# Evaluation of Energy Efficiency of Room Air Conditioner under Various condition

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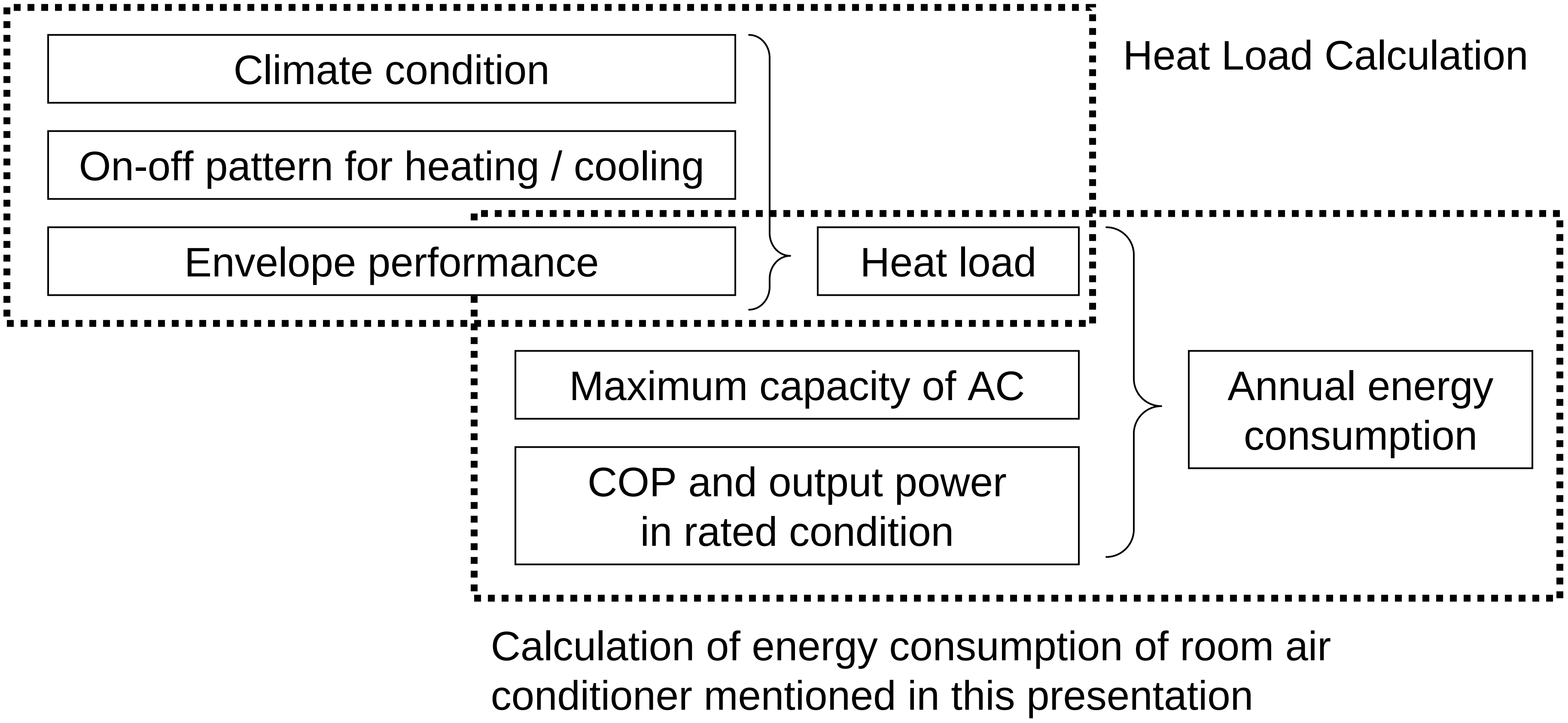
# Part I　Background

- 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.

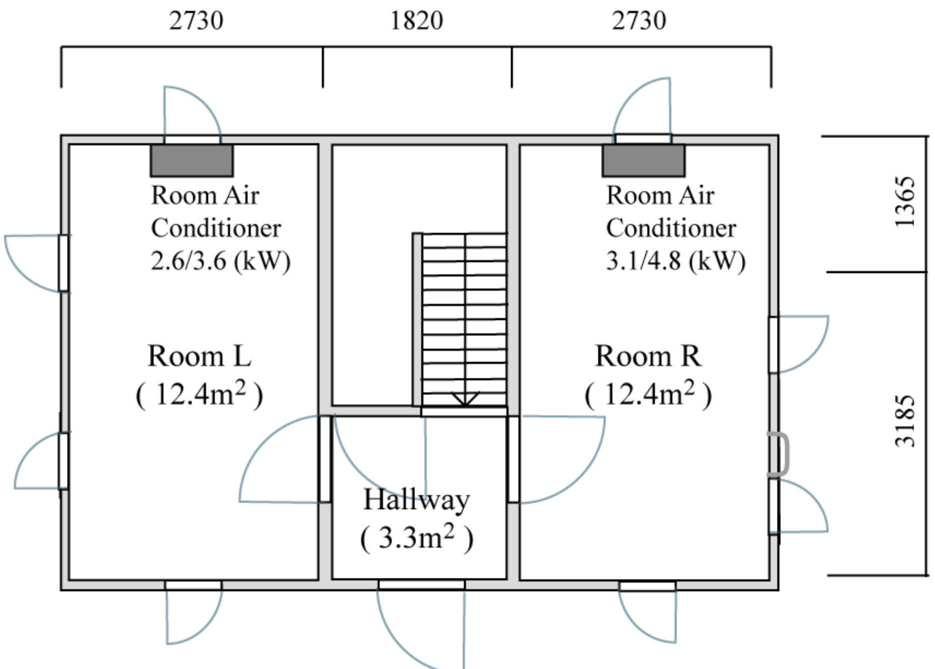
# Objective

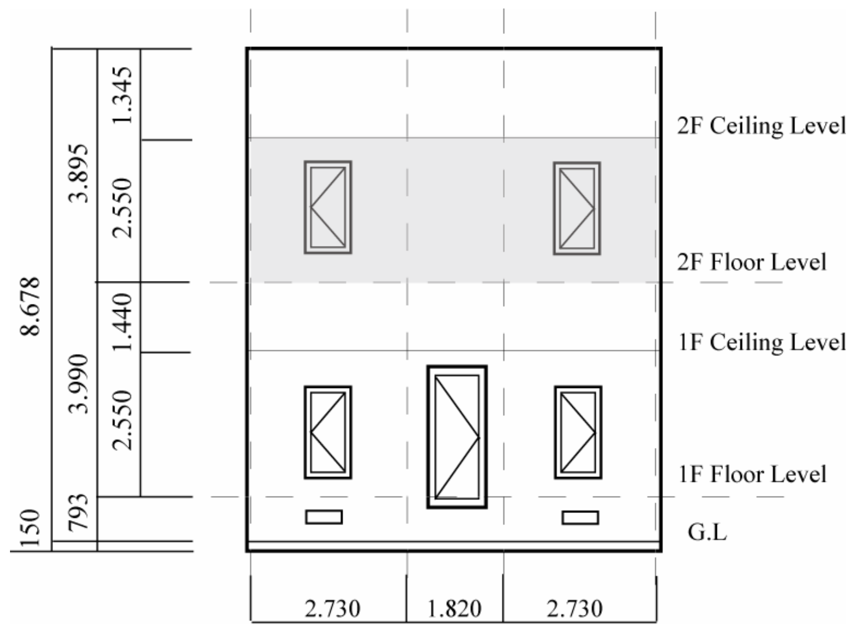
- Grasp the change of the energy efficiency under not only rated condition but also various condition by experiments
- Develop a method by which we can calculate energy efficiency under given condition and also calculate energy consumption.

# Necessary Input Information for Calculation



# 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 | Rated | Maximum | | Minimum | Rated | Maximum |
| | – | kW | kW | kW | – | kW | kW | 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 | 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 | |
| | 7 | 50 | 20 | External Humidity |
| | 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

