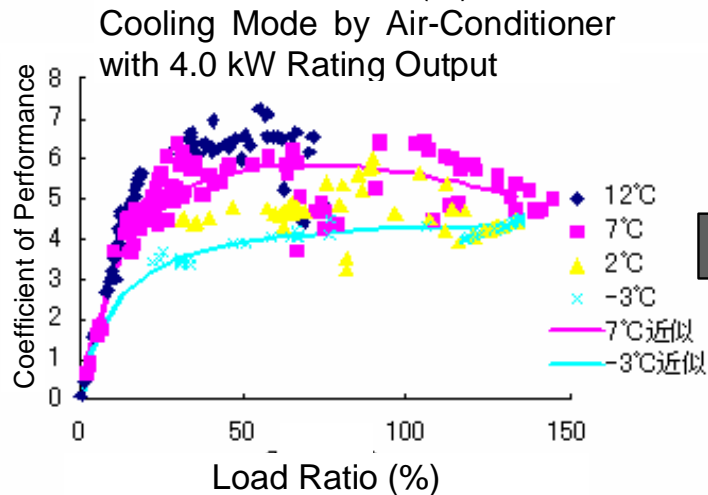
4.0kW

Heating

ADDITIONAL TESTS (AN EXAMPLE FOR AIR-CONDITIONERS)

