In hot humid regions which are generally very hot in summer, a diversity of climatic and environmental conditions are found particularly between suburbs and cities, and between coastal and inland areas. The fundamental of LEHVE is to maximize and make the most efficient use of natural energy such as cool winds, daylight and winter sun at individual building sites.

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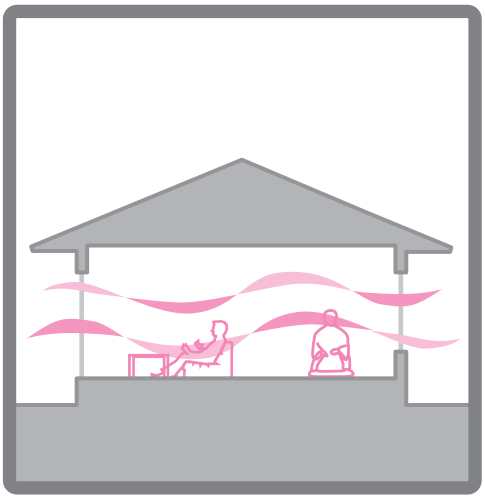
Chapter 3 : Natural Energy Application Technology

3

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

3.1 Use and Control of Wind



Wind utilization is a technology that aims to reduce cooling energy consumption and improve comfort, by actively introducing outdoor air into the building through cross ventilation when weather conditions are effective for improving thermal sensation such as during summer nights and in-between seasons. In order to effectively take in wind, it is necessary to skillfully integrate both methods for contriving building shapes and floor plan with methods for contriving window shapes and opening and closing operations of windows.

However, installing openings for wind utilization may lead to negative consequences in terms of security, noise and wind resistance. It is important to plan so that the security and comfort of the house will be maintained.

Furthermore, by combining methods for controlling internal heat generation through use of high-efficiency consumer electronics and methods for solar shading, we can achieve higher energy saving effects.

3.1.1 Purpose and Key Points of Wind Utilization

- **Wind utilization is a technology that aims to realize a pleasant indoor thermal environment and reduce cooling energy consumption without relying too much on air conditioning through active introduction of outdoor air into the building and heat exhaust to the outside during the summer (particularly nighttime) and in-between seasons.**
- **Possibility of wind utilization largely depends on the region in which the house is built and the surrounding environment of the house. For locations with open surroundings, the layout planning of openings based on the prevailing wind direction (wind direction which is peculiar to the region, season and time of day) is especially effective. On the other hand, as the surroundings become more crowded, the outside wind speed becomes lower due to the surrounding buildings, resulting in unstable wind direction. Landscaping such as trees and fences surrounding the house may also affect the wind flow around the house. In a highly dense residential area where it is difficult to position the openings based on the wind direction, it is effective to secure a large opening area, position openings that enable multiple cross ventilation routes and use high windows.**
- **An “entrance” and “exit” for the air is required in order to effectively introduce outside air into the building. Openings in the exterior walls in more than two different directions more effectively utilize wind. If openings in the exterior walls are only available in one direction, you can secure the “entrance” and “exit” of wind by installing openings in the exterior walls in the adjacent space via openings in the partition walls (e.g. transom windows and sliding doors).**
- **The use of landscaping ingenuity to block solar radiation, such as planting trees around the house, can keep down the temperature of wind introduced into the room. Such solar shading controls the reflected solar radiation and the heat radiation from the heated ground surface and inhibits the heat from entering through openings, etc.**
- **Wind utilization technology consists of methods for contriving building shapes and floor plans and landscaping planning, as well as methods for contriving the positions, shapes, and opening and closing operations of the openings.**
- **The prerequisite of this technology is that the occupants appropriately open the openings. That is why we also need to exercise ingenuity to encourage the opening and closing of the openings. For example, we must make security measures so that the occupants can feel safe to leave the openings open.**
- **It is necessary to use opening parts with high wind resistance in preparation for storms. Even if there is heavy wind, wind utilization may be still possible by controlling and adjusting the wind.**

3.1.2 Energy Conservation Target Levels for Wind Utilization

1. Definition of target levels

- Energy conservation target levels by wind utilization refer to the following levels 1 to 3. These levels indicate the reduction rates of energy consumed by cooling systems are indicated for Zones VI and V.
- The target levels provided for Zone VI are based on the reinforced concrete house and for Zone V are based on the wooden house.

			Zone VI	Zone V
Level − 1	:	Cooling energy increase rate	Approx. 4%	Approx. 6%
Level 0	:	Cooling energy reduction rate	None	None
Level 1	:	Cooling energy reduction rate	Approx. 4%	Approx. 5%
Level 2	:	Cooling energy reduction rate	Approx. 9%	Approx. 12%
Level 3	:	Cooling energy reduction rate	Approx. 12%	Approx. 18%

- **The typical cooling energy consumption in 2000 was 10.3 GJ (approximately 16% of total energy consumption) for Zone VI and 5.7 GJ (approximately 8% of total energy consumption) for Zone V (See Section 6.1 on p.339).**
- **Level –1 refers to the case of "not utilizing wind at all without opening windows" and Level 0 refers to the case of "occupants opening the windows only when they are at home without design ingenuity in wind utilization".**
- **The cooling energy reduction rate by wind utilization is set using the air change rate of the house that is obtained through wind utilization as an index. The above-mentioned energy reduction rates are the values obtained assuming a similar air change rate in each room. If the air change rate significantly varies between rooms, set the target level based on the air change rate of the living room and other major rooms (where cooling energy consumption is the largest). Meanwhile, Section 3.1.6 Calculation Method for Cooling Energy Reduction Rate by Room on p.064 explains a more accurate method for calculating the energy reduction rate which reflects the differences in the air change rates by room.**

2. Requirements for achieving target levels

1) Zone classification

- **As the cooling energy reduction rate by wind utilization differs between Zone VI and Zone V, it is necessary to confirm the applicable zone classification first.**
- **For the zone classification, check it in Appendix 1: Zone Classification Data on p.384.**

2) Weather conditions (outside wind direction and speed)

- **Weather conditions of the construction site, such as temperature, humidity, wind speed and direction, influence the possibility of wind utilization, but the outside wind direction and speed is particularly important. The outside wind direction and speed usually changes according to the season and time of day and have regional characteristics.**
- **The amount of cross ventilation allowed into the room is directly influenced by the outside wind speed. There is a tendency for the outside wind speed and the air change rate (i.e. amount of cross ventilation) to be proportional with one another.**
- **For building sites with open surroundings, the outside wind direction is of particular importance as the installation of openings in the prevailing wind direction secures an airflow rate. Even in a highly dense residential area, the effectiveness of cross ventilation varies depending on the position of high windows in the outside wind direction if high windows (e.g. top side windows) are used as the cross ventilation route.**

Key Point

Outside wind speed in hot humid regions

- **The table below shows the average outside wind speed of four representative cities in Zones VI and V in the summer for waking hours, sleeping hours and the entire day.**
- **The outside wind speed varies according to the height from the ground. The wind speed shown in the table has been converted to the value at 6.5 m above the ground (equivalent to the eaves height of a two-storied house).**

Table: Average outside wind speed in major cities
(June – September)
Waking hours: 7:00 – 22:00
Sleeping hours: 23:00 – 6:00

City	Average outside wind speed [m/s]		
	Waking hours	Sleeping hours	Entire day
Naha	3.5	2.8	3.3
Kagoshima	2.2	1.6	2.0
Miyazaki	2.5	1.6	2.2
Kochi	1.6	1.1	1.5

* The average outside wind speed includes the wind speed of typhoons, but their influence on the average value is considered minor.
* Created based on the expanded AMeDAS weather data (for 20 years) from Expanded AMeDAS Weather Data 1981 – 2000 issued by the Architectural Institute of Japan (published in 2005).

Key Point

Outside wind direction in hot humid regions

- The table below shows the trend of outside wind direction of four representative cities in Zones VI and V during the summer. The frequency of becoming windward and leeward is shown by direction of the exterior wall (16 directions) and by time of day (waking hours and sleeping hours).
- The trends of these cities is shown below:
  - a. Naha: Openings facing east to south have a high frequency of becoming windward both night and day.
  - b. Kagoshima: As the prevailing wind direction is unclear during waking hours, the direction of the openings is hardly influential. During the sleeping hours, openings facing west-northwest to north to northeast become windward.
  - c. Miyazaki: Both the east and west sides may become windward during waking hours. The west to north side becomes windward during sleeping hours.
  - d. Kochi: The exterior wall facing east to south often becomes windward during waking hours. The direction of southwest to north-northwest dominates the windward side during sleeping hours.
- It is considered effective to place a room in which occupants spend time during the day (e.g. living room) in the direction which frequently becomes windward during waking hours and locate a bedroom in the direction which frequently becomes windward during sleeping hours.
- The weather station is usually built in an area with open surroundings representative of the region. However, if the topography around the building site is peculiar, the wind direction does not necessary correspond to that of the nearest weather station. If this is the case, it is necessary to gather closer observational data or check the wind direction on the site.

Table: Frequency of becoming windward and leeward by direction in major cities (June – September)

a. Naha

Direction of exterior wall		North	North-northeast	Northeast	East-northeast	East	East-southeast	Southeast	South-southeast	South	South-southwest	Southwest	West-southwest	West	West-northwest	Northwest	North-northwest
Windward	Waking hours	×	△	△	○	○	◎	◎	◎	◎	○	○	○	△	×	×	×
	Sleeping hours	×	△	△	○	◎	◎	◎	◎	◎	○	○	△	×	×	×	×
Leeward	Waking hours	◎	○	○	○	△	×	×	×	×	△	△	○	○	◎	◎	◎
	Sleeping hours	◎	○	○	△	×	×	×	×	×	△	△	○	◎	◎	◎	◎

b. Kagoshima

Direction of exterior wall		North	North-northeast	Northeast	East-northeast	East	East-southeast	Southeast	South-southeast	South	South-southwest	Southwest	West-southwest	West	West-northwest	Northwest	North-northwest
Windward	Waking hours	△	△	△	△	○	○	○	○	○	△	△	○	○	○	○	△
	Sleeping hours	◎	◎	○	△	△	×	×	×	×	×	×	△	○	◎	◎	◎
Leeward	Waking hours	○	△	△	○	○	○	○	△	△	△	△	△	○	○	○	○
	Sleeping hours	×	×	×	△	○	◎	◎	◎	◎	◎	○	△	△	×	×	×

c. Miyazaki

Direction of exterior wall		North	North-northeast	Northeast	East-northeast	East	East-southeast	Southeast	South-southeast	South	South-southwest	Southwest	West-southwest	West	West-northwest	Northwest	North-northwest
Windward	Waking hours	△	△	○	◎	◎	○	○	△	×	△	△	○	○	○	△	△
	Sleeping hours	○	×	×	×	×	×	×	×	×	×	△	◎	◎	◎	◎	◎
Leeward	Waking hours	×	△	△	○	○	○	△	△	△	△	○	◎	◎	○	○	△
	Sleeping hours	×	×	△	◎	◎	◎	◎	◎	○	×	×	×	×	×	×	×

d. Kochi

Direction of exterior wall		North	North-northeast	Northeast	East-northeast	East	East-southeast	Southeast	South-southeast	South	South-southwest	Southwest	West-southwest	West	West-northwest	Northwest	North-northwest
Windward	Waking hours	×	×	△	△	○	◎	◎	◎	○	△	△	△	△	△	△	×
	Sleeping hours	×	×	×	×	×	×	×	×	×	×	○	◎	◎	◎	◎	○
Leeward	Waking hours	○	△	△	△	△	△	△	×	×	×	△	△	○	◎	◎	◎
	Sleeping hours	×	×	○	◎	◎	◎	◎	○	×	×	×	×	×	×	×	×

Key: Frequency of the exterior wall direction to become windward and leeward; ◎: Over 40%, ○: 30 - 40%, △: 20 - 30%, ×: under 20%
* Created based on the expanded AMeDAS weather data (for 20 years) from *Expanded AMeDAS Weather Data 1981 – 2000* issued by the Architectural Institute of Japan (published in 2005).