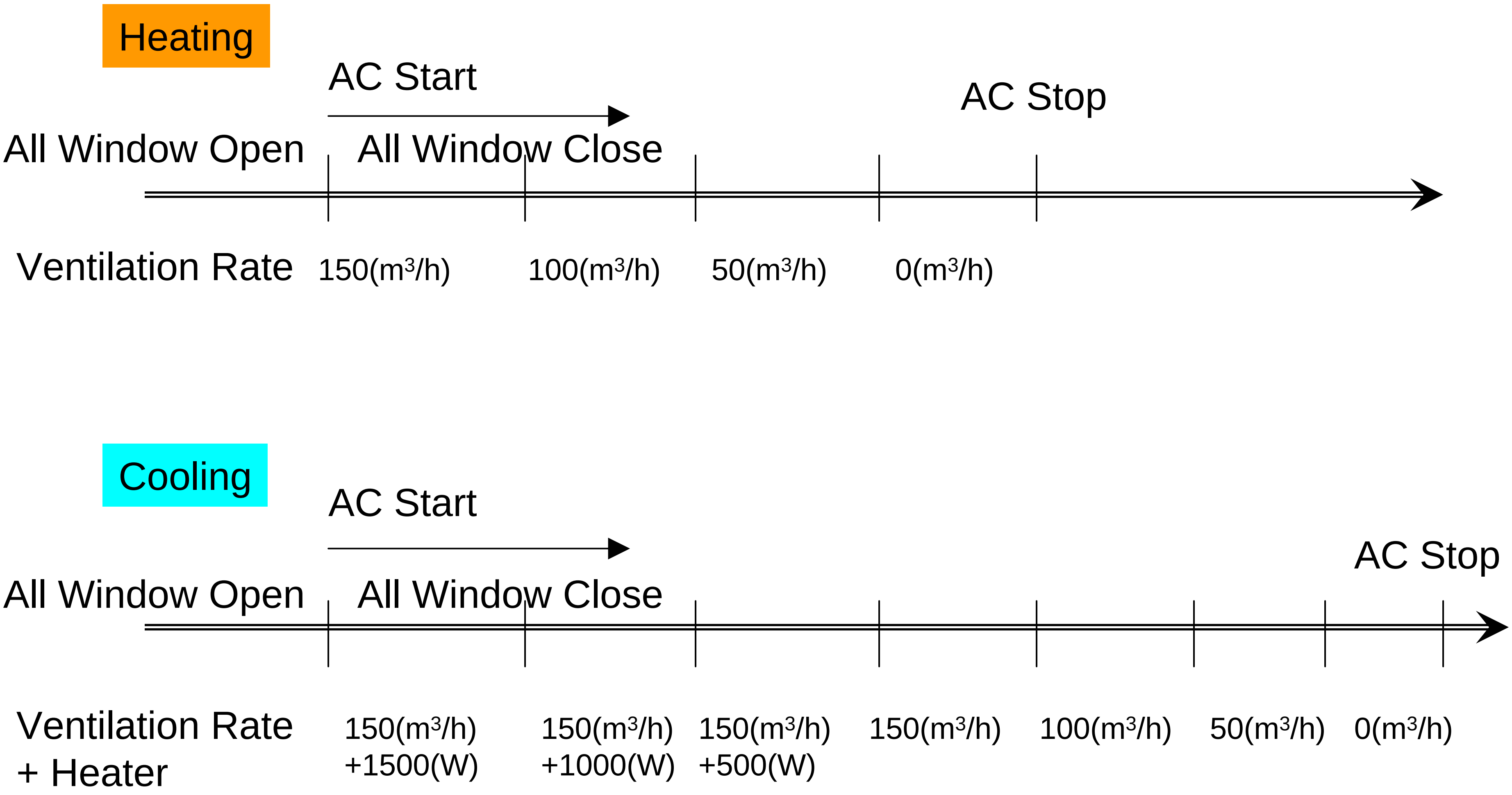
- Heat loads were given by changing exhaust air rate and if necessary, we use electric heater in the room.

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

$K$ : Heat loss coefficient ($W/m^2K$)
A : Area of Walls ($m^2$)
$\Delta T$ : Difference between external temperature and internal temperature ($^0C$)
Q : Ventilation rate, which was changed in the experiments ($m^3/s$)
$c\rho$ : Volumetric heat capacity of air ($J/m^3K$)
$H$ : Heat generation given by electric heater, which was used if necessary (W)

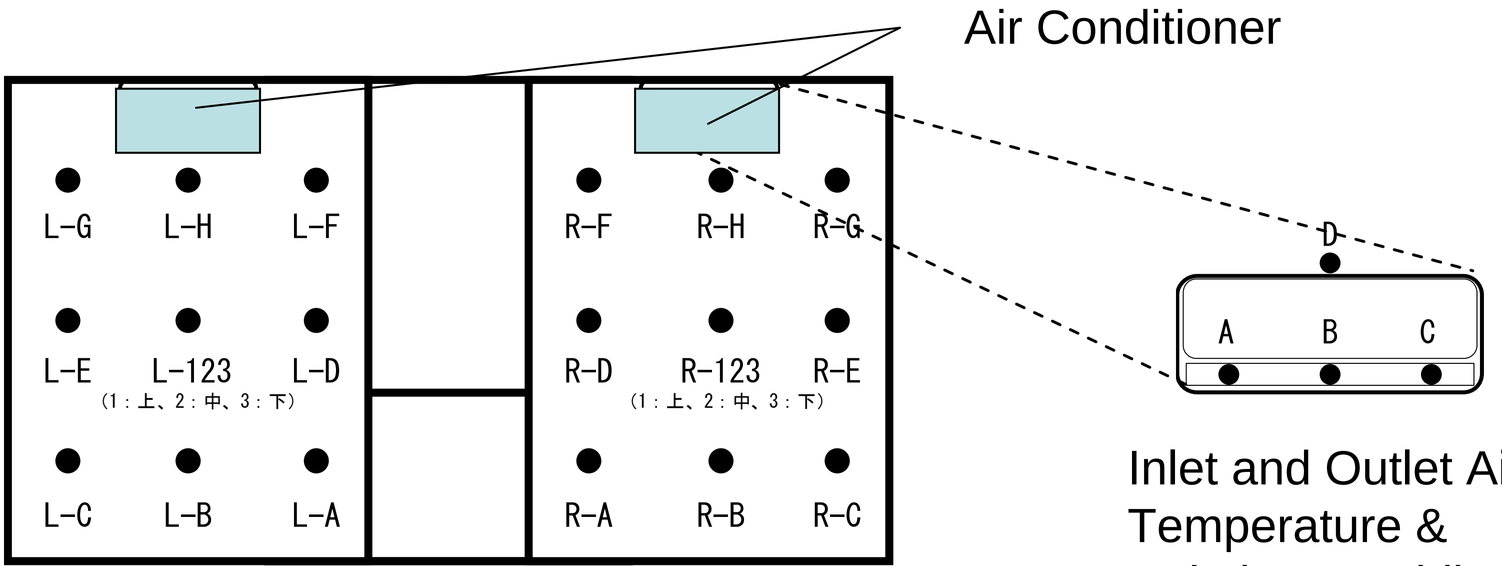
Set ventilation rate was 150, 100, 50 and 0 ($m^3/h$).