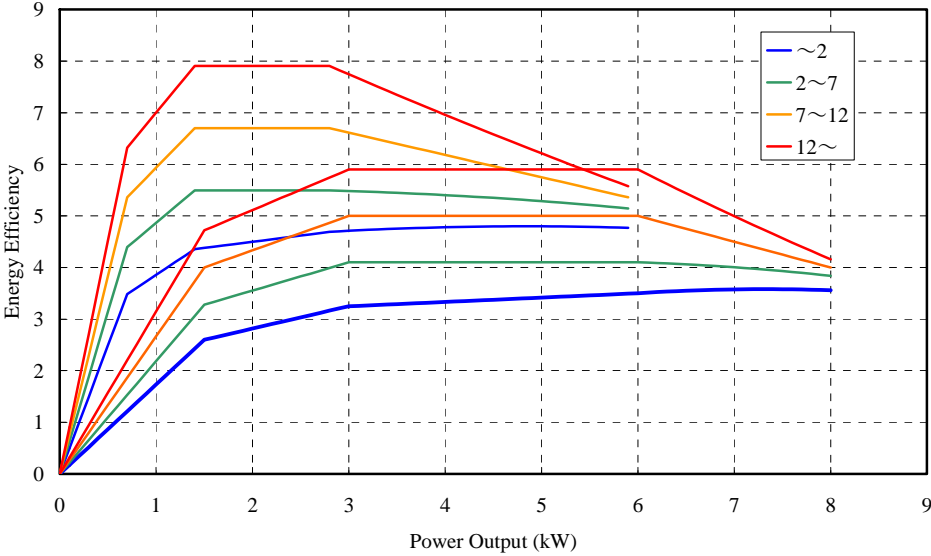


COP at rating output and condition for outdoor temperature

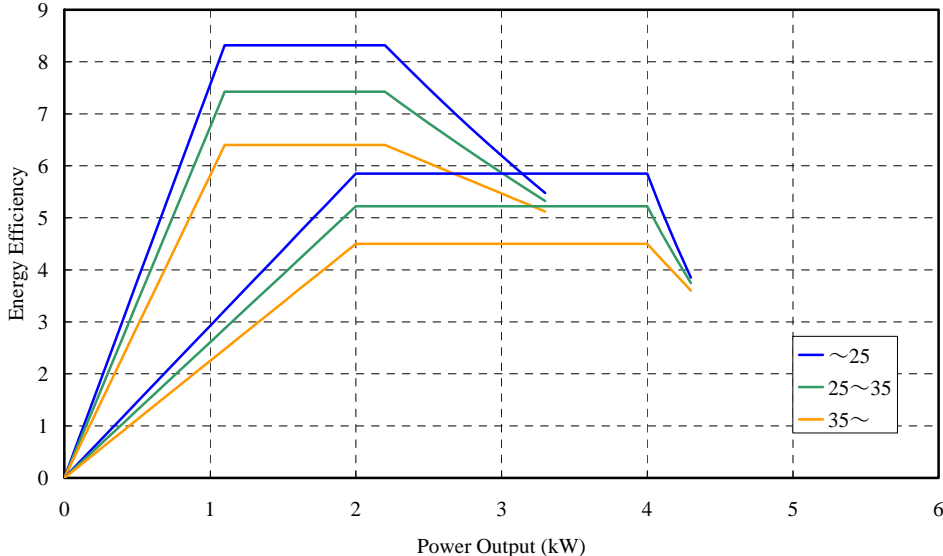


Heating Mode by Air-Conditioner with 4.0 kW Rating Output

Estimation of Energy Efficiency



Cooling



Heating

Energy Efficiency is represented by the function of external temperature heat load, COP, rated power output and maximum power output.

Estimation of COP

$$COP = COP_o \times c_l \times c_t$$

COP = COP in arbitrary load and in outdoor temperature,
 COP_o = COP in the rated output (cataloged efficiency),
 c_l = correction coefficient for load ratio
 c_t = correction coefficient for outdoor temperature.

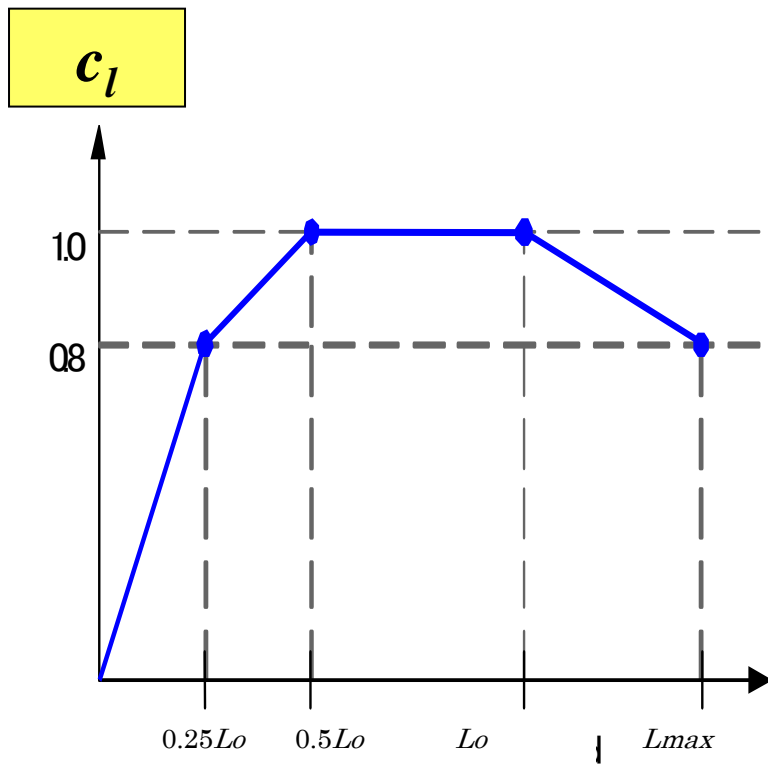


Fig.2 Formulation of c_l (correction coefficient for load ratio)