3

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

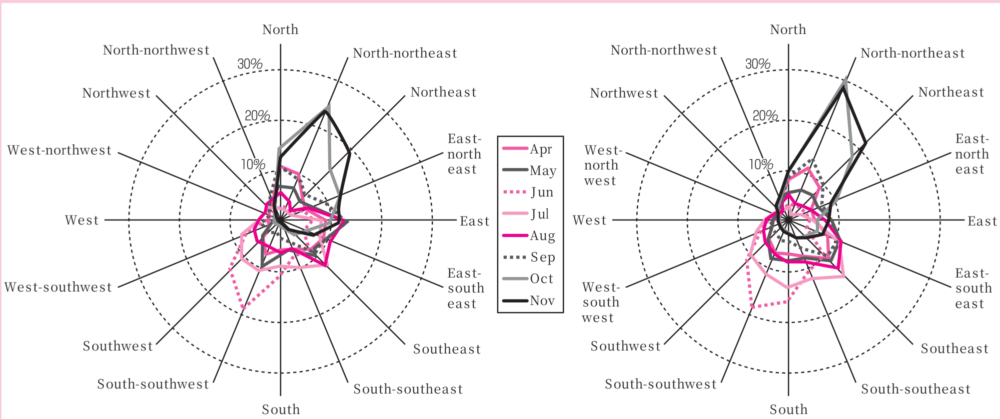
Glossary: Weather data
Weather data can be checked using the Chronological Scientific Tables (National Astronomical Observatory of Japan, Ministry of Education, Culture, Sports, Science and Technology) and the Japan Meteorological Agency's website (http://www.jma.go.jp).

Comment ● Publication of weather data

You can refer to the LEHVE's website (http://www.jjj-design.org) for the weather data information (for 842 locations in Japan) that has been compiled for studying wind utilization methods. In addition to the tables shown above for these locations (average outside wind speed, frequency of becoming windward and leeward by direction), the website also provides tables showing temperature, relative humidity, wind speed, and wind direction (wind rose). Take the following into consideration when using this information:

- The weather data is available in pdf format.
- The weather data is created based on the expanded AMeDAS weather data (for 20 years) from Expanded AMeDAS Weather Data 1981 – 2000 issued by the Architectural Institute of Japan (published in 2005, http://www.metds.co.jp/). For how to use the data and the data creation methods employed , check "How to use this data" and "Data creation method" Sections in the PDF file.
- Permission has been obtained from the Research Committee on Environment Engineering of the Architectural Institute of Japan and Meteorological Data System Co., Ltd to publish the weather data on the above-mentioned website only. Please refrain from reproducing this information or employing it for uses other than the design methods described in this document.

Fig. Data available on the website (part of Naha)



Wind rose on monthly basis(Waking hours) Wind rose on monthly basis(Sleeping hours)

Monthly weather data table

		April		May		June		July		August		September		October		November	
		Waking hours	Sleeping hours	Waking hours	Sleeping hours	Waking hours	Sleeping hours	Waking hours	Sleeping hours	Waking hours	Sleeping hours	Waking hours	Sleeping hours	Waking hours	Sleeping hours	Waking hours	Sleeping hours
Average temperature (°C)		21.9	20.3	24.5	22.7	27.3	25.6	29.4	27.5	29.1	27.3	28.0	26.3	25.6	23.9	22.4	21.0
Average relative humidity (%)		75	81	77	84	81	89	76	85	77	85	74	81	70	77	67	73
Average wind speed (m/s)		3.4	2.8	3.4	2.7	3.7	3.0	3.4	2.7	3.6	3.0	3.4	2.7	3.5	2.8	3.6	3.1
Wind direction	First direction	North 11%	Southeast 12%	East 13%	East-southeast 12%	South-southwest 20%	South-southwest 18%	Southeast 13%	Southeast 16%	Southeast 12%	Southeast 15%	East 13%	North-northeast 14%	North-northeast 25%	North-northeast 31%	North-northeast 24%	North-northeast 29%
	Second direction	North-northeast 10%	North-northeast 12%	East-southeast 10%	Southeast 12%	Southwest 15%	South 16%	Southwest 11%	South 13%	East 12%	East-southeast 13%	North 11%	East-southeast 12%	North 14%	Northeast 19%	Northeast 19%	Northeast 23%
	Third direction	East-southeast 10%	Northeast 11%	South-southwest 9%	East 10%	South 11%	South-southeast 11%	South-southwest 11%	South-southeast 12%	East-southeast 11%	East 8%	Southeast 10%	Northeast 11%	Northeast 14%	East-northeast 11%	North 13%	East-northeast 10%

- The wind rose in the upper figure shows the frequency of becoming windward by wind direction and allows you to see which direction the wind comes from on a monthly basis by waking and sleeping hours. The lower table shows the monthly data on temperature, relative humidity, wind speed, and wind direction by waking and sleeping hours.

3) Site conditions (building density around the site))

- **The possibility of wind utilization significantly depends on how crowded the area surrounding the construction site is.**
- **For a location that has open surroundings, such as a suburb, it is easy to maintain the wind pressure difference (driving force of cross ventilation) that acts on the building, which is effective for wind utilization. On the other hand, for a highly dense residential area in the city, it is difficult to utilize wind as the outside wind speed declines due to the surrounding buildings, which causes the wind pressure difference to decrease.**

・Generally, how the wind pressure acts on the building is evaluated by the wind pressure coefficient. In this section, we classify the site conditions (building density around the site) into the following two categories according to the differences in the wind pressure coefficient characteristics.

Location 1: Urban location (building coverage ratio of adjacent area = over 20%)
Location 2: Suburban location (building coverage ratio of adjacent area = 20% or below)

・An average residential area is classified as Location 1. Location 2 is supposed to be a suburban location with 20% or below of the building coverage ratio of adjacent area (ratio of total building area of the buildings in the adjacent area (surroundings) to the relevant adjacent area (dimensions)) within a 50 m diameter surrounding the planned building. For definition and calculation of the building coverage ratio of adjacent area, see the Key Point on the next page.

Key Point

Characteristics of wind pressure coefficient

- Since the wind pressure coefficient varies significantly depending on the shapes and surrounding conditions of the house, accurate estimation is difficult, particularly in dense residential areas.
- If the building density around the site is low (in the case of Location 2), the wind pressure coefficient varies significantly depending on the direction of the building in relation to the wind direction. If the wall is facing perpendicular to the wind direction, the surface which the wind hits generates a positive pressure and the remaining surfaces generates a negative pressure (Fig. a). Since the ease of maintaining cross ventilation depends on the wind pressure coefficient difference, it is not always necessary to install two openings in opposite walls in the case of Fig. a.
- If there is a wall tilting the building is at an angle of 45° to the wind direction, the two surfaces walls which the wind hits generate a positive pressure and the remaining surfaces generate a negative pressure (Fig. b). In the case of Fig. b, although the wind pressure on the windward side decreases by nearly 60 – 70% of Fig. a, it is easy to install effective openings for cross ventilation because the wind pressure coefficient difference between the windward and leeward side is not significantly different from that of Fig. a.
- In the case of a residential area with high building density (i.e. Location 1), the influence of the outside wind is small and the wind pressure coefficient decreases. The airflow around the building becomes complex and the wind pressure on the wall at the downstream end may become positive. The wind pressure coefficient difference obtained is approximately 0.05 – 0.1.
- The wind pressure coefficient is also influenced by trees, fences and other landscaping. Even if the site has a low building density (in the case of Location 2), the wind pressure coefficient difference obtained is usually small if there are dense trees on the windward side that block the wind.

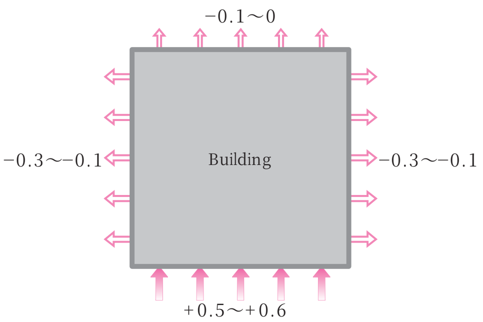


Fig. a Wind pressure coefficient on the wall perpendicular to the prevailing wind direction (in the case of low surrounding density)

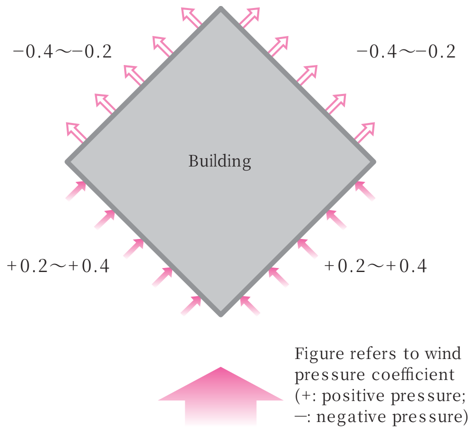


Fig. b Wind pressure coefficient on the wall tiltinga building at an angle of 45° to the prevailing wind direction
(in the case of low surrounding density)

Glossary: Wind pressure coefficient
Wind pressure coefficient refers to the ratio of the pressure that acts on the building surface to the wind's own pressure (dynamic pressure). It is used for estimation of the wind pressure (driving force of cross ventilation) that acts on the building. For example, a wind pressure coefficient of 0.5 means that a half of the pressure acts as a pressure that pushes the building surface.
Generally, the wind pressure is positive on the windward side and negative on the leeward side. Cross ventilation can be easily achieved by installing two openings at locations where there is a major difference in the positive and negative pressures (wind pressure coefficient difference).

3

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

Key Point

What is building coverage ratio of adjacent area?

・The “building coverage ratio of adjacent area” is an indicator that has been defined in this document to judge the density around the site which is related to the possibility of wind utilization. It has been modified and adapted from the “building coverage ratio” used in the Building Standard Law of Japan. While the building coverage ratio stipulated in the Building Standard Law refers to the “ratio of the building area of the building to the site area”, the building coverage ratio of adjacent area refers to the “ratio of the total building area of the buildings in a certain adjacent area (surroundings) to the relevant adjacent area (dimensions)” in the surrounding area of the construction site that is assumed to influence the wind pressure which acts on the building . The adjacent area (dimensions) includes an area of roads, parks, waterways and elements outside the site at which the building is constructed, and the building area includes surrounding buildings in addition to the building area of the planned building. Considering the influences on the possibility of wind utilization, this design method defines an area 50 m in diameter surrounding the planned building as the area to be calculated as the relevant adjacent area (dimensions).

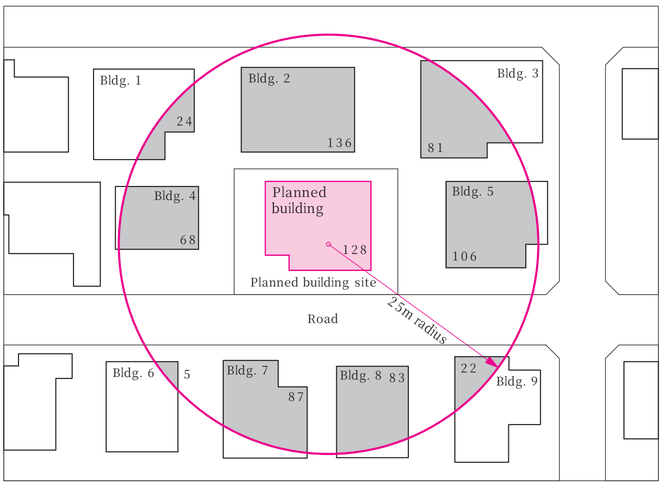
・The following shows how to obtain the “building coverage ratio of adjacent area”:

(1) Draw a circle with 50 m diameter (25 m radius) around the construction site on the residential map according to the reduced scale.