# Set of Experimental Condition



# Points of Measurements

- Temperature & Humidity




Inlet and Outlet Air Temperature & Relative Humidity

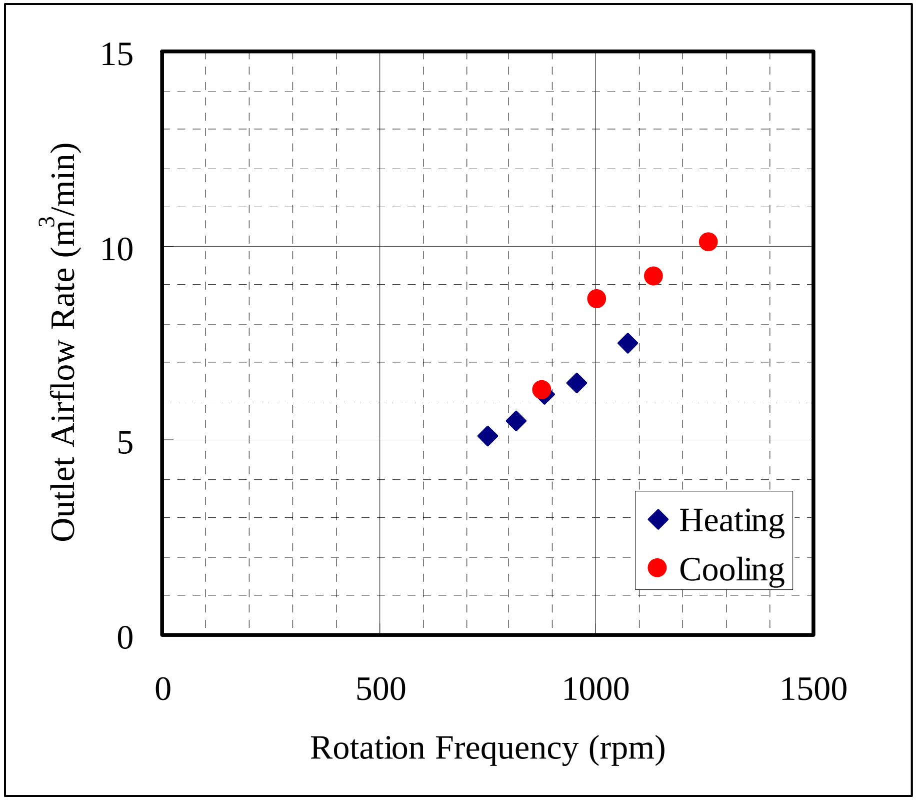
Room Air Temperature

# 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.

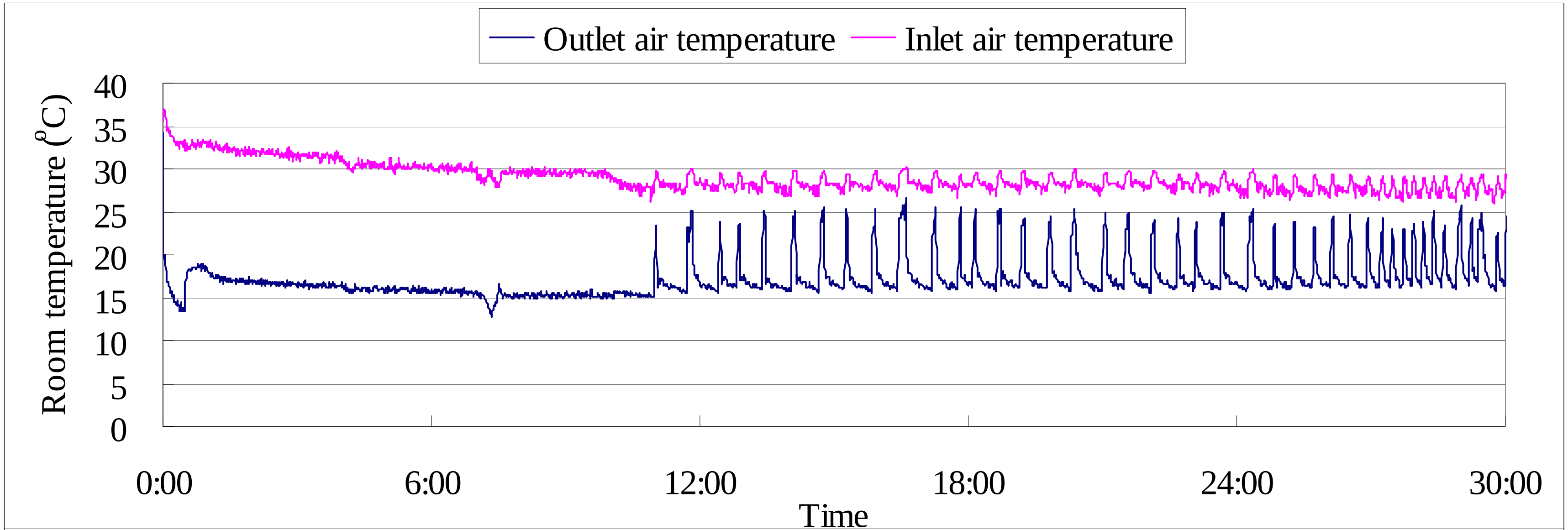
# Additional Measurements
# Relation between Outlet Air Flow Rate and Rotation Frequency

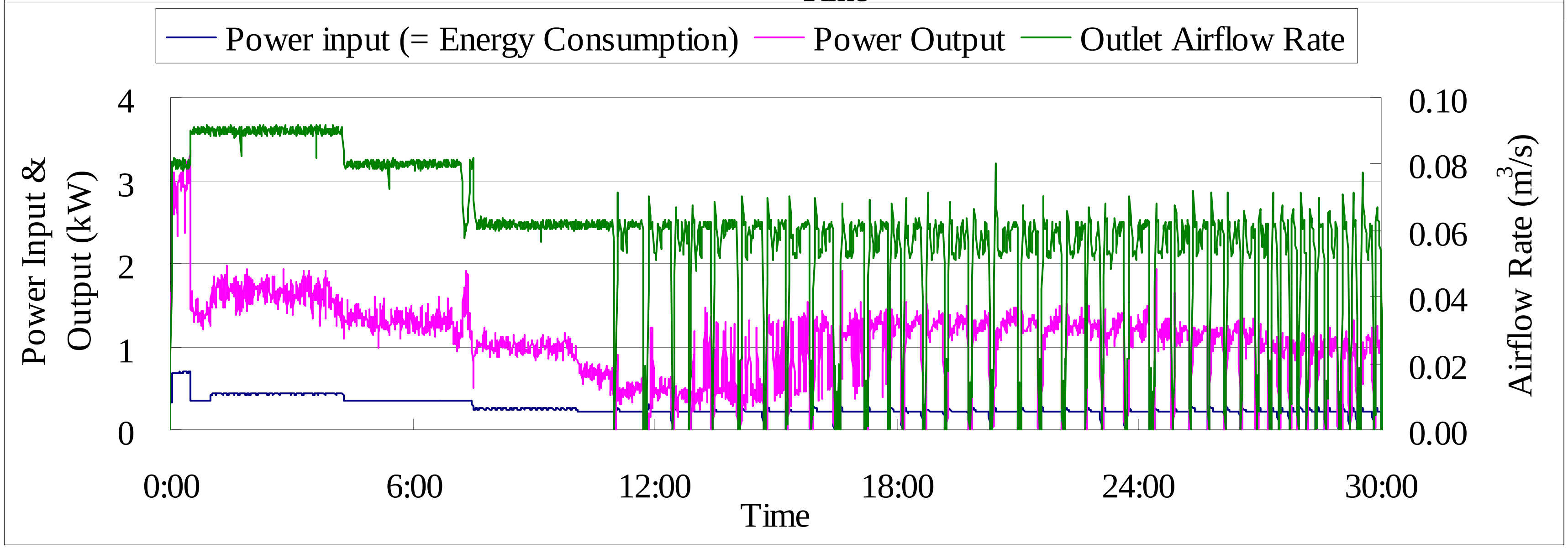
Measurement of Outlet Air Flow Rate



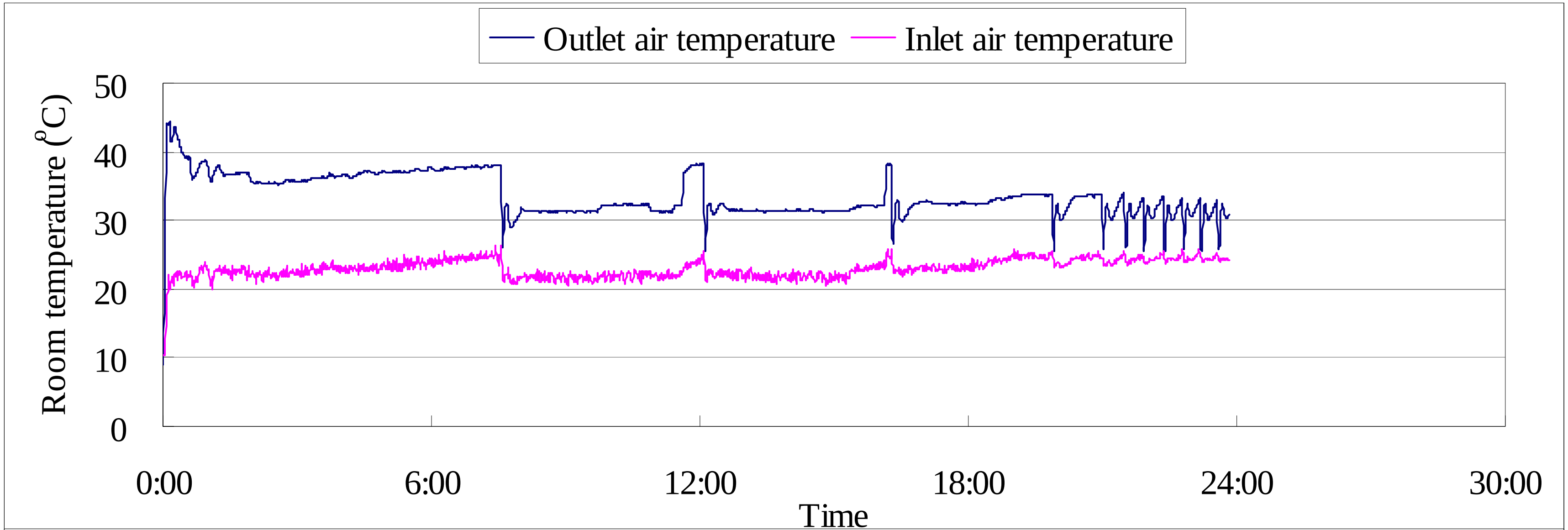

Relational Expression

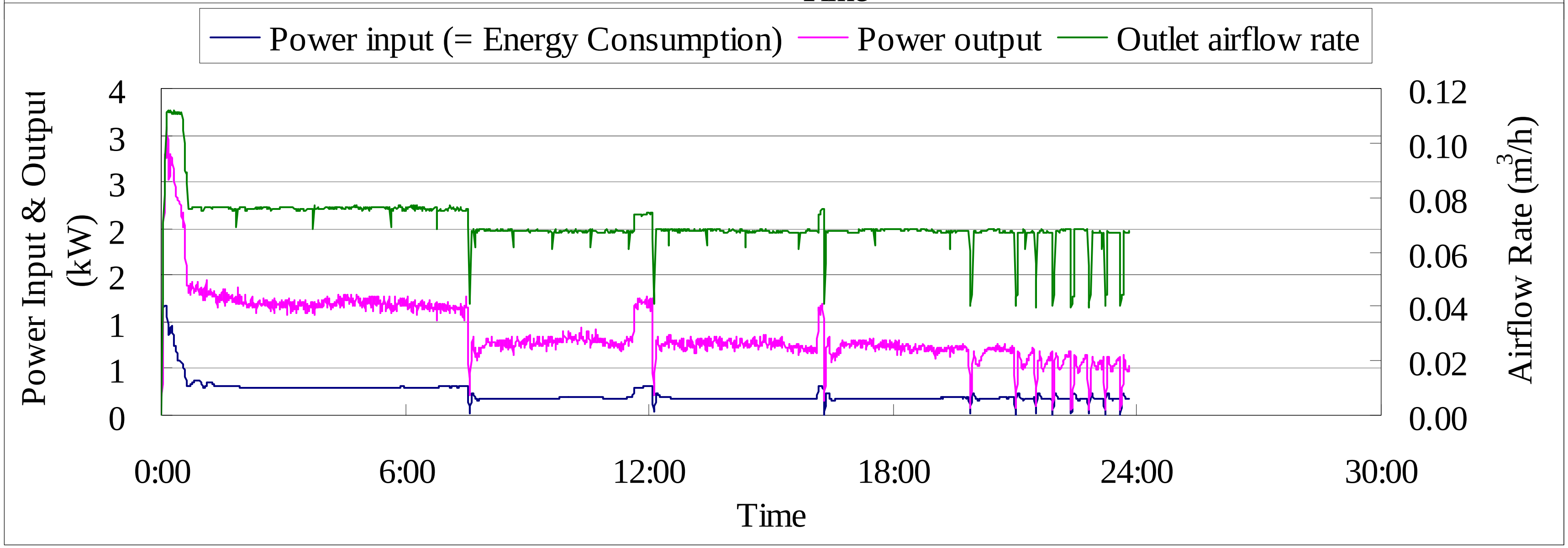
# Results (Cooling)