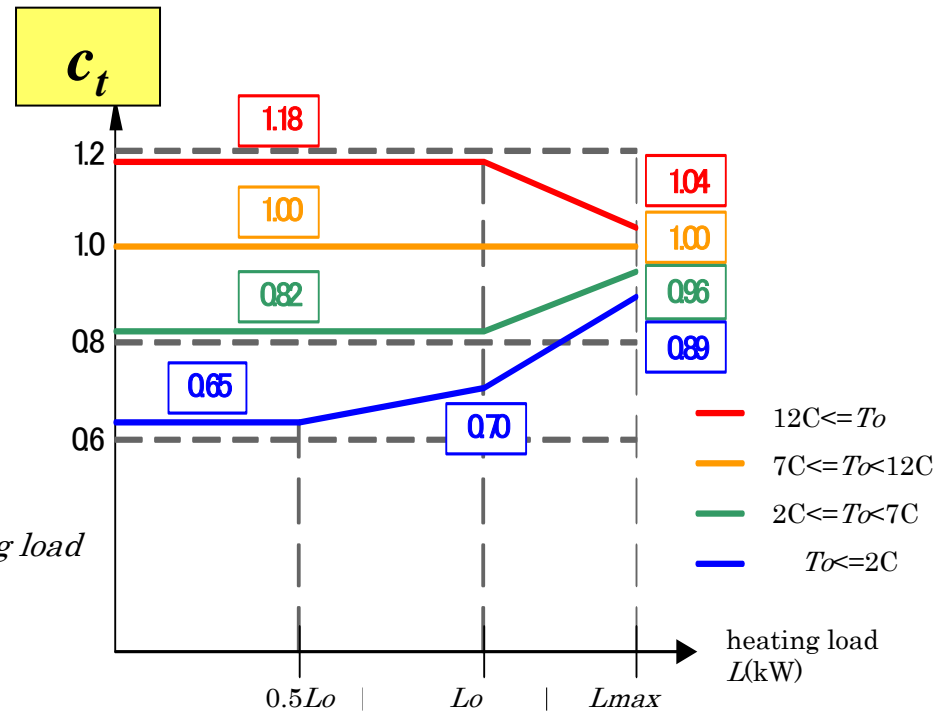


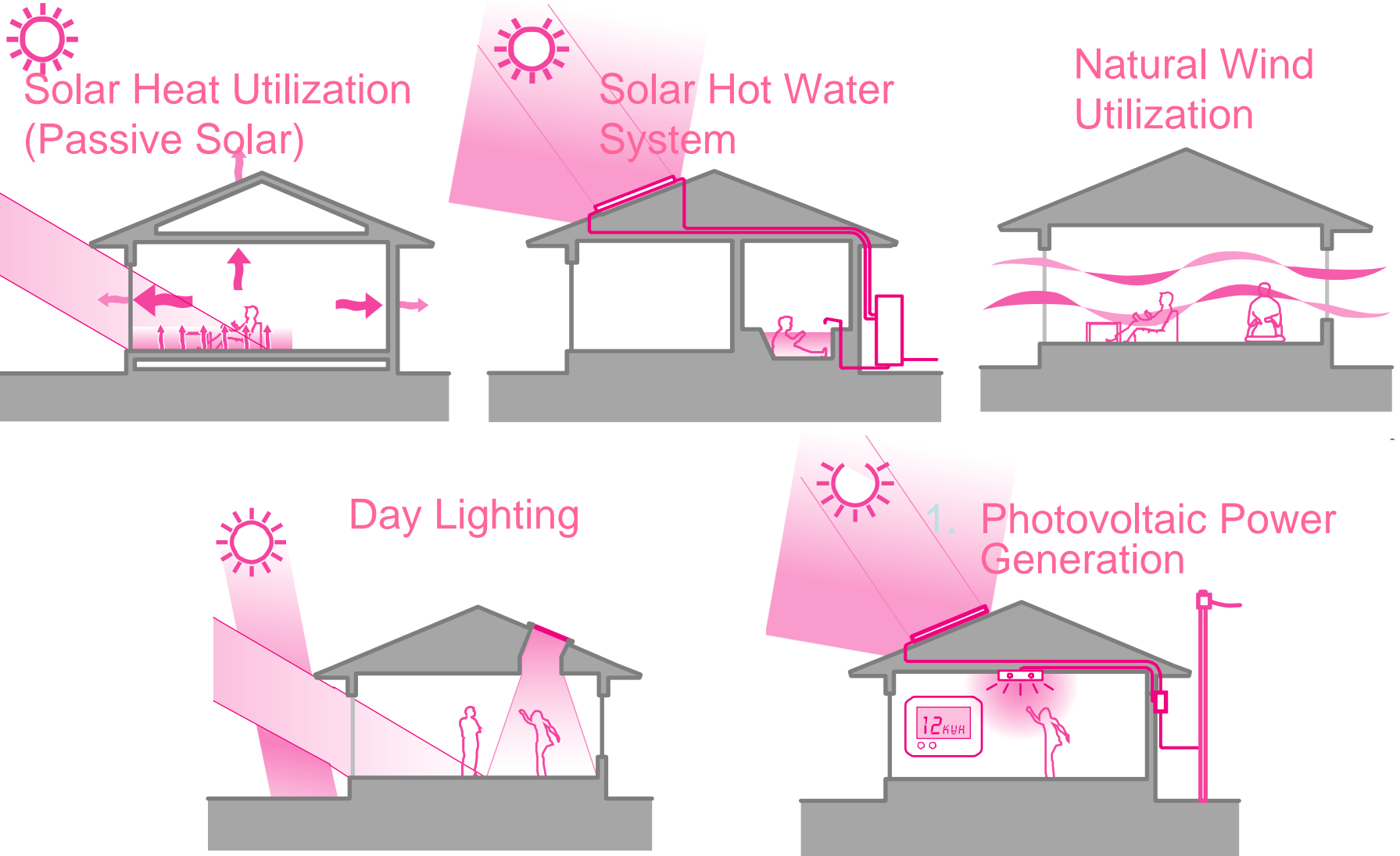
Fig.3 Formulation of c_t (correction coefficient for outdoor temperature)