(2) Make a rough estimate of the building area from the outlines of buildings that exist inside the circle drawn in (1) and calculate the total value (For buildings that are partially within this circle, only the portion within the circle is included).

(3) Add the building area (assumed value can be used) of the planned building to the value obtained in (2). This value is regarded as the building area of the buildings in the adjacent area (surroundings) for obtaining the “building coverage ratio of adjacent area.

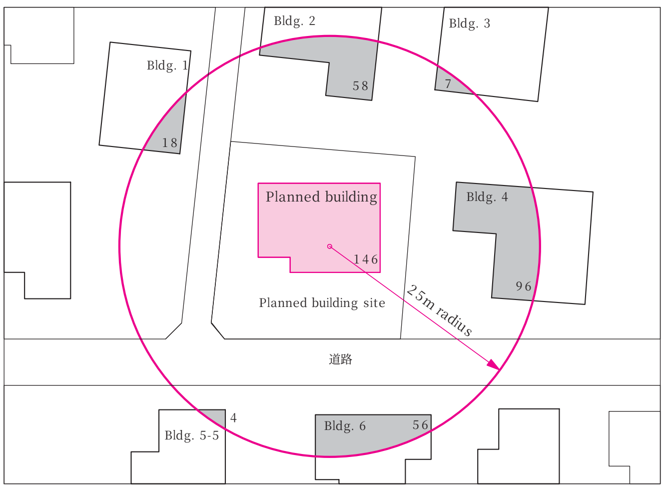
(4) Determine the ratio of the area obtained in (3) to the adjacent area (dimensions) (1963.5 m2). This value is the “building coverage ratio of adjacent area”.



* Figures in the diagram refer to the area (m²) to be calculated for buildings in the adjacent area (surroundings).

Building area of buildings in adjacent area (surroundings)
= building area of Bldgs. 1 to 9 + building area of planned building
= (24+136+81+68+106+5+87+83+22) + 128
= 740 m²
Adjacent area (dimensions) = 1963.5 m²
Building coverage ratio of adjacent area
= building area of buildings in adjacent area (surroundings) / adjacent area (dimensions)
= 740 / 1963.50
= 0.3769
= 37.7% > 20% (therefore, Location 1)

Fig. a Example of residential area in urban location (Location 1)



* Figures in the diagram refer to the area (m²) to be calculated for buildings in the adjacent area (surroundings).

Building area of buildings in adjacent area (surroundings)
= building area of Bldgs.-1 to -6 + building area of planned building
= (18+58+7+96+4+56) + 146
= 385 m²
Adjacent area (dimensions) = 1963.5 m²
Building coverage ratio of adjacent area
= building area of buildings in adjacent area (surroundings) / adjacent area (dimensions)
= 385 / 1963.50
= 0.1961
= 19.6% ≦ 20% (therefore, Location 2)

Fig. b Example of residential area in suburban location (Location 2)

Fig. Calculation example of building coverage ratio of adjacent area in a residential area

4) Lifestyle orientation of occupants and use of rooms

Cooling energy consumption varies depending on how the occupants like to utilize wind and cooling systems. The different uses of wind and cooling systems according to the use of rooms in the house also affect cooling energy consumption.

For that reason, it is desirable to confirm and examine the use of wind and cooling systems in the rooms that are used mainly during the day (e.g. living and dining rooms) and the rooms that are used mainly at night (e.g. master bedrooms and children's rooms). This enables one to estimate the air change rate and examine the cooling energy consumption (See Section 3.1.6 on p.064).

5) Wind utilization method

- **The following is a list of wind utilization methods discussed in this document, which are expected to provide energy saving effects:**

Method 1: Securing opening area on cross ventilation route	1a: Combination of small opening areas
	1b: Combination of large opening areas
Method 2: Opening layout according to prevailing wind direction	
Method 3: Use of high windows	3a: Combination of small opening areas
	3b: Combination of large opening areas

- **For wind utilization, it is necessary to install a combination of openings which serve as the "entrance" and the "exit". Methods 1 and 3 are designed to examine the opening area of the room into which wind is introduced and are classified into a and b according to the size of the opening area.**
- **Method 2 increases the effect of wind utilization by taking full advantage of the prevailing wind direction, and is only applicable to Location 2 (suburban location).**
- **Section 3.1.4 Wind Utilization Methods explains the details of each method.**

Comment ● Night ventilation and cold storage

The fundamental idea of passive solar heating is to introduce the solar radiation heat during a winter day into the house and store heat so that a heating effect can be obtained throughout the night. The area used for heat storage is an interior component with a large heat capacity and is called a heat storage component. Conversely, in summer, a large amount of ventilation is performed during the night when the temperature is low to cool down the building so that a cooling effect can be obtained during the hot daytime hours the next day. In Japan, probably because of the traditional prevalence of wooden houses with small heat capacity, cross ventilation is the most well known method for achieving a cooling sensation using wind. Cross ventilation can also provide an intentional cold storage effect and this effect is larger in regions with greater daily temperature range .

How about in the hot and humid regions? Generally, it is believed to be difficult to obtain cold storage effects in the hot humid regions as the daily temperature range is smaller, and even if it is possible, condensation on the surface of the heat storage component is a concern. However, this does not mean there is no cold storage effect and we can prevent condensation damage by using appropriate materials or taking preventive measures for the surface of the heat storage component. In fact, we can experience the cold storage effect in brick buildings in South East Asia and cold storage is well established in these buildings as they do not cause condensation damage.

In Okinawa, the number of concrete houses has rapidly increased after World War II. Can we obtain a cooling effect by utilizing its heat capacity? To achieve this, we must fully shade the concrete building envelope so that it does not receive solar radiation. There are an increasing number of cases in which night ventilation and cold storage are intentionally combined in the design and it will not be long before this becomes an established design method for the LEHVE in the hot humid regions.

3

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

3. How to achieve target levels

- **The energy conservation target levels for wind utilization are set using the air change rate of the house that is obtained through wind utilization as an index. The corresponding relationship between the target levels and the air change rate is as shown in Table 1.**

Table 1 Corresponding relationship between the target levels of wind utilization and the air change rate

Target level	Energy saving effect (Cooling energy reduction rate)		Air change rate of house
	Zone VI	Zone V	
Level −1	Approx. 4% increase	Approx. 6% increase	0 ACH
Level 0	No reduction	No reduction	At least 2 ACH
Level 1	Approx. 4%	Approx. 5%	At least 5 ACH
Level 2	Approx. 9%	Approx. 12%	At least 10 ACH
Level 3	Approx. 12%	Approx. 18%	At least 20 ACH

Glossary: Air change rate
A value that expresses the number of times the indoor air is exchanged with the outdoor air per hour. This value is calculated by the amount of ventilation (amount of cross ventilation) divided by the volume of the room, and the units are measured in air changes per hour (ACH). (h)

- **The air change rate of a house is generally determined by the wind utilization methods adopted and outside wind speed. The air change rate changes according to the site conditions even under the same method and outside wind speed. Table 2 shows the air change rate obtained from a combination of different methods and outside wind speeds.**
- **For the outside wind speed, search the weather data of the construction site (or its vicinity) on the website (See Comment on p.044) and obtain the full-day mean wind speed (at 6.5 m from the ground). In the case of estimating the air change rate by room according to Section 3.1.6 Calculation Method for Cooling Energy Reduction Rate by Room on p.064, see the mean outside wind speed during the time of day when the room is mainly used (waking or sleeping hours). When checking the air change rate, as shown in Table 2, the outside wind speed should be studied in three phases; below 1 m/s, 1 – 1.9 m/s, and 2 m/s or above.**

Table 2 Air change rate obtained in the combination of wind utilization methods and outside wind speed
(1) Location 1

Method	Outside wind speed		
	Below 1 m/s	1 – 1.9 m/s	2 m/s or above
Method 1a or 3a	2 ACH	5 ACH	8 ACH
Method 1b or 3b	3 ACH	10 ACH	17 ACH

(2) Location 2

Method	Outside wind speed		
	Below 1 m/s	1 – 1.9 m/s	2 m/s or above
Method 1a or 3a	3 ACH	10 ACH	17 ACH
Method 1a + 2 or Method 3a + 2 or 3b	5 ACH	15 ACH	25 ACH
Method 1b or 3b	7 ACH	20 ACH	33 ACH
Method 1b + 2 or Method 3b + 2	10 ACH	30 ACH	50 ACH

* Calculation of air change rate was performed based on a room with the ceiling height of 2.4 m.

Glossary: Difference between ventilation and cross ventilation
Ventilation and cross ventilation are the same in terms of introducing outdoor air into the room, but are clearly different in the amount of air introduced (air change rate). The aim of ventilation is to improve the indoor air environment and exchange the air at the rate of 0.5 ACH throughout the year. In the meantime, cross ventilation exchanges the air at the late of at least 2 ACH and aims to contain room temperature increases and reduce cooling consumption energy. Section 5.3 Ventilation System Planning explains ventilation.

- **In the case of Location 1 with an outside wind speed of below 1 m/s or Location 2 with an outside wind speed of below 1 m/s adopting Method 1a or 3a (combination of small opening areas), the expected air change rate is small and cooling energy reduction cannot be anticipated (Level 0). In order to reduce cooling energy, it is necessary to examine the adoption of other methods (in the case of Location 2) and the application of other elemental technologies.**
- **At Location 2, an extremely high air change rate can be achieved through certain methods. If the air change rate is in the order of tens of air changes per hour , the airflow velocity near the window may instantaneously exceed 1 m/s.**

3.1.3 Steps for Examining Wind Utilization Technology

- **As a prerequisite of examining methods, it is necessary to check the zone classification, weather conditions and site conditions. The possibility of wind utilization is examined by confirming the outside wind speed and prevailing wind direction at the construction site during the wind utilization period as well as the conditions such as the topography related to local winds in the surrounding area and density around the site.**
- **Next examine the adoption of wind utilization methods.**
- **For security, noise control and wind resistance, examine them equally in all types of houses regardless of the location.**

Step 1 Checking weather conditions, site conditions, lifestyle orientation of occupants, etc.

1) Check zone classification (Zone VI, Zone V)
2) Check weather conditions (outside wind speed and direction)
3) Check site conditions (building density around the site)
4) Check lifestyle orientation of occupants and use of rooms

▼

Step 2 Examining the securing of opening areas in the cross ventilation route (Method 1)

1) Examine the installation of cross ventilation routes and openings
2) Examine openings in the exterior wall
3) Examine openings in the partition wall

▼

Step 3 Examining the securing of wind pressure coefficient difference

1) Examine the position of openings according to the prevailing wind direction (Method 2): Location 2 only
2) Examine the use of high windows such as top side windows (Method 3)

▼

Step 4 Considerations for security, heavy wind and rain, noise, etc.