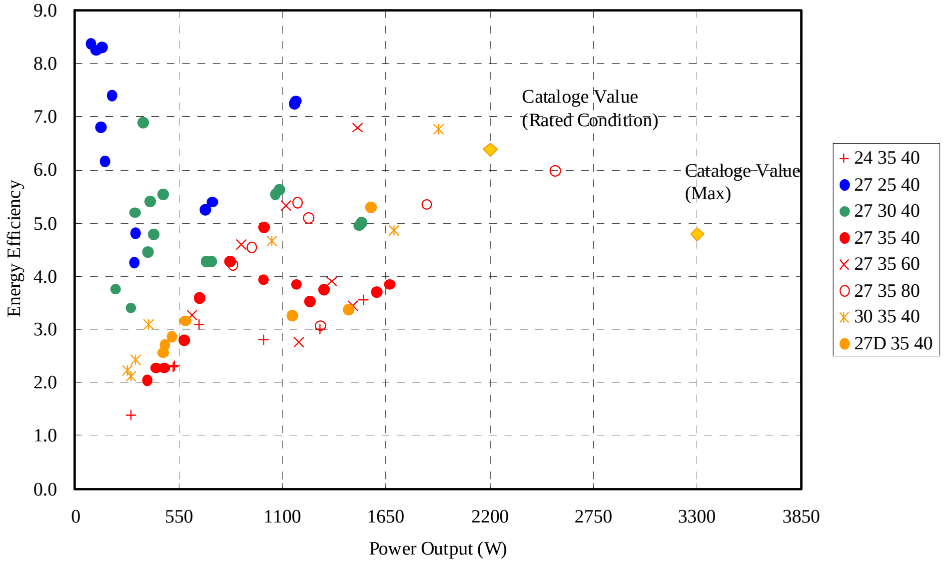



# Results (Heating)

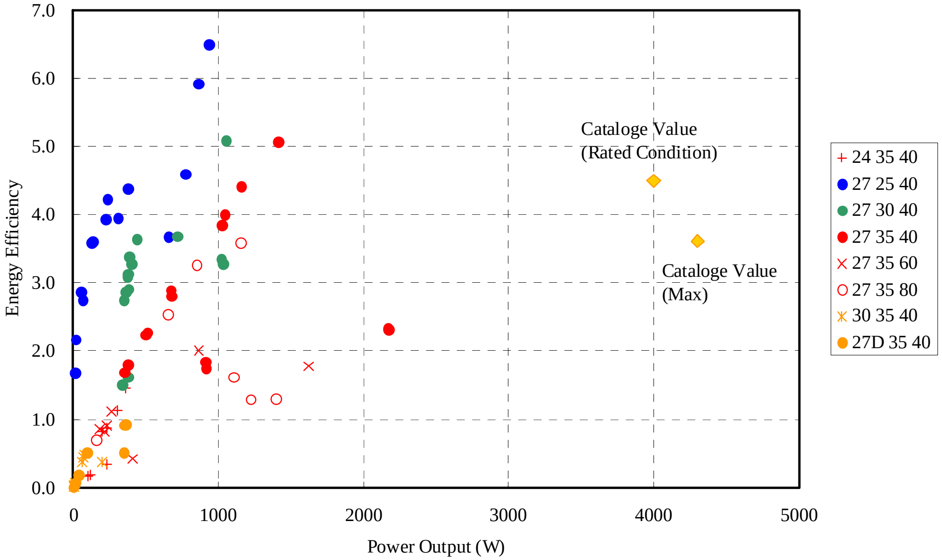


# Power Output vs. Energy Efficiency



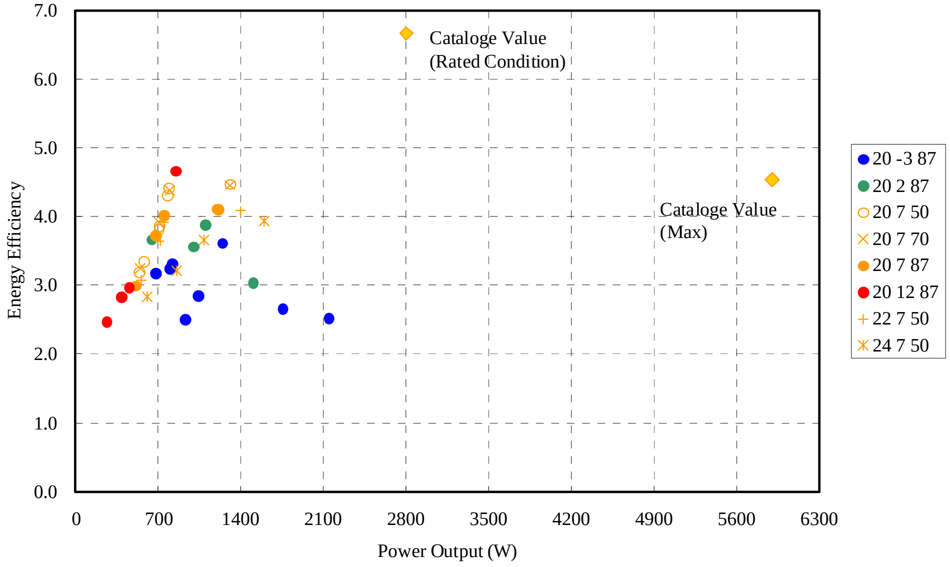

2.2kW



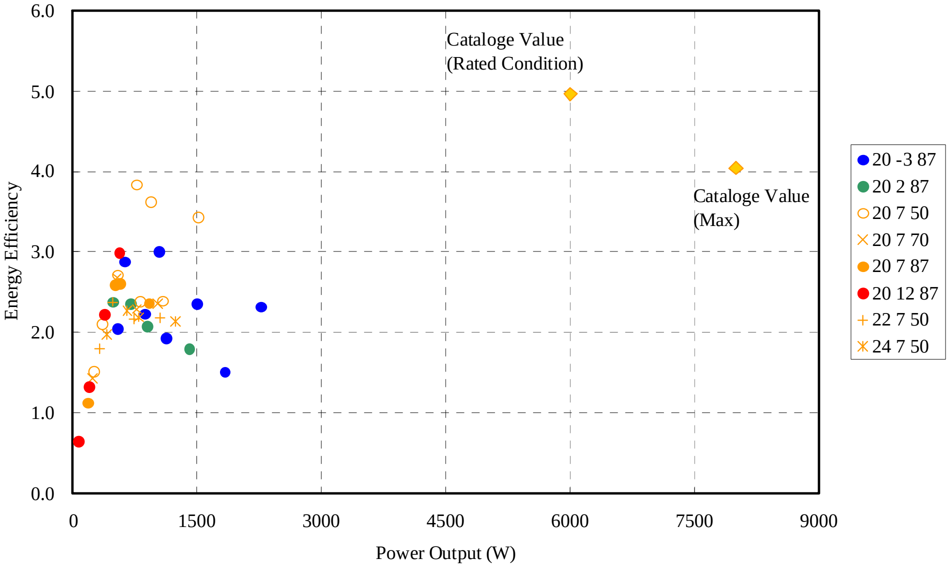

4.0kW

Cooling

# Power Output vs. Energy Efficiency



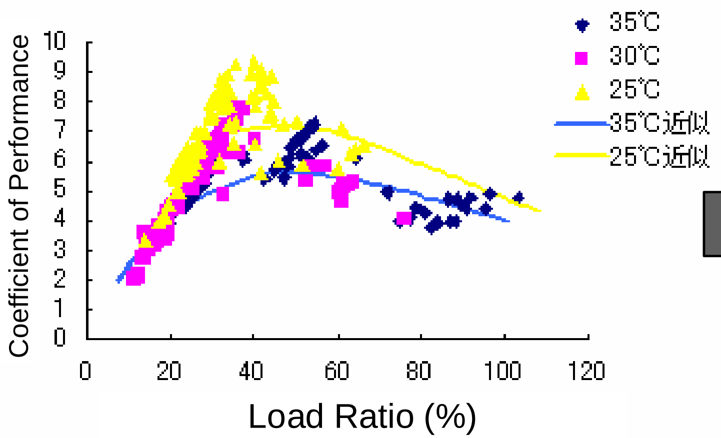

2.2kW



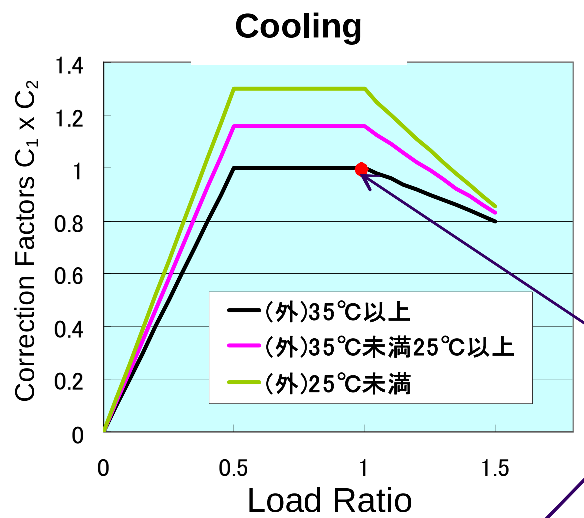

4.0kW

Heating

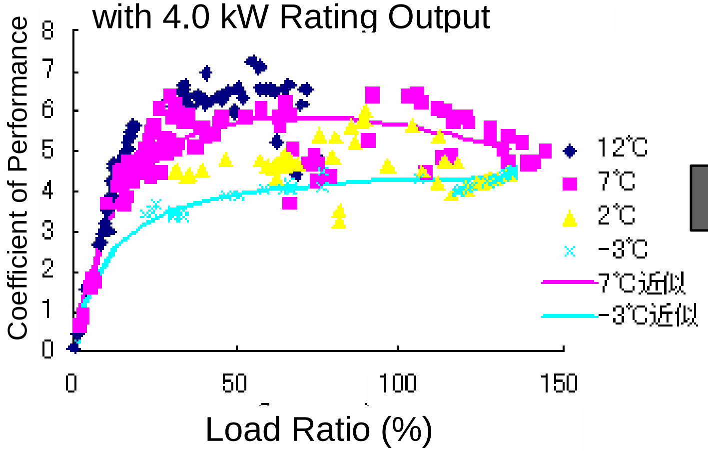