Part II Background

TWELVE TECHNOLOGICAL ELEMENTS

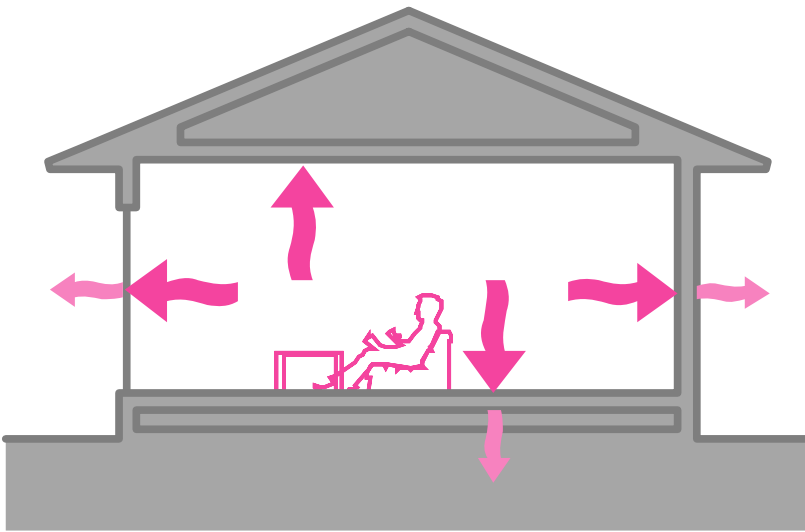
- Natural Energy Utilization
 1. Solar Heat Utilization (Passive Solar)
 2. Solar Hot Water System
 3. Natural Wind Utilization (Cross Ventilation)
 4. Day Lighting
 5. Photovoltaic Power Generation
- Heat Control through Envelope
 6. Envelope Insulation
 7. Solar Shading
- Energy Efficient Equipment
 8. Heating and Air-Conditioning Equipment
 9. Domestic Hot Water System
 10. Energy Efficient Ventilation
 11. Energy Efficient Artificial Lighting
 12. Home Electric Appliances