1) Examine security measures
2) Examine measures for heavy wind and rain
3) Examine noise control measures

3.1.4 Wind Utilization Methods

Method 1 : Securing opening area on cross ventilation route

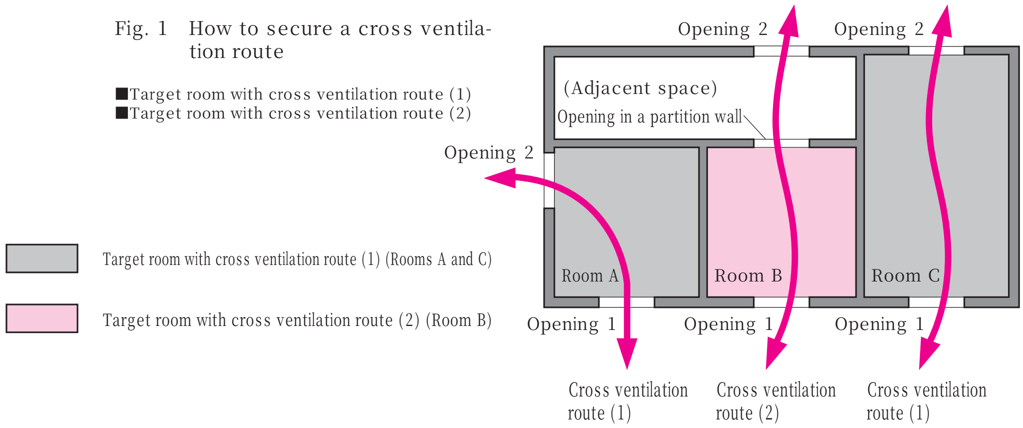
1. Cross ventilation route and opening area

In order to effectively introduce outside air into the building, we need to install openings, which serve as the "entrances" and "exits" for the air, in the walls in more than two different directions. Method 1 involves the following two techniques for installing two openings and cross ventilation routes (Fig. 1).

Cross ventilation route (1) in Fig. 1 is a technique for ensuring cross ventilation by installing an opening in two exterior walls facing different directions in a room. If an opening can only be placed in one of the exterior walls of the room, consider cross ventilation route (2). This technique ensures cross ventilation by installing an opening in the exterior wall of the adjacent space which shares the same opening in the partition wall with the room.

Fig. 1 How to secure a cross ventilation route

■Target room with cross ventilation route (1)
■Target room with cross ventilation route (2)



The larger the opening area on cross ventilation routes (1) and (2), the greater the expected amount of cross ventilation (air change rate) as well as the energy saving effect, in general.

Requirements for the opening area on cross ventilation routes (1) and (2) needed for Method 1 are classified into two levels, respectively (Table 3). Method 1a is intended for a small opening area and Method 1b is for an opening area twice as large as the opening area of Method 1a.

Table 3 Requirements for opening area on cross ventilation route (Method 1)

Method		Ratio of opening area to floor area		
		Opening 1	Opening in a partition wall	Opening 2
Method 1a (Combination of small opening areas)	Cross ventilation route (1)	at least 1/35	–	at least 1/35
	Cross ventilation route (2)	at least 1/20	at least 1/50	at least 1/20
Method 1b (Combination of large opening areas)	Cross ventilation route (1)	at least 1/17	–	at least 1/17
	Cross ventilation route (2)	at least 1/10	at least 1/25	at least 1/10

Although it is desirable to use the net floor area of the relevant room as the floor area shown in Table 3, you can use the floor area measured from the center line of the wall to simplify the calculation. In both cases of cross ventilation routes (1) and (2), the floor area of the target room should be examined.

The opening area refers to an area that can be open for cross ventilation for a certain period of time (an area calculated from the inside dimensions of the open area). If there are multiple openings in the same direction in the exterior wall, all the opening areas can be (included) added together as a single opening in the calculation. In addition to securing the proper opening area, it is necessary to ensure the security of the openings during the night (Section 3.1.5 explains security measures).

Comment ● Method for judging Method 1 by calculating the combined effective opening area in the cross ventilation route

Requirements of the opening area shown in Table 3 are based on the assumption that openings 1 and 2 in the exterior wall have the same area. If the area of the two openings in the cross ventilation route is unequal and the area of either opening does not satisfy the requirements in **Table 3**, the table below can be used to calculate whether or not requirements of Method 1 are met (When examining cross ventilation route (1), keep the Opening in a partition wall column blank).

Example of calculation and steps thereof

Step	Entry item and other factors	Opening 1	Opening in a partition wall	Opening 2
1	Width (m)	a_1	a_i	a_2
2	Height (m)	b_1	b_i	b_2
3	Discharge coefficient	c_1	c_i	c_2
4	Effective opening area (m^2)	$d_1 \leftarrow c_1 \times (a_1 \times b_1)$	$d_i \leftarrow c_i \times (a_1 \times b_1)$	$d_2 \leftarrow c_2 \times (a_2 \times b_2)$
5	$\left(\frac{1}{\text{Effective opening area}}\right)^2$	$e_1 \leftarrow 1/d_1^2$	$e_i \leftarrow 1/d_i^2$	$e_2 \leftarrow 1/d_2^2$
6	$\Sigma\ \left(\frac{1}{\text{Effective opening area}}\right)^2$	$f \leftarrow e_1+e_i+e_2$		
7	Combined effective opening area (m^2)	$g \leftarrow 1/\sqrt{f}$		
8	Floor area (m^2)	h		
9	Combined effective opening area / floor area	$i \leftarrow g/h$		
10	Determination	i≥0.006: Satisfies Method 3a i≥0.006: Satisfies Method 3a i≥0.012: Satisfies Method 3b i≥0.012: Satisfies Method 3b		

Steps 1, 2: Enter width and height of each opening. Note that inside dimensions of the actual opening, instead of sash nominal dimensions, should be used for the width and height of the opening. Similar to the examination using Table 3, if there are multiple openings in the same direction in the exterior wall it is possible to use their combined area as a single effective opening area.

Step 3: Enter discharge coefficient (See p.054) of each opening. Although the discharge coefficient varies depending on the angle of airflow and opening coverings, use the following as a reference.
Opening in a partition wall: approx. 0.6; double sliding window (with a screen): approx. 0.5; projected window, inward/outward-opening window: approx. 0.3

Steps 4 - 7: Calculate using the formula in the column (shown on the right of the arrow)

Steps 8 - 9: Enter the floor area of the target room and obtain the ratio of the combined effective opening area to the floor area.

Step 10: Based on the calculated figures and value for determination (e.g. 0.01, 0.02), check which method (Method 1a, 1b, 3a or 3b) the opening satisfies.

Calculation example: Example of calculating cross ventilation route (2) of the 8-tatami-mat room (13.2 m^2)

Opening 1: Double sliding window; sash inside size 1,650 mm (width) x 1,100 mm (height)
→If the overlap of the glazed sliding door is 70 mm, the opening size is 755 mm (width) x 1,100 mm (height).

Opening in a partition wall: Transom window opening above the door to the hallway; inside size 800 mm (width) x 450 mm (height)

Opening 2: Vertical projected window (triple window); sash inside size 160 mm (width) x 1,300 (height)

Step	Entry item and other factors	Opening 1	Opening in a partition wall	Opening 2
1	Width (m)	a_1 0.755	a_i 0.8	a_2 0.16 x 3
2	Height (m)	b_1 1.1	b_i 0.45	b_2 1.3
3	Discharge coefficient	c_1 0.5	c_i 0.6	c_2 0.3
4	Effective opening area (m^2)	$d_1 \leftarrow c_1 \times (a_1 \times b_1)$ $0.42 \leftarrow 0.5 \times (0.755 \times 1.1)$	$d_i \leftarrow c_i \times (a_1 \times b_1)$ $0.22 \leftarrow 0.6 \times (0.8 \times 0.45))$	$d_2 \leftarrow c_2 \times (a_2 \times b_2)$ $0.19 \leftarrow 0.3 \times (0.48 \times 0.13)$
5	$\left(\frac{1}{\text{Effective opening area}}\right)^2$	$e_1 \leftarrow 1/d_1^2$ $5.67 \leftarrow 1/0.42^2$	$e_i \leftarrow 1/d_i^2$ $20.66 \leftarrow 1/0.22^2$	$e_2 \leftarrow 1/d_2^2$ $27.7 \leftarrow 1/0.19^2$
6	$\Sigma\ \left(\frac{1}{\text{Effective opening area}}\right)^2$	$f \leftarrow e_1+e_i+e_2$ 54.03		
7	Combined effective opening area (m^2)	$g \leftarrow 1/\sqrt{f}$ 0.136		
8	Floor area (m^2)	h 13.2		
9	Combined effective opening area / floor area	$i \leftarrow g/h$ 0.01		
10	Determination	ii≥0.01: Satisfies Method 1a → Satisfies Method 1a i≥0.02: Satisfies Method 1b i≥0.006: Satisfies Method 3a i≥0.012: Satisfies Method 3b		

3

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

Key Point

Controlling the indoor environment through landscape planning

- **The use of landscaping ingenuity to block solar radiation, such as planting shrubs and trees around the house, can keep down the temperature of wind introduced into the room. This also controls the reflected solar radiation and the heat radiation from the heated ground surface and inhibits the heat from entering through windows and other means. On the other hand, if a tiled terrace or paved parking lot that is exposed to solar radiation is facing a large window, deterioration of the external thermal environment affects the indoor environment.**

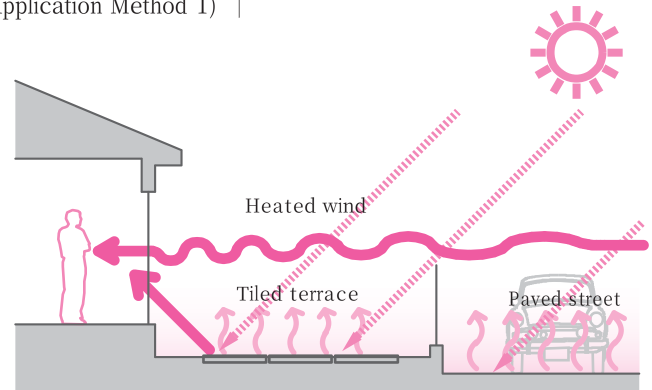


Fig. a Example of landscape planning that increases temperature of wind to be introduced

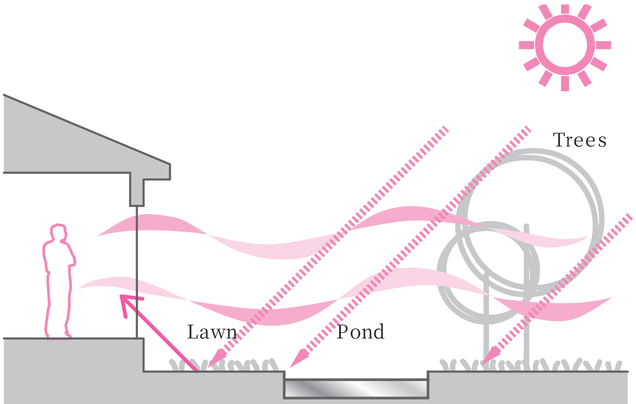


Fig. b Example of landscape planning that keeps down temperature of wind to be introduced

Comment ● Size of opening and cross ventilation quality

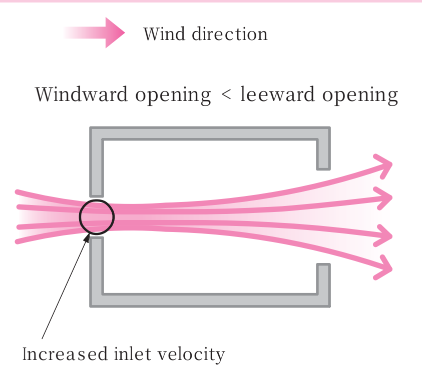


Fig. a Cross ventilation with a small windward opening area

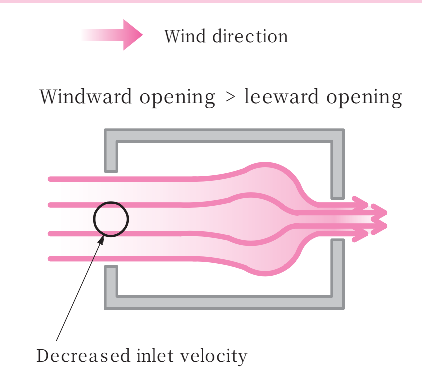


Fig. b Cross ventilation with a small leeward opening area

Ventilation quality depends on the relationship of the size between the "entrance" and "exit" of the wind.