# ADDITIONAL TESTS (AN EXAMPLE FOR AIR-CONDITIONERS)



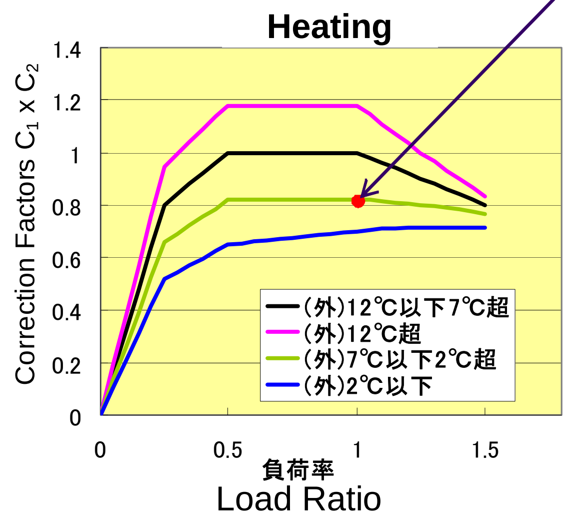

Cooling Mode by Air-Conditioner with 4.0 kW Rating Output



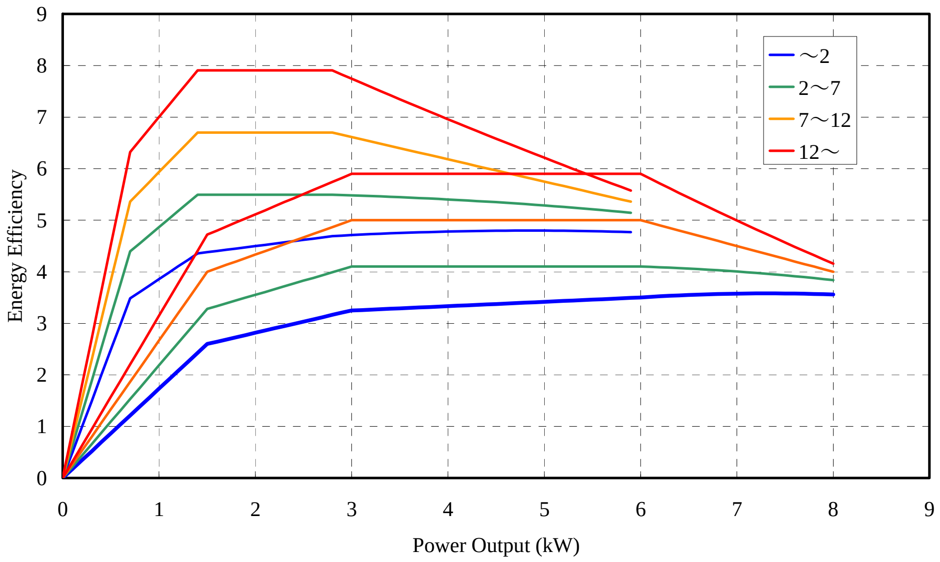

COP at rating output and condition for outdoor temperature

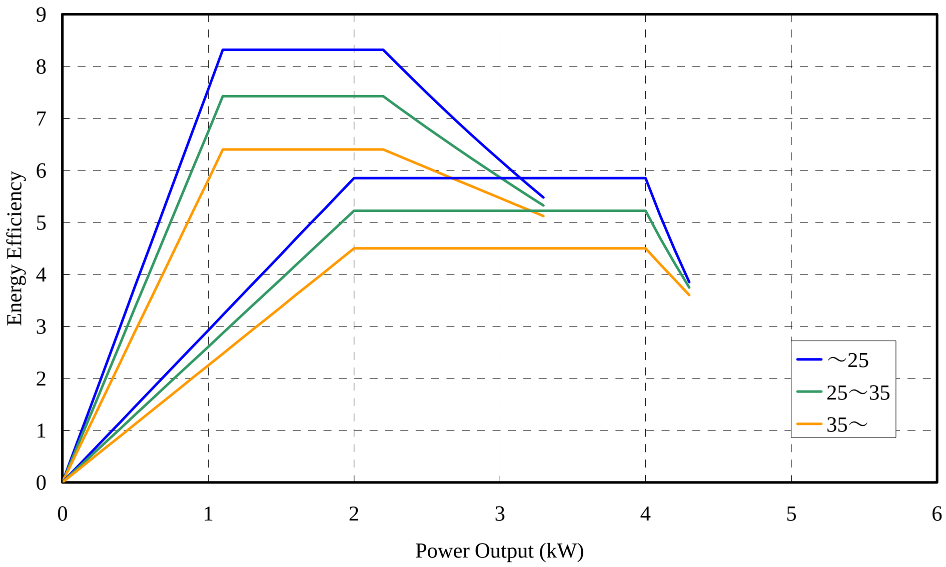



Heating Mode by Air-Conditioner with 4.0 kW Rating Output



# 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.**

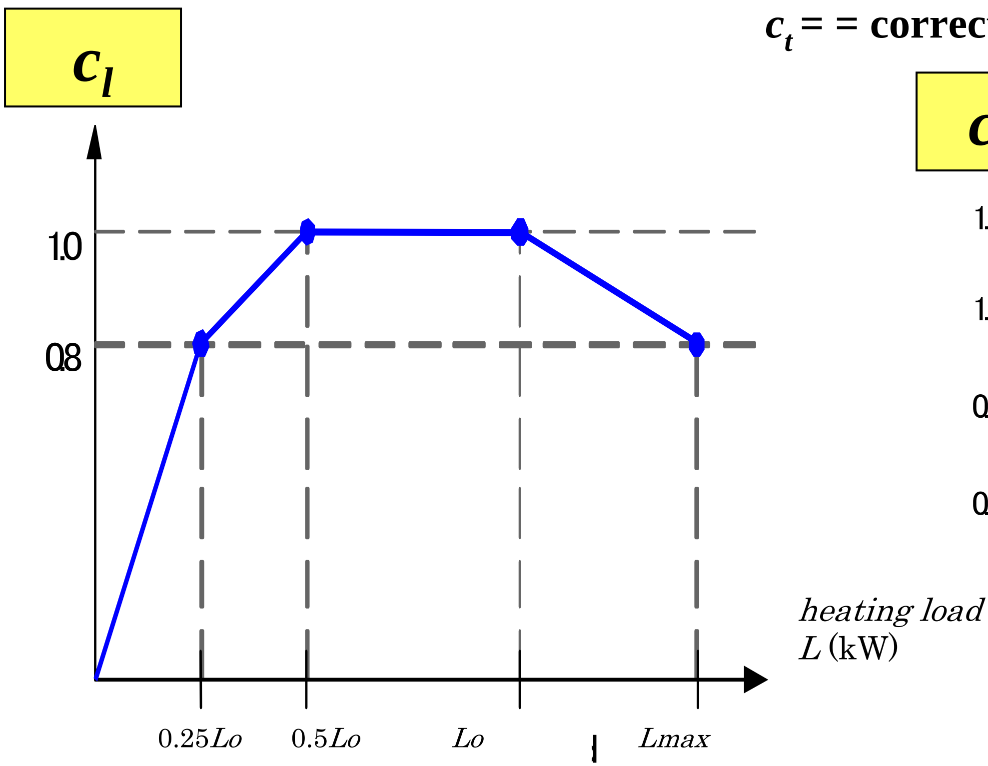



Fig.2 Formulation of $c_l$ (correction coefficient for load ratio)