Natural Energy Utilization

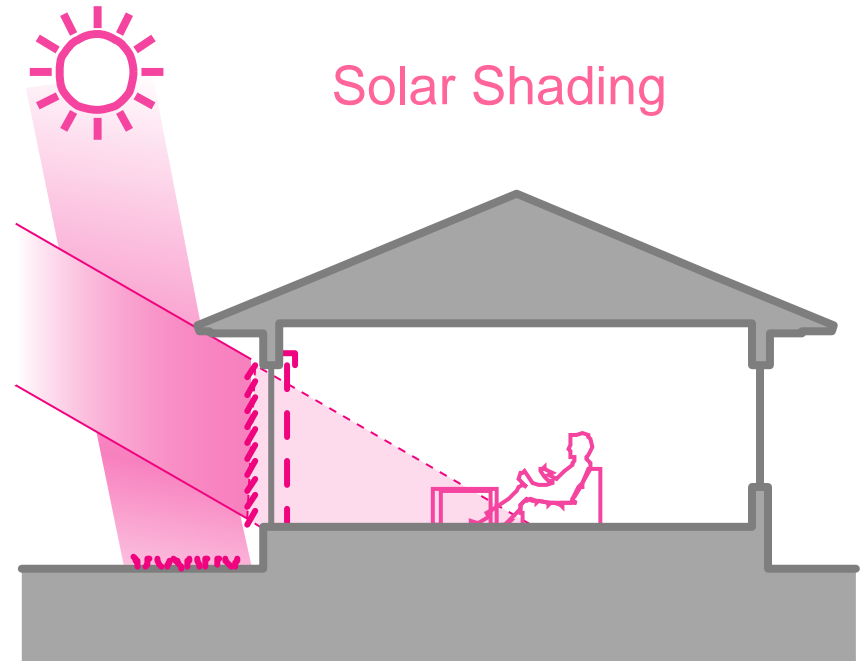


Heat Control through Envelope

Envelope Insulation

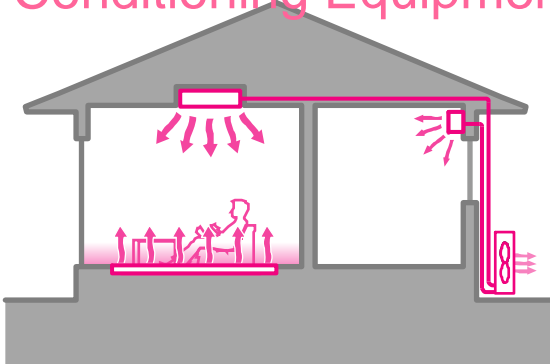


Solar Shading

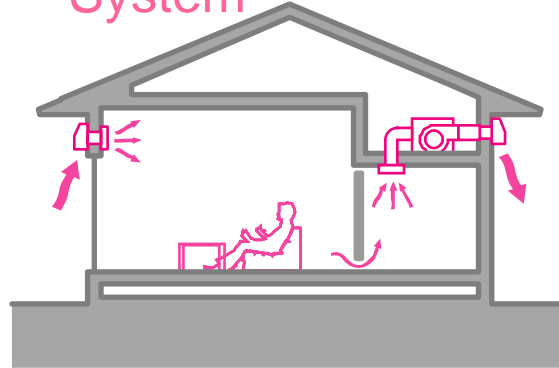


Energy Efficient Equipment

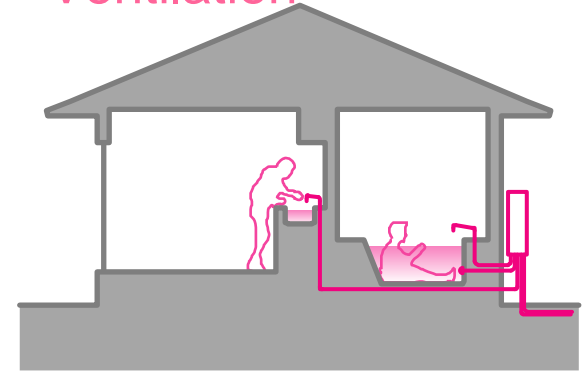
Heating and Air-Conditioning Equipment



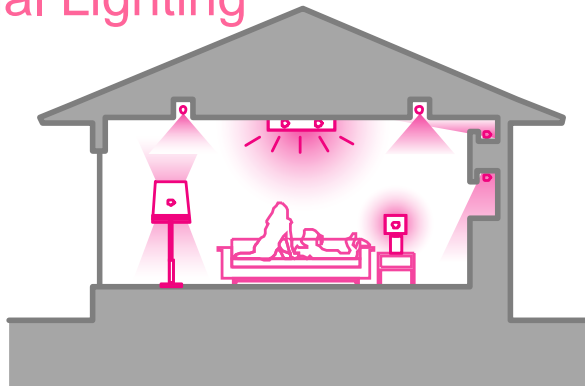
Domestic Hot Water System



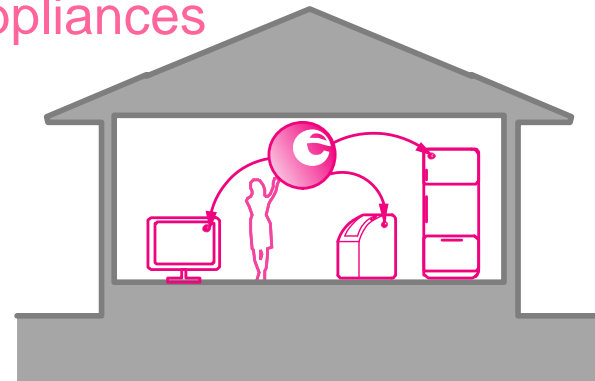
Energy Efficient Ventilation



Energy Efficient Artificial Lighting



Home Electric Appliances



ASSUMPTIONS FOR ENERGY USE ESTIMATION

- 4 persons: 45 year-old husband, 42 year-old full-time housewife, 17 year-old high school girl, 15 year-old junior high school boy.
- Use of Time: determined by referring to the large scale survey carried out by NHK (Japan Broadcasting Corporation)
- Heating and Air-Conditioning Schedule: Intermittent schedule is determined by referring to questionnaire survey carried out by BRI. Continuous and overall schedule is also assumed independently.
- Possession of electric appliances: determined by referring to various surveys
- Use of electric appliances: determined by referring to detailed field measurement by BRI and AIJ

Table-3 Reference energy consumption (primary energy)for intermittent and continuous heating/air-conditioning

Energy Use	Reference energy consumption (primary energy)			
	Intermittent heating/air-conditioning case		Continuous and overall heating/air-conditioning case	
Heating	12.8 GJ	15.4 %	43.2 GJ	37.1 %
Air-Conditioning	2.4 GJ	2.9 %	5.3 GJ	4.6 %
Ventilation	4.7 GJ	5.6 %	4.7 GJ	4.0 %
Domestic Hot Water	24.5 GJ	29.4 %	24.5 GJ	21.0 %
Lighting	10.7 GJ	12.9 %	10.7 GJ	9.2 %
Electric Appliances	23.7 GJ	28.5 %	23.7 GJ	20.3 %
Cooking	4.4 GJ	5.3 %	4.4 GJ	3.8 %
Total	83.2 GJ	100.0 %	116.5 GJ	100.0 %

HOW TO ESTIMATE PRIMARY ENERGY CONSUMPTION

- “Energy Consumption Ratio”