(1) Opening area and amount of cross ventilation

- The larger the opening area the higher the cross ventilation effect. Nevertheless, halving the area of one of the openings in the cross ventilation route that passes through multiple openings does not mean the amount of cross ventilation is reduced by half.
- Having either a couple of large opening areas or multiple openings of equal area in total does not provide any significant difference in cross ventilation effects. In short, even if a large opening cannot be installed, a similar amount of cross ventilation can be obtained by securing a similar opening area with a combination of small openings.

(2) Difference in windward and leeward opening areas and cross ventilation effects

- When planning two openings in one room, as long as both openings are large enough you can obtain a large amount of cross ventilation. However, if there is a size difference in the two openings, the windward and leeward windows, the indoor airflow patterns can change depending on which is larger (**Fig. a and Fig. b**).
- When the windward opening is small, the inlet velocity increases and a person standing in the wind passage can feel very cool (**Fig. a**). Careful attention needs to be paid, as placing a bed near the small windward opening can cause airflow to directly hit the occupants during sleep, which may negatively affect their health.
- When the leeward opening is small, it results in a decrease in the inlet velocity, but mild breeze (with gentle airflow velocity) can be expected in the wide area of the room (**Fig. b**).

2. Planning openings in the exterior wall

It is important to install an opening area that effectively allows outside wind into the room while paying attention to securing sunshine, view and privacy.

1) Securing exterior opening areas

It is necessary to secure two exterior openings in the cross ventilation route that satisfy the area requirements for Method 1 shown in Table 3 on p.050. Examples of dimensions of the exterior opening that satisfy the requirements are shown below for reference purposes (Table 4).

Table 4 Examples of dimensions of exterior openings that satisfy Method 1 requirements

Type of opening	Area ratio	Room size				
		6 *tatami* mats(10 m^2)	8 *tatami* ats(13 m^2)	10 *tatami* mats(16 m^2)	12 *tatami* mats(20 m^2)	15 *tatami* mats(25 m^2)
Waist-level window (Height: 1.1 m)	1/35	Width: 0.26m	Width: 0.34m	Width: 0.43m	Width: 0.51m	Width: 0.64m
	1/20	Width: 0.45m	Width: 0.6m	Width: 0.75m	Width: 0.9m	Width: 1.13m
	1/17	Width: 0.53m	Width: 0.71m	Width: 0.88m	Width: 1.06m	Width: 1.32m
	1/10	Width: 0.9m	Width: 1.2m	Width: 1.5m	Width: 1.8m	Width: 2.25m
Patio door (Height: 1.8 m)	1/35	Width: 0.16m	Width: 0.21m	Width: 0.26m	Width: 0.31m	Width: 0.39m
	1/20	Width: 0.28m	Width: 0.37m	Width: 0.46m	Width: 0.55m	Width: 0.69m
	1/17	Width: 0.32m	Width: 0.43m	Width: 0.54m	Width: 0.65m	Width: 0.81m
	1/10	Width: 0.55m	Width: 0.73m	Width: 0.92m	Width: 1.1m	Width: 1.38m

* The width and height of the opening are inside dimensions.
The area ratio refers to a ratio of the opening area to the floor area of the room.

Windows you can use vary according to the required opening area. It is necessary in particular to consider security aspects when planning openings. For example, if a 0.26 m wide opening is needed, installing double windows with 0.13 m wide effective opening each on the same wall is acceptable and this may be more advantageous for security reasons.

Pay attention to the following when selecting window sashes:

- **When using a regular double sliding window sash, an openable area is less than the one side of the glazed sliding door. Additionally, although it is necessary to install window bars for increased security, if only a moderate level of security is required, a metal lock can be used to lock the sliding door frame at the middle.**
- **Bottom-hinged inswinging windows and projected windows are suitable for securing a relatively small opening area. However, it is possible to secure a large opening area by installing more than two windows on the same wall.**

Fig. 2 Example of secured open area with security considerations
Combination of a waist-level window and a small floor-level window. A wooden window bar is installed for the small floor-level window (double sliding window).

2) Planning opening coverings

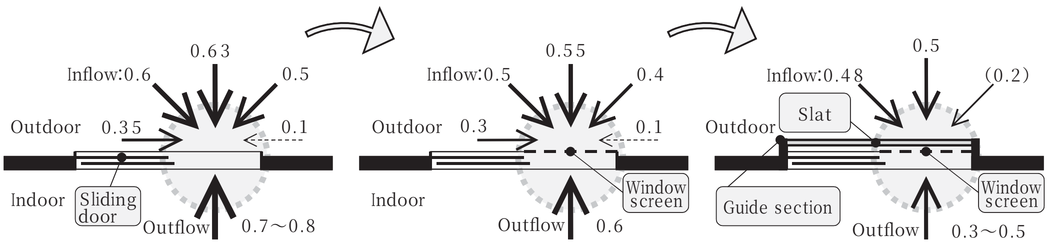
Coverings are usually installed on the openings. It is necessary to recognize how much effect coverings have on cross ventilation and take it into consideration when planning openings.

Key Point

Cross ventilation disturbance by window screens and shutters

- **Changes in inflow due to the direction of incoming wind are shown using discharge coefficient values (Fig.). The discharge coefficient is a value that indicates the ease of passage of wind. As shown in the figure, the discharge coefficient that receives wind from the front of the opening is 0.63 for "a. Double sliding window only" whereas it is 0.55 for "b. Double sliding window + window screen", indicating a 10 – 20% decrease with the use of window screens. It decreases a further 10 – 20% if blind shutters are also used as shown in c.**
- **Using a window screen only during the daytime when the temperature is high to let in ample wind and a window screen and a blind shutter at night is a rational way in terms of efficient cross ventilation as well as security and privacy protection.**
- **A combination of a window screen and a curtain significantly prevents cross ventilation as the curtain adheres closely to the window screen when wind flows out of the window. Even with a sheer curtain, if it adheres closely to the window screen the discharge coefficient decreases to approximately 0.2 (1/3 of normal condition). Bamboo and other blinds may also adhere to the window screen, depending on the wind direction and speed, thus careful attention is required when using them.**

Glossary: Discharge coefficient
This refers to a ratio of the effective area of cross ventilation to the actual opening area. For example, as shown in Fig. a on the right, even when wind flows perpendicular into the opening the discharge coefficient is 0.63 and an effective area of cross ventilation is approximately 60% of the actual opening area. A value obtained from multiplying a discharge coefficient with an actual opening area is referred to as an effective opening area, which is an effective area of cross ventilation.



a. Double sliding window only
b. Double sliding window + window screen
c. Double sliding window + window screen + blind shutter (slat angle of 30°)

Fig. Easing passage of wind through combination of opening coverings

Comment ● Wind introducing effects of side walls and other means

If there is an airflow parallel to the wall surface in the space between the house and the adjacent building, placing a fence, plants and a side wall will increase the wind pressure in that area and introduce wind into the room.

If this is the case, it is important to install a fence and other elements that are large enough for the opening, and the height and width of the fence and other elements need to be equal to or greater than that of the opening. The figure shows a calculation example using a side wall to introduce wind into the room, which results in an approximately 2.5-fold amount of cross ventilation compared to no side wall.

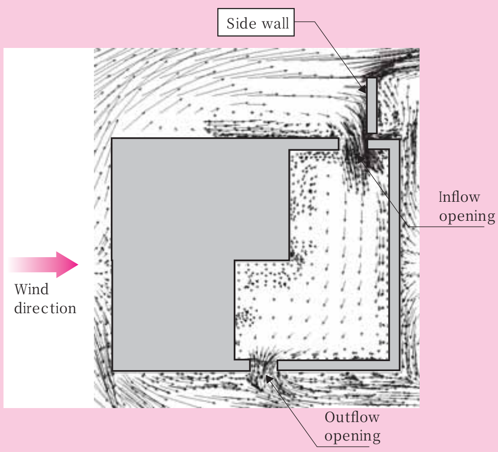


Fig. Introducing wind into a room with a side wall

2. Planning opening in a partition wall

Even if an "entrance" and "exit" for the wind has been installed, sufficient cross ventilation cannot be achieved unless there is a passage of wind in the house. To realize this, it is necessary to use an open concept floor plan with as few partition walls as possible and choose the right interior fittings and fixtures.

1) Area of opening in a partition wall

In the case of cross ventilation route (2), it requires openings in the partition wall in the cross ventilation route that satisfy the area requirements for Method 1 shown in Table 3 on p.050. Examples of dimensions of the interior opening that satisfy the requirements are shown below for reference purposes (Table 5).

Table 5 Examples of dimensions for interior openings that satisfy Method 1 requirements

Type of opening in partition wall	Area ratio	Room size				
		6 *tatami* mats (10 m^2)	8 *tatami* mats (13 m^2)	10 *tatami* mats (16 m^2)	12 *tatami* mats (20 m^2)	15 *tatami* mats (25 m^2)
Opening equivalent to door (Height: 1.8 m)	1/50	W: 0.11m	W: 0.15m	W: 0.18m	W: 0.22m	W: 0.28m
	1/25	W: 0.22m	W: 0.29m	W: 0.37m	W: 0.44m	W: 0.55m
Transom window opening above door (Width: 0.8 m)	1/50	H: 0.25m	H: 0.33m	H: 0.41m	H: 0.5m	H: 0.62m
	1/25	H: 0.5m	H: 0.66m	H: 0.83m	H: 0.99m	H: 1.24m

* The width and height of the opening are inside dimensions.
The area ratio refers to a ratio of the opening area to the floor area of the room.

- **The easiest way to ensure cross ventilation by an opening in the partition wall is to leave the door open. However, as this makes it difficult to protect privacy and the door may close due to a sudden gust of wind, it may be difficult to leave the door open to ensure appropriate cross ventilation. Therefore, in this section, standard doors lacking any of the appropriate measures for cross ventilation are not regarded as openings in the partition wall in the cross ventilation route (2). The prerequisite is to exercise ingenuity for ensuring cross ventilation such as adopting a sliding door shown below (Fig. 3) and installing a door stopper (Fig. 6).**
- **For openings other than the openings in the partition wall in the cross ventilation route, it is important to ensure that they can be opened as needed using such ingenuity to increase the cross ventilation performance of the room.**

2) Adoption of sliding doors

Compared to single swing doors, sliding doors make effective fixtures for cross ventilation as not only do they prevent movement from being hindered when open, but also the extent to which they are open can be freely adjusted. Furthermore, installing a sliding door that is as high as the ceiling allows for a movable partition wall-like fixture with high flexibility, thereby achieving an open space (Fig. 3).

Fig. 3
Example of sliding door
(effective opening area: approx. 1.3 m^2)

3) Adoption of transom windows

A Japanese traditional ranma transom is an excellent tool for ensuring air flow while providing a clear visual division. This idea can be fully applied to modern houses (Fig. 4). Single swing fixtures with top-mounted transom windows are now available on the market.

Fig. 4
Example of transom windows (effective opening area: approx. 0.1 m^2)

4) Adoption of lattice doors

Depending on the spacing of the lattice, lattice doors can block other people's gaze to some extent as well as being effective for cross ventilation. By combining lattice doors with wooden and other types of sliding doors that do not let air through, it is possible to reduce heating load in winter as well as achieve active cross ventilation in summer (Fig. 5).

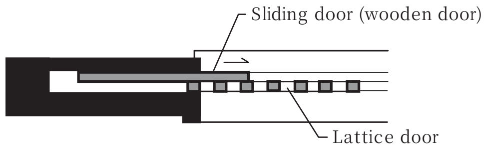


Fig. 5
Example of lattice door
(effective opening area: approx. 0.4 m^2)

5) Adoption of door with opening

If a sliding door cannot be used and a hinged door has to be installed, as is the case for a hallway, bathroom or washing room, and if it is difficult to leave the door open, it is effective to adopt a door that has an opening which can be opened and closed such as a double hang window.