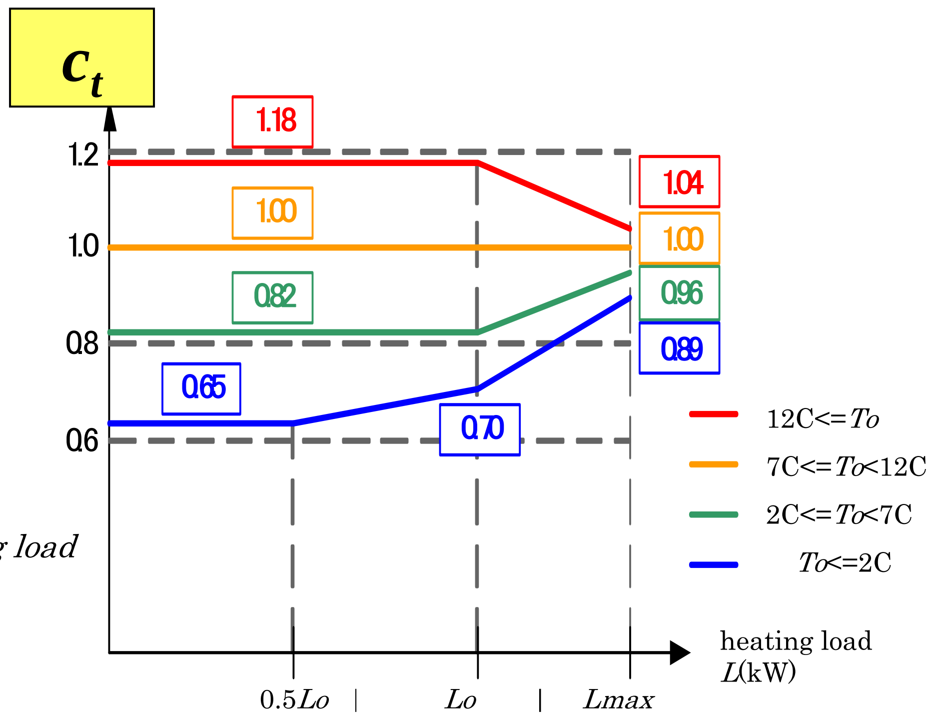


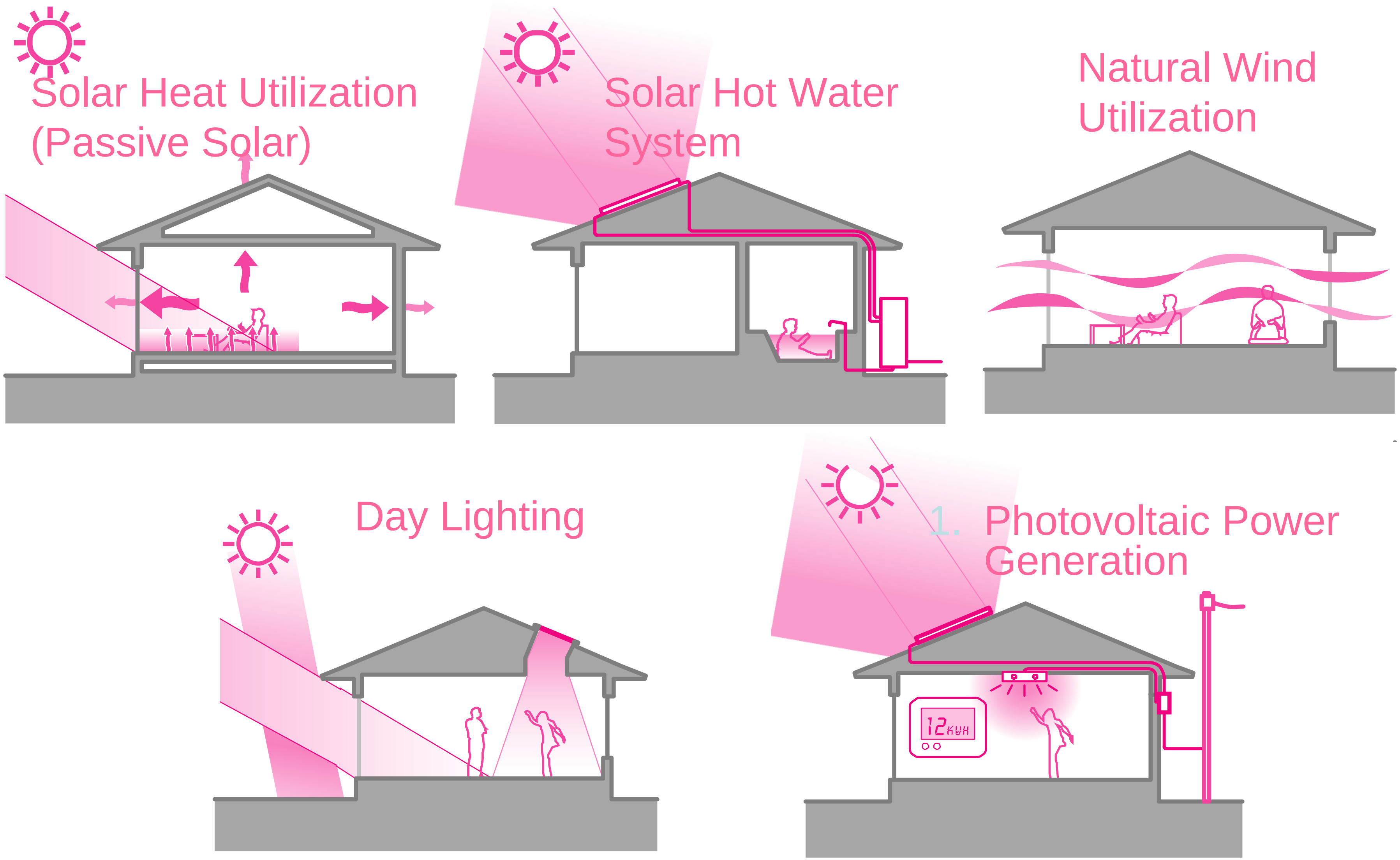

Fig.3 Formulation of $c_t$ (correction coefficient for outdoor temperature)