(= Estimated Consumption / Reference Consumption) is determined on the basis of the validation experiment and/or simulation.
- At present, some limitations exist for climate, building type, family type, etc.
- Succeeding work is being done for other conditions

TABLES OF “ENERGY CONSUMPTION RATIOS” (AN EXAMPLE FOR “DHW”)

Table 7 Domestic hot water energy and related technological elements

Energy use	Ref. Energy	Tech. Element	Design methods	Energy consumption ratio (reference energy=1.0)				
				Level 0	Level 1	Level 2	Level 3	Level 4
Domestic hot water	24.5GJ	Solar Hot Water System, Domestic Hot Water System	Methods: 1. solar hot water tank, 2. solar heat collector, 3-1. latent heat recovery gas instant water heater, 3-2.CO ₂ heat pump, 4. utilization of well insulated pipe and faucet with thermostat or single lever, etc.	1.0	0.9	0.8	0.7	0.5
				Conventional gas water heater	1 or 3-1 or 4	1+3 or 3+4 or 3-2	2 or 1+3+4	2+3 or 2+3+4

Short Description on Requirement for Different Levels

Energy Consumption Ratios for Different Levels

TABLES OF “ENERGY CONSUMPTION RATIOS” (AN EXAMPLE FOR “COOLING”)

Table 5 Cooling energy and related technological elements (for intermittent cooling)

Energy use	Ref. Energy	Tech. Element	Design methods		Energy consumption ratio (reference energy=1.0)				
					Level 0	Level 1	Level 2	Level 3	Level 4
Cooling	2.4GJ	Natural wind utilization	Methods: 1.direct method, 2.indirect method, 3.roof window, 4.buoyancy driven ventilations, 5.internal openings		1.0	0.9	0.8	0.7	
					-	Site 3: 1+5, Site 2: 2+3+5 Site 2: 4+5	Site 3: 1+2+5 Site 2 2+3+4+5	Site 3: 1+2+3+4+5	
		Solar Shading	Orienta tion of main facade	South	1.0	0.85	0.7	0.55	
				South East or South West	1.3	0.8	0.75	0.65	
				East or West	1.1	0.8	0.75	0.65	
			Solar heat gain coeffici ent	North±30°	About 0.79	<=0.79	<=0.55	<=0.55	
				Other orientation	About 0.79	<=0.60	<=0.45	<=0.30	
		Cooling Equipment	A.C.	COP	1.0	0.8	0.7	0.6	
					<4.0	<5.0	>=5.0	>=6.0	