6) Installation of door stopper

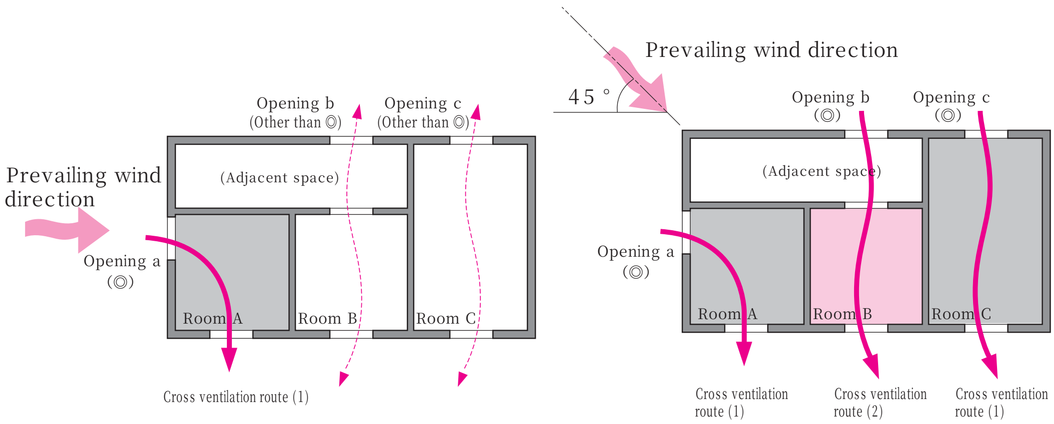
When installing a hinged door in the hallway, bathroom or washing room, the use of a door stopper (Fig. 6) allows the door to be left open for cross ventilation. It is recommended to select a door stopper that does not extrude from the floor to avoid hindering movement.

Fig. 6
Example of door stopper

Method 2 : Opening layout according to prevailing wind direction

At a site with open surroundings (Location 2: suburban location), installing openings on one side in the prevailing wind direction (windward) ensures a significant wind pressure coefficient difference between the inflow and outflow openings, which allows for a large amount of cross ventilation.

Method 2 has two requirements (Fig. 7). If the prevailing wind direction is known, the direction of one side of the openings in the cross ventilation route must be within 45° of the prevailing wind direction. If it needs to be determined from the table of Key Point Outside wind direction in hot humid regions on p.043, the frequency of the direction of one side of the openings in the cross ventilation route to become windward must be at least 40% (indicated with ◎ in Table on p.043). Method 2 cannot be applied to Location 1 (urban location).



Pattern 1: Method 2 is applicable to Room A

◎: Frequency of direction of one side of openings in cross ventilation route to become windward is at least 40% (See Table on p.043)

Fig. 7 Patterns for achieving Method 2 requirements

Key Point

Influence of housing density and wind direction on the wind pressure coefficient difference

- **Based on the wind tunnel test results for different housing densities, the relationship between the site conditions and the average wind pressure coefficient difference is summarized (Table). Assuming the linear cross ventilation route (opposite openings) and the right-angled cross ventilation route (openings in the corners), the table shows the average wind pressure coefficient difference in cases where the openings are on the windward side (i.e. there is an opening facing within 45° of the prevailing wind direction) and where they are not.**
- **At sites with open surroundings (Location 2), an average wind pressure coefficient difference of approximately 0.5 – 0.8 can be obtained if there is an opening on the windward side. However, if there is no opening on the windward side, only approximately 0.1 – 0.4 of wind pressure coefficient difference can be anticipated.**
- **Meanwhile, at sites with high surrounding density (Location 1), the influence of whether or not openings are on the windward side is small, and there is a wind pressure coefficient difference of approximately 0.05 – 0.2 regardless of the direction of the openings.**

Table Average wind pressure coefficient difference of each cross ventilation route obtained from wind tunnel test

Site onditions	Relationship of opening location and wind direction (Assumed relationship of cross ventilation routes (Plan view))	1st floor (corner)	2nd floor (corner)	1st floor (opposite)	2nd floor (opposite)	Value used in this examination
Location 1 (Urban location)	In the case of windward opening	0.1~0.14	0.08~0.21	0.08~0.15	0.08~0.23	0.05
	In the case of no windward opening	0.05~0.07	0.06~0.08	0.08~0.13	0.08~0.14	0.05
Location 2 (Suburban location)	In the case of windward opening	0.55	0.77	0.62	0.78	0.5
	In the case of no windward opening	0.14	0.19	0.36	0.37	0.2

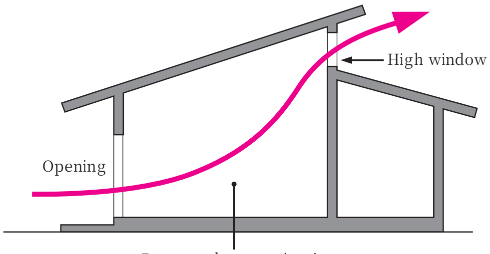
* For verification of energy saving effects by wind utilization in this document, a wind pressure coefficient difference of 0.05 is used for Location 1, 0.5 for Location 2 with openings on the windward side, and 0.2 for Location 2 without openings on the windward side

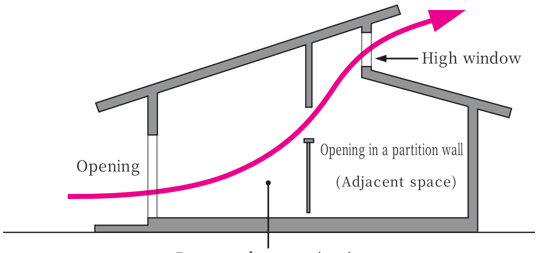
Method 3 : Use of high windows

1. Cross ventilation routes and opening area

The use of high windows (e.g. top side windows in the wall near the top of the building, skylights in the roof) can ensure cross ventilation. In this case, openings in the exterior wall and high windows often serve as the entrance and exit for wind, respectively. Method 3 discusses how to use the following two techniques (Fig. 8).

- **Since high windows on the leeward side allow for a significant wind pressure coefficient difference, it is effective to install them even if the area of the window is small. Furthermore, installing windows in a high position can effectively ensure a stable amount of cross ventilation by taking advantage of the air density difference caused by the inside and outside temperature difference. This is also effective from the perspective of security considerations at night.**





* High window can be installed on the transverse wall.

Fig. 8　How to secure a cross ventilation route using a high window

Method 3 assumes high windows installed on the leeward side. If the prevailing wind direction is known, the direction of the high windows must be within 45° of the leeward side of the prevailing wind direction. If it needs to be determined from the table of Key Point Outside wind direction in hot humid regions on p.043, the frequency of the direction of the high windows to face leeward must be at least 40% (indicated with ◎ in Table on p.043).

Similar to Method 1, the larger the opening area in cross ventilation routes (1) and (2), the greater the expected amount of cross ventilation (air change rate) as well as the energy saving effect. Requirements for the opening area in cross ventilation routes (1) and (2) needed for Method 3 are classified into two levels, respectively (Table 6). Method 3a is intended for a small opening area and Method 3b is for an opening area twice as large as the opening area of Method 3a. Method 3a and Method 1a have an equal expected amount of cross ventilation (air change rate), as do Method 3b and Method 1b. Compared to the opening of Method 1 (See Table 3 on p.050), the use of high windows can achieve a similar effect with a small window area.

See Method 1 for other items that require careful attention. The opening area ratio in Table 6 is a value calculated with an assumption that a high window is installed at the leeward side of the roof in a room with a ceiling height of 2.4 m

Table 6　Requirements for opening area on cross ventilation route using high window (Method 3)

Method		Ratio of opening area to floor area		
		Opening in exterior wall	Opening in partition wall	High window
Method 3a (Combination of small opening areas)	Cross ventilation route (1)	at least 1/35	—	at least 1/80
	Cross ventilation route (2)	at least 1/20	at least 1/50	at least 1/70
Method 3b (Combination of large opening areas)	Cross ventilation route (1)	at least 1/17	—	at least 1/40
	Cross ventilation route (2)	at least 1/10	at least 1/25	at least 1/35

Similar to Method 1, it is also possible for Method 3 to examine whether the opening satisfies Method 3a or 3b based on the area of each opening. When making this judgment, replace the last judgment criteria in the table on p.051 of Comment ● Method for judging Method 1 by calculating the combined effective opening area in the cross ventilation route according to the following criteria:

i≥0.006: Satisfies Method 3a

i≥0.012: Satisfies Method 3b

It is necessary to secure high windows in the cross ventilation route that satisfy the area requirements of Method 3 shown in Table 6. Examples of dimensions for high window that satisfy the requirements are shown below for reference purposes (Table 7).

Table 7 Examples of opening dimensions for high windows that satisfy Method 1 requirements

Type of high window	Area ratio	Room size				
		6 *tatami* mats (10 m²)	8 *tatami* mats (13 m²)	10 *tatami* mats (16 m²)	12 *tatami* mats (20 m²)	15 *tatami* mats (25 m²)
Top side window (Height: 0.4 m)	1/80	W: 0.31m	W: 0.41m	W: 0.52m	W: 0.62m	W: 0.77m
	1/70	W: 0.35m	W: 0.47m	W: 0.59m	W: 0.71m	W: 0.88m
	1/40	W: 0.62m	W: 0.83m	W: 1.03m	W: 1.24m	W: 1.55m
	1/35	W: 0.71m	W: 0.94m	W: 1.18m	W: 1.41m	W: 1.77m
Top side window (Height: 0.6 m)	1/80	W: 0.21m	W: 0.28m	W: 0.34m	W: 0.41m	W: 0.52m
	1/70	W: 0.24m	W: 0.31m	W: 0.39m	W: 0.47m	W: 0.59m
	1/40	W: 0.41m	W: 0.55m	W: 0.69m	W: 0.83m	W: 1.03m
	1/35	W: 0.47m	W: 0.63m	W: 0.79m	W: 0.94m	W: 1.18m
Skylight (Square)	1/80	0.35x0.35 m	0.41x0.41 m	0.45x0.45 m	0.5x0.5 m	0.56x0.56 m
	1/70	0.38x0.38 m	0.43x0.43 m	0.49x0.49 m	0.53x0.53 m	0.59x0.59 m
	1/40	0.5x0.5 m	0.57x0.57 m	0.64x0.64 m	0.7x0.7 m	0.79x0.79 m
	1/35	0.53x0.53 m	0.61x0.61 m	0.69x0.69 m	0.75x0.75 m	0.84x0.84 m

* The width and height of the opening are inside dimensions.
The area ratio refers to a ratio of the opening area to the floor area of the room.

- In the case of using a top side window, the opening can satisfy Method 3 as long as a relatively long width is maintained even if the height is low.
- When a top side window or skylight is installed, excessive solar radiation enters into the room, which may result in an increase in cooling energy consumption. In addition to studying the right direction and angle of elevation of the top side window and skylight, it is necessary to take measures such as solar shading considerations for the top side window and thorough solar shading of the skylight.

2. Planning high windows

1) Installing top side windows and other means (in the case of a roof with a pitch of 15° or greater)

Cross ventilation can be ensured by installing top side windows and other means in the roof where the wind pressure coefficient is negative (Fig. 9).

- If the roof pitch is 15° or greater, there is a spot on the leeward side of the building where the wind pressure is negative. Installing a window in this spot creates an effective opening for venting air.
- A wind tunnel test was performed on a house in a dense residential area that has a top side window on the leeward side. The result shows an approximately 0.15 of wind pressure coefficient difference between the wall and the top side window (approximately two- to three-fold of the expected wind pressure coefficient from the cross ventilation route between the walls (Method 1)).