# Part II Background

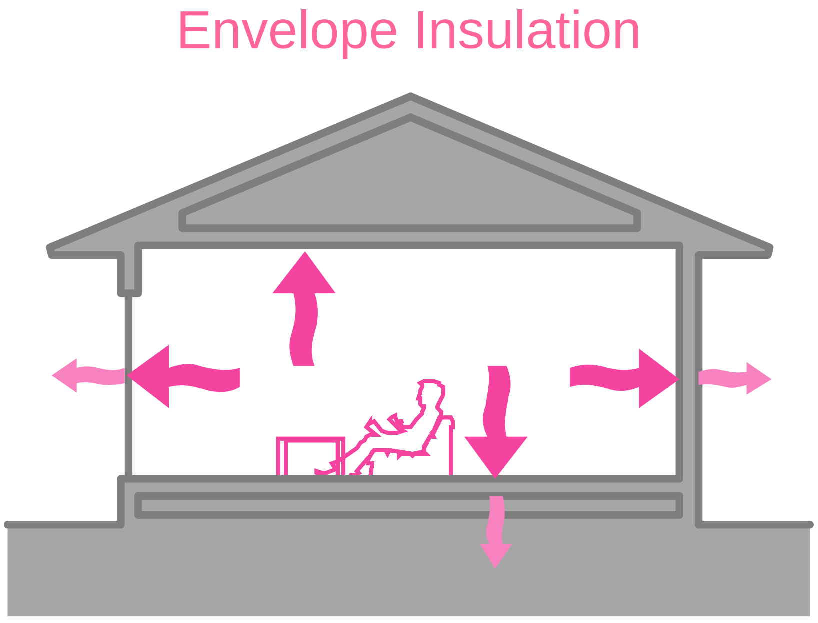
## TWELVE TECHNOLOGICAL ELEMENTS

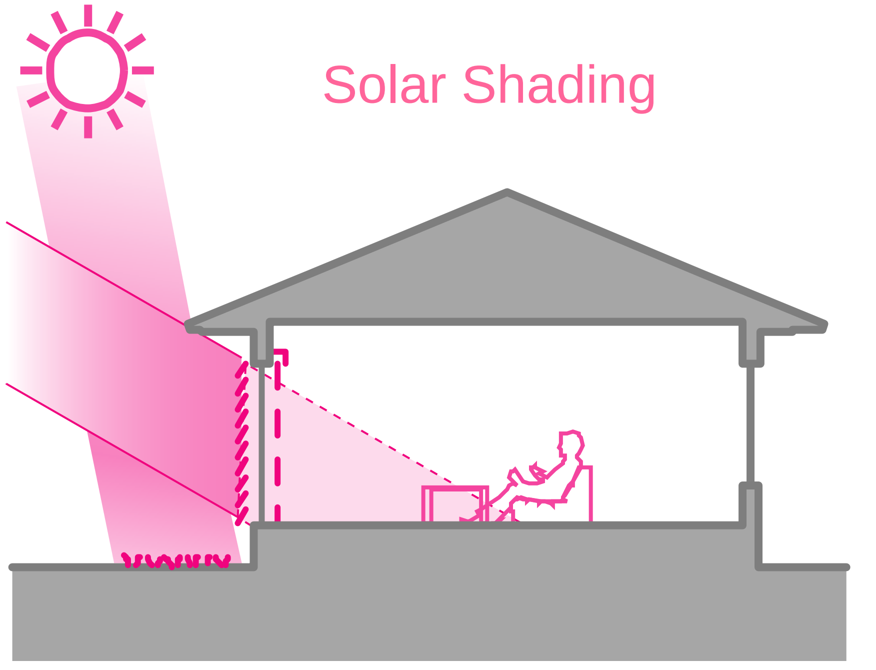
- Natural Energy Utilization
  1. Solar Heat Utilization (Passive Solar)
  2. Solar Hot Water System
  3. Natural Wind Utilization (Cross Ventilation)
  4. Day Lighting
  5. Photovoltaic Power Generation
- Heat Control through Envelope
  6. Envelope Insulation
  7. Solar Shading
- Energy Efficient Equipment
  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



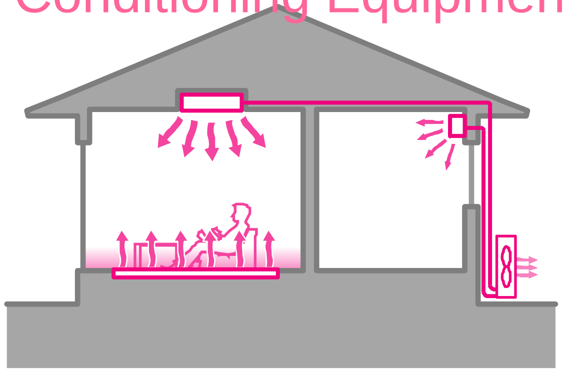
# Heat Control through Envelope



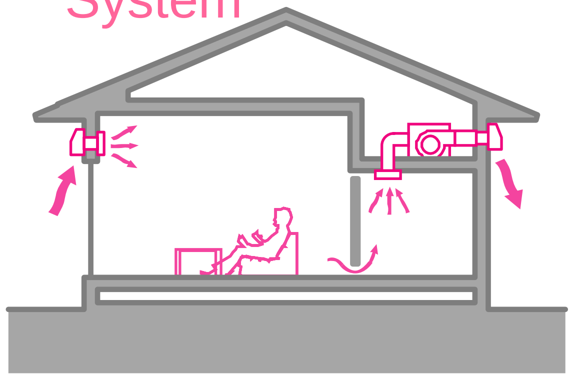



# Energy Efficient Equipment

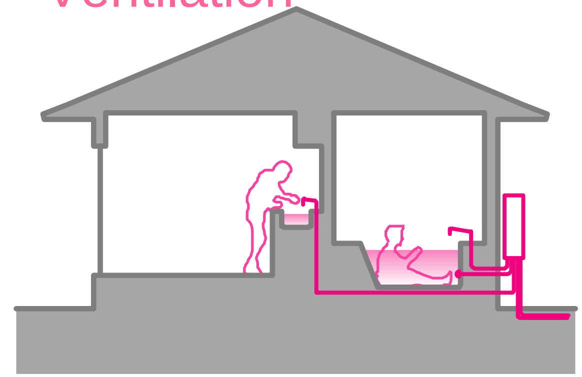
Heating and Air-Conditioning Equipment



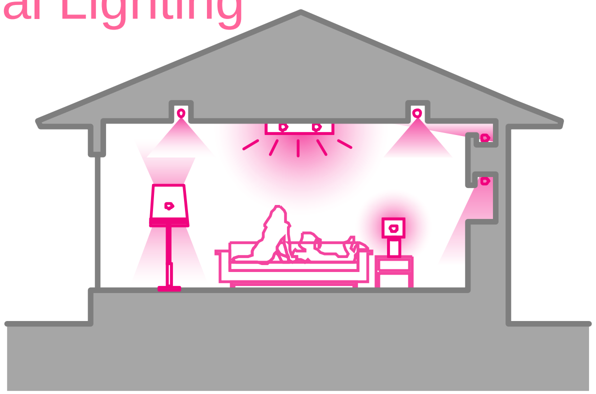
Domestic Hot Water System



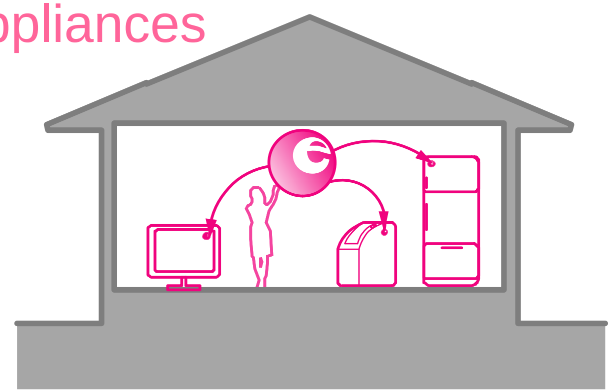
Energy Efficient Ventilation



Energy Efficient Artificial Lighting



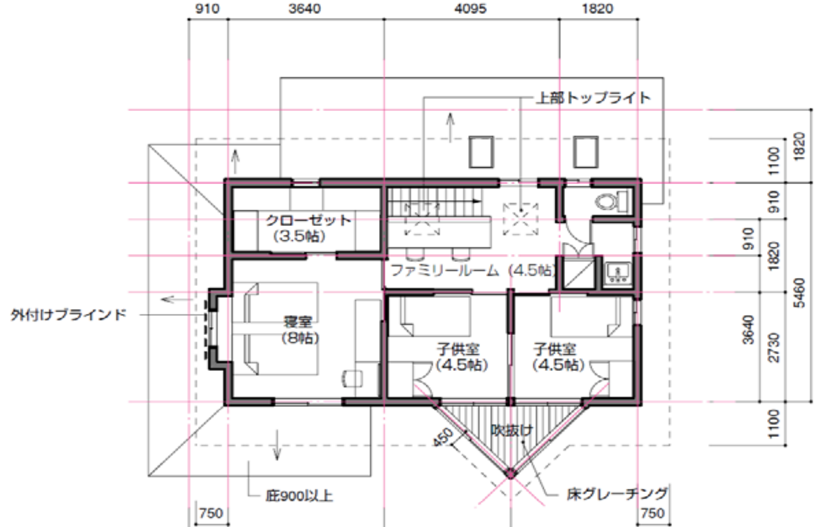
Home Electric Appliances



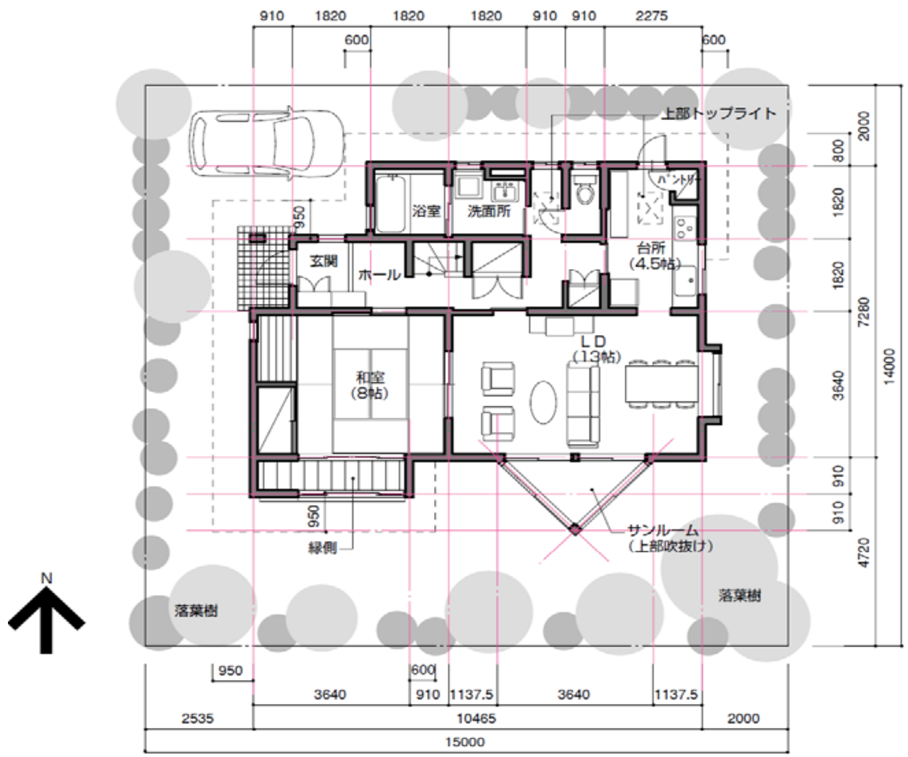
# ASSUMPTIONS FOR ENERGY USE ESTIMATION

- 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

# ASSUMPTION ON PLAN OF THE HOUSE



■2階平面図



■1階平面図

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 3-1or 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 ventilation, 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 | Orientation 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 coefficient | 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 | |