Technologic
al Elements
Influential
on This Part
of Energy
Use



AN EXAMPLE OF CALCULATION TO KNOW TOTAL ENERGY CONSUMPTION

Assumptions:

envelope insulation / Level 3

solar heat utilization / Level 2 (methods 1+2+3, facing south in site with 5-hour-sunlight on the winter solstice)

heating equipment / Level 3

natural wind utilization / Level 2 (methods 2+3+4+5, in Site 2),

solar shading / Level 3 (solar heat gain coefficient ≤ 0.3 except for north $\pm 30^\circ$)

air-conditioning equipment / Level 3

energy efficient ventilation / Level 2 (duct diameter ≥ 75 mm, consideration in layout of supply terminals)

domestic hot water / Level 4 (solar heat collector+ well insulated pipe/bath tub and faucet with thermostat or single lever)

day lighting / Level 2 (every room has windows on different facades, hall with a window, in Site 2)

Lighting / Level 2 (efficient lamp and apparatus, automatic control by using sensor(s))

electric appliances / Level 2

EXAMPLE OF TOTAL PRIMARY ENERGY CALCULATION

(Figures in [] are energy consumption ratios known from Table 4~9)

Energy use	Calculation	Prediction (GJ)	Reference energy consumption (GJ: primary energy)	Reduction ratio (%)
Heating	$12.8 \times ([0.55] \times [0.9] \times [0.6])$	3.8GJ	12.8GJ	-70%
Cooling	$2.4 \times ([0.8] \times [0.55] \times [0.6])$	0.6GJ	2.4GJ	-75%
Ventilation	$4.7 \times [0.6]$	2.8GJ	4.7GJ	-40%
Domestic Hot Water	$24.5 \times [0.5]$	12.3GJ	24.5GJ	-50%
Lighting	$10.7 \times ([0.95] \times [0.6])$	6.1GJ	10.7GJ	-43%
Electric Appliances	$23.7 \times [0.6]$	14.2GJ	23.7GJ	-40%
Cooking		4.4GJ	4.4GJ	±0%
Subtotal		44.2GJ	83.2GJ	-47%
Power Generation	3kW: -29.3GJ/4kW: -39.1GJ	-0GJ		
Total		44.2GJ	83.2GJ	-47%

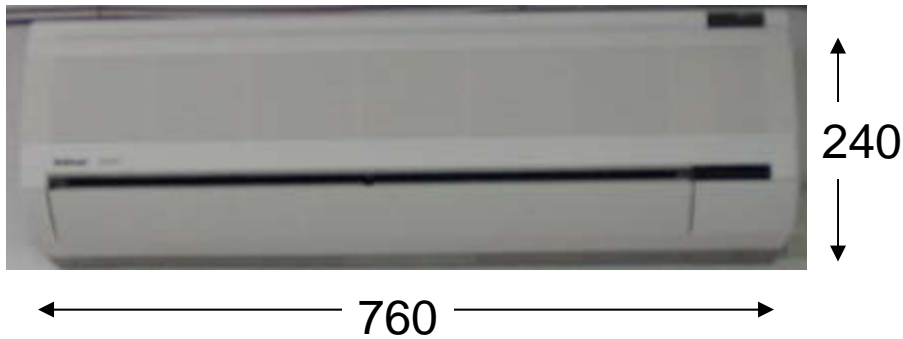
EXPERIMENTAL VALIDATION WITH OVERALL SIMULATED OCCUPANCY



Heat Pump Air Conditioners (for Individual Rooms)