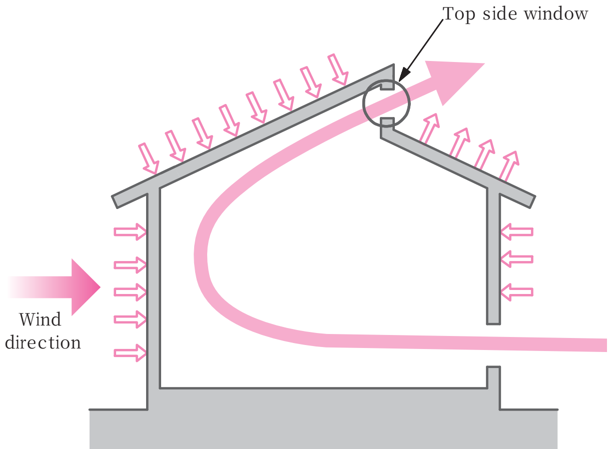


Fig. 9
Cross ventilation by top side window
(Roof pitch of 15° or greater)

2) Planning skylights and other means (in case of low pitch roof)

Installing skylights and other means in the roof where the wind pressure coefficient is negative can ensure cross ventilation.

- If the roof receives a sufficient amount of wind, outside air can be efficiently introduced into the room by taking advantage of the blow-off force (negative pressure) generated on the roof. At Location 1 (urban location), the blow-off force is small as the roof does not receive sufficient amount of wind. Nevertheless, installing a skylight on the leeward side of the roof ensures approximately two- to three-fold (approximately 0.15) of the expected wind pressure coefficient from the cross ventilation route between the walls (Method 1). A larger wind pressure coefficient difference (driving force of cross ventilation) means that it can ensure the same amount of cross ventilation as Method 1 using a small area of high window.

3

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

3.1.5 Considerations for Planning and Designing Openings

Consideration has to be given to security and noise issues when leaving the windows open for cross ventilation during the night. Openings require wind resistance and water tightness in preparation for rainstorms. Moreover, when utilizing wind during heavy wind it is necessary to control and adjust it.

1. Security measures

- **It is necessary to select a window that provides high security performance during cross ventilation as well as when closed (openable window with nighttime security).**
- **The security performance of windows significantly varies depending on the sash structures (opening and closing styles, locking mechanisms, window sizes, etc.), types of glazing, and the use of shutters and window bars, etc.**
- **Security should be ensured not only by windows but also by an overall security plan, such as combining security systems and devices as well as planning landscape with security considerations.**

* Inside dimensions
The Joint Government and Business Meeting on the Promotion and Development of High Performance Building Security Components considers that openings through which any blocks with the following dimensions cannot pass through are effective for preventing home invasion regardless of the structures and specifications.
- 400x250 mm rectangle →αA 0.06 m²
- 400x300 mm ellipse →αA 0.06 m²
- 350 mm diameter circle →αA 0.06 m²

Key Point

Example of ventilating windows considered effective for security

- **There are various tactics of burglars; however this section lists examples of windows that are considered to provide effective security measures against “cat burglars” who enter the house while hardly making noise using hands or a small screwdriver and other tools, as well as against “destructive burglars” who break the window to enter the house using tools.**

【Examples of windows with measures against cat burglars】

(1) Window with stopper

This type of window is often hinged and is available in a wide range of products. The moving part can be fixed so that the window stays slightly open but cannot be opened from outside.

Fig. a
Example of vertical projected window with stopper (partial image)

(2) Window with window bar

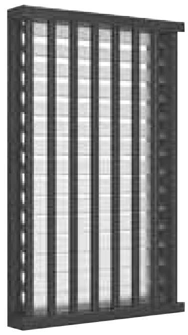


Fig. b
Example of louver window with window bar

(3) Ventilating storm door and window with ventilating storm shutter

Some storm doors and shutters allow cross ventilation while being closed. These products are used particularly with double sliding windows.

Fig. c
Example of ventilating shutter

The shutter section cannot be pulled up from outside during cross ventilation (Electric type is more common)

Fig. d
Example of ventilating storm door

【Examples of windows with measures against destructive burglars】

(1) Windows with security bars

Compared to regular window bars, security bars are designed so that they are more difficult to be destroyed. These windows have enhanced security features; for example, the screws are hidden, the bars are crossed for increased strength or integrated into the sash.

Fig. e
Example of combination of stainless window bar and double-hung window

(2) Slit windows

Windows with small inside dimensions of the frame that prevent people from going through provide high security. These long and narrow windows also ensure the required area of cross ventilation.

Fig. f
Example of slit vertical projected window

2. Measures for heavy wind and rain

- **Wind pressure resistance, water tightness and rustproof performance are required for sashes to cope with heavy wind and rain.**
- **In Okinawa, where typhoons frequently hit and reinforced concrete houses are common, sashes for reinforced concrete buildings are usually used. Since sashes for reinforced concrete buildings are intended for use on the upper floors of multi-family residential buildings as well, they have high wind pressure resistance and water tightness compared to regular sashes for wooden houses (Fig. 10).**
- **Select the thickness, types and area of the glazing for the sashes according to the required wind pressure resistance. If the resistance is insufficient, such measures as installing middle sash bars and dividing the opening into multiple sashes are required.**
- **From the perspective of rustproof performance and durability, aluminum window components including sashes, doors, window bars and shutters are commonly used. Additionally, glass fiber or resin mesh is used for window screens.**
- **In Okinawa, there are some examples of exercising architectural ingenuity in preventing wind and rain from entering the windows with poor water tightness. Fig. 11 shows the side walls that are placed on both sides of the high window for blocking cross wind and preventing rain drops from entering.**

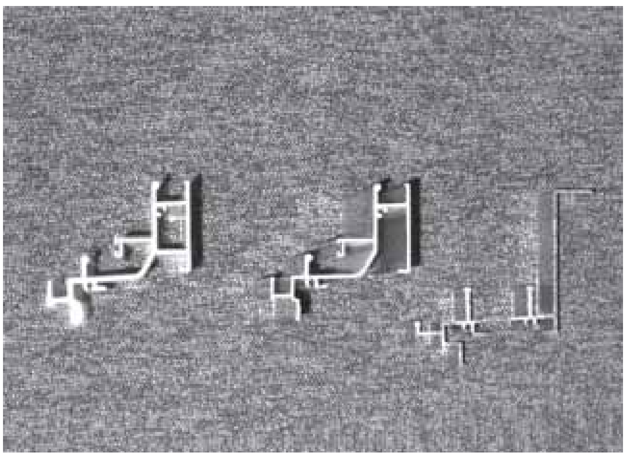


Fig. 10 Cross section example of the sash lower frame
(The frame on the far left is equipped with reinforced board and flashing.)

Fig. 11 Side walls installed on high window in the transverse wall

Glossary: Destructive burglar
This section refers to information from the Joint Government and Business Meeting on the Promotion and Development of High Performance Building Security Components on the website for the Japanese National Policy Agency (http://www.npa.go.jp/safetylife/seianki26/top.html).

Glossary: Measures against destructive burglars
These components are certified as "building security components (for which use of the CP sticker has been approved)" that are included on the list of building components with high security performance on the website managed by the Japan Crime Prevention Association (http://www.cp-bohan.jp). If security performance is a major priority, it is advisable to select the components that have the CP (crime prevention) sticker.

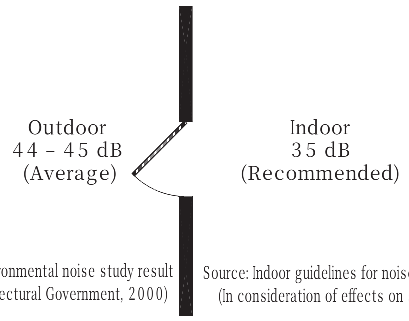
CP mark

3

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

3. Noise control measures

- **When using cross ventilation in the bedroom during the night, it is necessary to make cross ventilation planning that introduces outside air directly into the bedroom. However, people are more sensitive about outside noise at night and it is highly possible that it will be too noisy to sleep with windows open even though this achieves cross ventilation. It is therefore necessary to exercise design ingenuity for openings so that outside noise is reduced while leaving the windows open for cross ventilation.**
- **Fig. 12 shows the average outdoor noise level in a residential area during the night and the recommended indoor noise level which takes into account the effect of noise on sleep. Even when the windows are open, if the sound insulation performance (indoor and outdoor noise level difference) is approximately 10 dB, it is possible to open windows during sleeping hours.**
- **The noise level depends on whether the window is facing the noise source. If the noise source is known from the beginning of the design stage, it is possible to address the noise concern by using sound insulating fittings and fixtures or reducing the size of openings which face the source. The selection of single swing windows that open on the opposite direction from the noise source (quiet direction) achieves a higher sound insulating effect. (Fig. 13).**



Source: Environmental noise study result (Osaka Prefectural Government, 2000)

Source: Indoor guidelines for noise impact (In consideration of effects on sleep)

Fig. 12 Recommended indoor and outdoor noise level

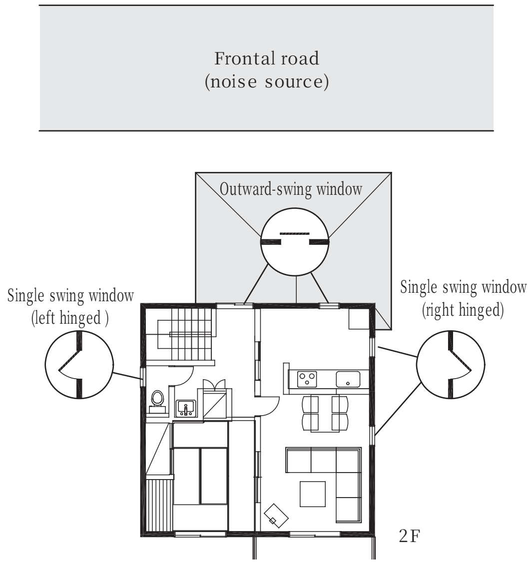


Fig. 13 Example of openings effective for sound insulation

Key Point

Sound insulation performance of open windows

- **The figure below illustrates the sound insulation performance of the single swing window (width: 0.7 m, height: 1.3 m) based on the result of measuring the indoor noise level of the sound generated from the two outside directions.**
- **If the open width is 25 cm, the sound directly enters the room as shown with (1) even though it still provides approximately 10 dB of sound insulation. On the other hand, the result shows when the window serves as a wall blocking the sound as shown with (2), the sound insulation increases by approximately 5 dB to 15 dB.**

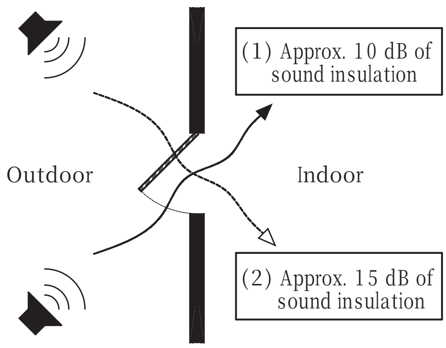


Fig.
Sound insulation performance of single swing window by opening direction

Comment ● Cautionary advice on high air change rate

If the air change rate is in the order of tens of air changes per hour and the indoor airflow velocity increases, a significant amount of heat is removed from the surface of the body, providing a cooling sensation even when the air temperature is relatively high. However, since this cools down the body too much when sleeping and increases the risk of catching a cold, openings need to be controlled according to the situation.

Comment ● Window opening habits of occupants

Even if considerable design ingenuity has been employed, cross ventilation cannot be obtained unless occupants actually open the windows. It is often the case that occupants do not open the windows, particularly during summer nights even when the outside air temperature decreases.

What is needed here is a system that informs occupants when the outside air temperature decreases. Compact outside air temperature thermometers are available on the market, and we recommend that you use these thermometers to encourage occupants to open the windows.