Technological 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±30°)

***air-conditioning equipment*** / Level 3

***energy efficient ventilation*** / Level 2 (duct diameter>=75mm, 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

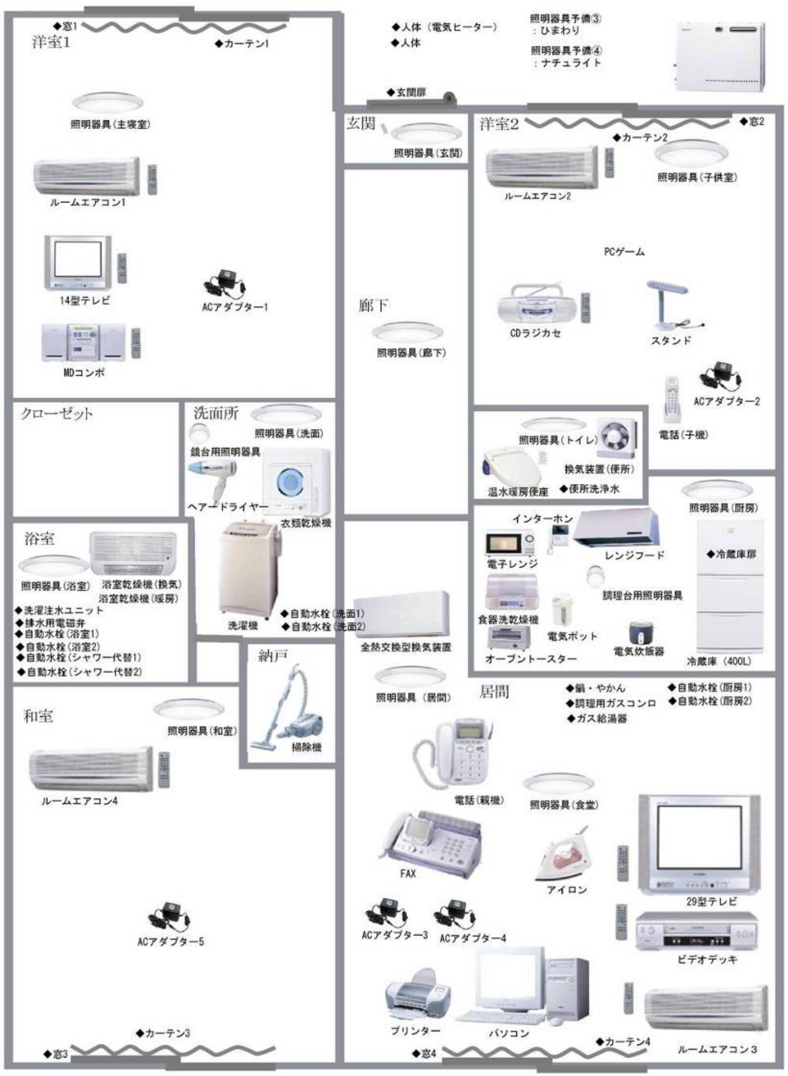
(Figures in [    ] are energy consumption ratios known from Table 4~9)

| Energy use | Calculation | Prediction (GJ) | Reference energy consumption (GJ: primary energy) | Reduction ratio (%) |
|---|---|---|---|---|
| Heating | 12.8 × ([0.55] × [0.9] × [0.6]) | 3.8GJ | 12.8GJ | -70% |
| Cooling | 2.4 × ([0.8] × [0.55] × [0.6]) | 0.6GJ | 2.4GJ | -75% |
| Ventilation | 4.7 × [0.6] | 2.8GJ | 4.7GJ | -40% |
| Domestic Hot Water | 24.5 × [0.5] | 12.3GJ | 24.5GJ | -50% |
| Lighting | 10.7 × ([0.95] × [0.6]) | 6.1GJ | 10.7GJ | -43% |
| Electric Appliances | 23.7× [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

# APPLIANCES SIMULATED THEIR USE

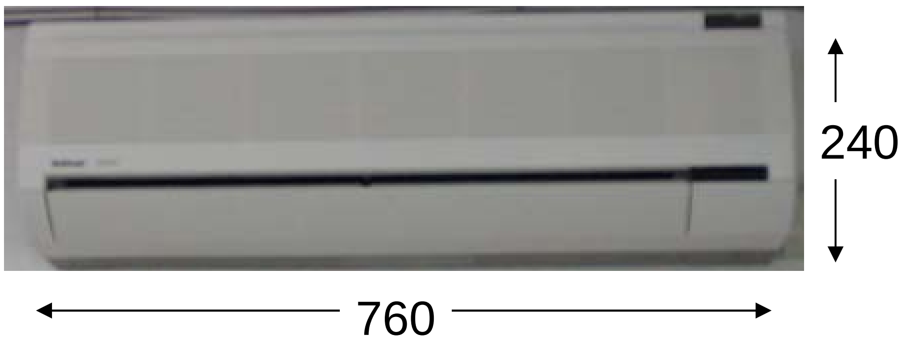


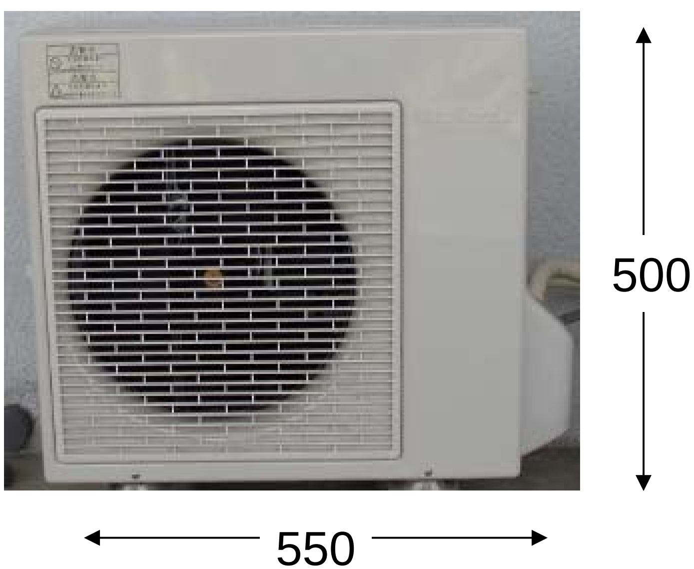

- Lighting
- Microwave
- Room air conditioner
- Range hood
- TV & Video recorder
- Mechanical Ventilation
- Floor heating
- Personal Computer
- Iron
- Refrigerator
- TV game
- Audio such as CD player
- Clothes washer
- Cleaner
- Shower Toilet seat with heater
- AC adapter
- Hot water supply system
  - Gas Boiler
  - $CO_2$ Heat pump
  - Solar collector
  - Fuel cell

# Heat Pump Air Conditioners (for Individual Rooms)

Standard dwelling for comparison
(Average COP: 2.75)

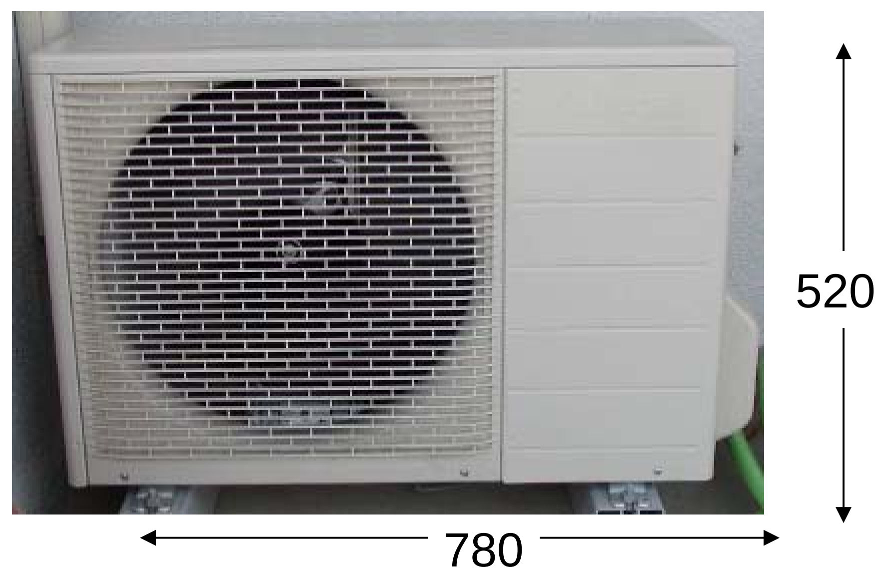
Refrigerant: R-22 (570 g)




Energy conserving dwelling
(Average COP: 6.00)

Refrigerant: R-410A (1100 g)

# Range Hoods (Cooker Hoods)

Energy conserving dwelling

(High efficiency motor; power consumption: 25 W)

Standard dwelling for comparison (Power consumption: 77 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

Energy conserving dwelling

(High efficiency inverter light fixtures) 22W

Standard dwelling for comparison

(Incandescent lights + inverter light fixtures)

100 W

# 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

$CO_2$ 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