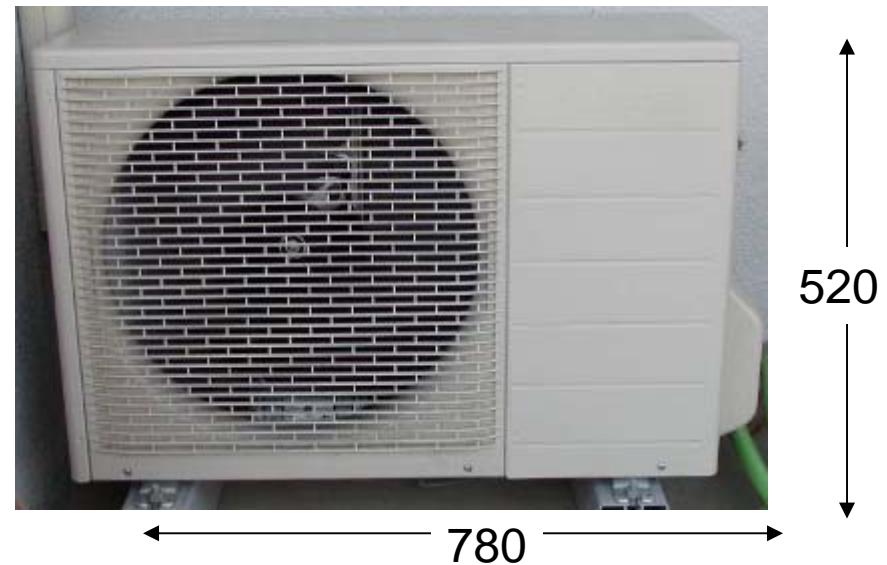
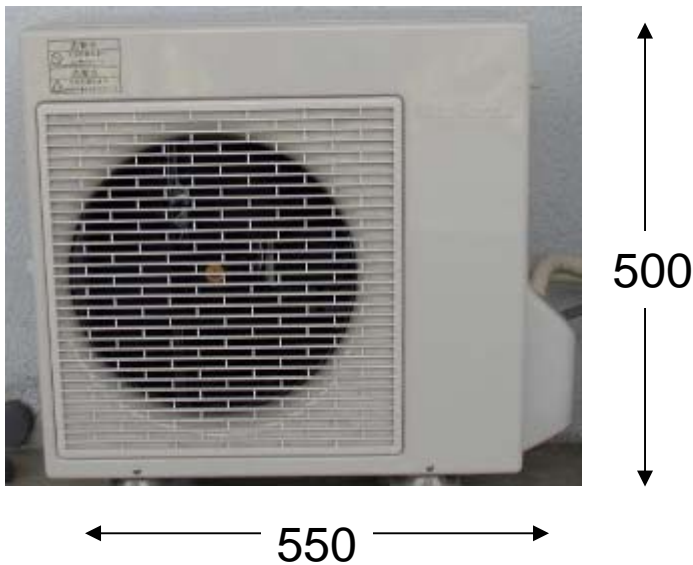
Standard dwelling for comparison
(Average COP: 2.75)

Refrigerant: R-22 (570 g)



Energy conserving dwelling
(Average COP: 6.00)

Refrigerant: R-410A (1100 g)



Range Hoods (Cooker Hoods)



Standard dwelling for comparison (Power consumption: 77 W)

Energy conserving dwelling
(High efficiency motor; power consumption: 25 W)



Local Exhaust Fans



Standard dwelling for comparison (Power consumption: 13 W)

Energy conserving dwelling
(High efficiency motor; power consumption: 8.4 W)



Lighting Equipment



Standard dwelling for
comparison
(Incandescent lights +
inverter light fixtures)
100 W

Energy conserving dwelling
(High efficiency inverter
light fixtures) 22W



Domestic Hot Water Boilers

Conventional Boiler
(heat efficiency 0.80 at
rating condition)



Boiler with latent heat
recovery function
(0.93 at rating condition)



Other Types of Water Heaters



Solar Hot Water System

CO₂ heat pump
Hot Water System



METHODS TO EXTRACT RELIABLE AND TRANSPARENT KNOWLEDGE ON EFFECTIVENESS FOR ENERGY CONSERVATION

- Experimental Validation
 - Integrated Test Under Simulated Occupancy
 - Additional Tests for Individual Equipment (air-conditioners, floor heating systems, refrigerators, water heaters)
- Simulation on PC
 - Heating/Cooling Load