A simple way to do this is to stick a thermometer on the window (Fig. a). Placing a thermometer on the inside and outside of the window allows occupants to see both room temperature and outside air temperature. These thermometers typically cost between 1,000 and 2,000 yen.

Some digital thermometers can simultaneously measure the indoor and outdoor temperature by installing an external sensor on an extended cord from the indoor unit (Fig. b). One advantage of digital thermometers is that they catch people's eyes and are typically available between 3,000 and 5,000 yen.

Either type of thermometer requires careful attention to ensure that the temperature sensor (or the main thermometer body) is protected from rain or snow and is not exposed to direct sunlight.

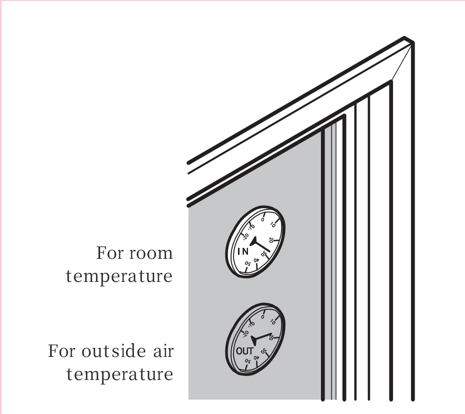


Fig. a Use of thermometers
A couple of analog thermometers are placed on the inside and outside of the window. The use of a thin outside air temperature thermometer does not hinder the opening and closing of window screens.

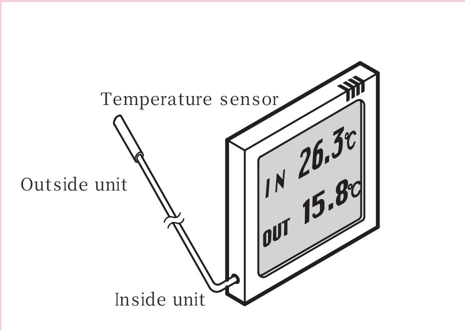


Fig. b Digital thermometer
A digital thermometer's sensor can be extended to the outside.

3.1.6 Calculation Method for Cooling Energy Reduction Rate by Room

Estimating an air change rate by room can calculate the cooling energy reduction rate more accurately. This section explains the calculation method.

The calculation procedures are as follows:

(1) Determine the method to be used for the living and dining rooms (used mainly during waking hours), master bedroom (used only during sleeping hours) and children's room (used from the evening till the morning), respectively, and estimate the air change rate based on Table 2 on p.048.

(2) Table a shows the cooling energy reduction (or increase) rate by room for each zone according to the different air change rate. Determine the energy consumption ratio (a consumption ratio, where reference energy consumption = 1.0) based on the cooling energy reduction (or increase) rate for each room given in Table a.
The cooling energy reduction rate varies slightly depending on the room in which wind is being utilized. This is due to the fact a room, which is more frequently used during hours when the outside air temperature is low (primarily during the night), achieves a higher wind utilization effect. Therefore, the cooling energy reduction rate of master bedrooms, which are used mostly during the night, is estimated to be higher than that of living, dining and children's rooms.

(3) For a room without an air conditioner, check the energy consumption during the period of using an electric fan according to Table b (Use 0 for energy consumption if electric fan is not used).

(4) Table c is a calculation table for the overall cooling energy reduction rate of the house. Calculate the cooling energy consumption by multiplying the reference cooling energy consumption by the energy consumption ratio obtained from Table a. For the period of using an electric fan, include the energy consumption listed in Table b. The overall energy reduction rate can be determined from these calculations.

Table a Cooling energy reduction rate by room and air change rate

Air change rate (ACH)	Zone VI			Zone V		
	Living/Dining	Master bedroom	Children's room	Living/Dining	Master bedroom	Children's room
0	4% increase (1.04)	7% increase (1.07)	3% increase (1.03)	6% increase (1.06)	16% increase (1.16)	5% increase (1.05)
2	No reduction (1.0)	No reduction (1.0)	No reduction (1.0)	No reduction (1.0)	No reduction (1.0)	No reduction (1.0)
5	4% reduction (0.96)	7% reduction (0.93)	3% reduction (0.97)	4% reduction (0.96)	9% reduction (0.91)	6% reduction (0.94)
10	9% reduction (0.91)	15% reduction (0.85)	7% reduction (0.93)	10% reduction (0.9)	22% reduction (0.78)	12% reduction (0.88)
20	10% reduction (0.9)	22% reduction (0.78)	11% reduction (0.89)	16% reduction (0.84)	33% reduction (0.67)	18% reduction (0.82)

* Figures in parentheses refer to energy consumption ratio.

■Conditions of study
Set cooling temperature: 28 °C
Rated capacity of air conditioner: Living/Dining rooms 5 kW; master bedroom 2.8 kW; children's room 3.6 kW (Zone VI) / 2.2 kW x 2 units (Zone V)
Rated COP of air conditioner: Approx. 3

Table b　Primary energy consumption during the period of using an electric fan (Unit: GJ)

Air change rate (ACH)	Zone VI			Zone V		
	Living/Dining	Master bedroom	Children's room	Living/Dining	Master bedroom	Children's room
0	0.57	0.26	0.41	0.41	0.15	0.53
2	0.52	0.23	0.36	0.38	0.13	0.47
5	0.47	0.19	0.31	0.35	0.11	0.41
10	0.4	0.16	0.26	0.31	0.08	0.35
20	0.35	0.13	0.22	0.27	0.06	0.29

■Conditions of study
Power consumption of electric fan: 30 W (low setting; oscillation)
The calculations assume that an electric fan is being used when an occupant is in the room, a temperature of 28 ° C or greater, and that a cooling system is not being used.
Primary energy conversion factor: Electricity 9,760 (kJ/kWh; value based on the revised 2006 building energy conservation standard)

Table c　Calculation table of cooling energy reduction rate

	Room			Entire house
	Living/Dining room	Master bedroom	Children's room	
(1) Reference energy consumption (GJ)	6.1(VI), 3.4(V)	1.3(VI), 0.5(V)	2.9(VI), 1.8(V)	10.3(VI), 5.7(V)
(2) Air change rate (ACH) ←Table 2				
(3) Energy consumption rate ←Table a				
(4) Cooling energy consumption (GJ) (1) x (3) or Energy consumption during use of an electric fan (GJ) ←Table b				
(5) Reduction rate of entire house (%)(1 - (4) / (1) x 100)				

* For reference energy consumption of (1), use the figures on the left for Zone VI and on the right for Zone V.
The reference energy consumption of (1) and the energy consumption during use of an electric fan (GJ) in Table b are indicated on a primary energy (electricity) basis (Primary energy conversion factor: Electricity 9,760 (kJ/kWh; value based on the revised 2006 building energy conservation standard).
For a room without air conditioner, leave (3) blank and enter the energy consumption during the period of using an electric fan of (4) according to Table b.
The reference value of (1) for Zone VI and the energy consumption during the period of using an electric fan in Table b refer to the value for a children ' s room (shared by two children).
The reference value of (1) for Zone V and the energy consumption during the period of using an electric fan in Table b refer to the total value for two children ' s rooms.

【Calculation example】

Conditions of calculation　Zone: Zone VI
Air change rate: Living and dining rooms 10 ACH; master bedroom 5 ACH; children ' s room 10 ACH
Air conditioner is not installed in the children ' s room

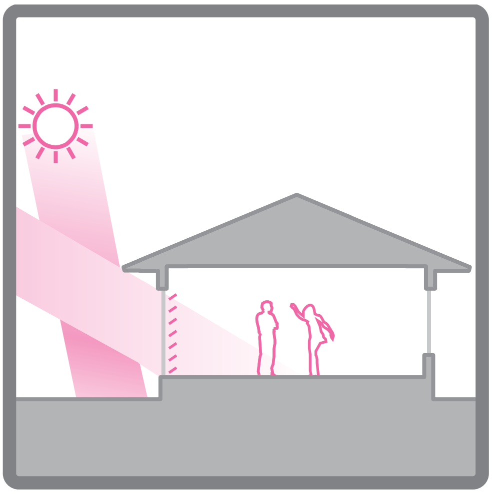
Calculation results　Cooling energy reduction rate for entire house: Approximately 31%

	Room			Entire house
	Living/Dining room	Master bedroom	Children's room	
(1) Reference energy consumption (GJ)	6.1(VI), 3.4(V)	1.3(VI), 0.5(V)	2.9(VI), 1.8(V)	10.3(VI), 5.7(V)
(2) Air change rate (ACH) ←Table 2	10	5	10	
(3) Energy consumption rate ←Table a	0.91	0.93	— (No air conditioner)	
(4) Cooling energy consumption (GJ) (1) x (3) or Energy consumption during use of an electric fan (GJ) ←Table b	5.6	1.2	0.26	7.1
(5) Reduction rate of entire house (%)(1 - (4) / (1) x 100)				31%

3

Chapter 3
Natural Energy
Application Technology
(Elemental Technology
Application Method 1)

3.2 Daylight Utilization (Sunlight Utilization 1)



Daylight utilization planning is a technology that aims to secure light during the day and achieve a reduction in lighting energy consumption as well as increased comfort by skillfully introducing sunlight into a building. It can be largely classified into the daylighting method and the daylight guiding method.

Daylight utilization requires a well-planned scheme to maintain a good balance with solar shading, particularly in the summer. Moreover, since openings for cross ventilation may be an effective in daylighting, comprehensive planning is crucial for daylight utilization planning.

3.2.1 Purpose and Key Points of Daylight Utilization

- In a hot humid region (Zone VI), daylight utilization is hardly taken into consideration, particularly in the summer when solar shading is of the most significance, and lighting energy tends to increase. However, the skillful introduction of daytime brightness into the room reduces unnecessary use of lighting, thereby enabling a reduction in lighting energy consumption.
- As seen in indoor light environments that employ intense daylight in such regions as Zone VI, there is a stark contrast in lighting between an opening and the inside of a room. When the lighting contrast is too strong, the result is daytime lighting, a situation in which unnecessary lighting is used due to dark indoor conditions despite sufficient daylighting.
- Skillful sun control, which regulates the brightness coming from openings, can decrease the stark contrast in lighting inside the room and achieve visual comfort as well as reduced use of lighting, while implementing solar shading.
- The daylight utilization technology consists of the daylighting method, which directly introduces the brightness of openings into the room, and the daylight guiding method, which is an indirect approach involving reflection from the windows into the room. In Zone VI, a critical aspect of the daylighting method is controlling the introduction of daylight into the room (sun control) rather than securing daylight, and for the daylight guiding method, it is very important to effectively use controlled daylight as much as possible.

3.2.2 Energy Conservation Target Levels for Daylight Utilization

1. Definition of target levels

- Energy conservation target levels for daylight utilization are divided into the following levels 1 to 3. These levels indicate the necessity of artificial lighting, i.e. the reduction rate of the energy consumption of a lighting system.

Level 0	:	Cooling energy reduction	None
Level 1	:	Cooling energy reduction rate	Approx. 2-3%
Level 2	:	Cooling energy reduction rate	Approx. 5%
Level 3	:	Cooling energy reduction rate	Approx. 10%

- The typical lighting energy consumption in 2000 was 13.6 GJ (approximately 20% of total energy consumption) for Zone VI, and 11.3 GJ (approximately 17% of total energy consumption) for Zone V (See Section 6.1 on p.339).

- Energy conservation target levels for daylight utilization can be achieved by combining the site conditions and indoor daylighting conditions of a house.

2. Requirements for achieving target levels

1) Site conditions

- The possibility of sunlight utilization varies depending on conditions around the building site, such as whether there is a building that prevents sunlight from entering the house that is being built. This also determines which method is effective for energy conservation. It is effective to review the site conditions using the following three categories (See Section 2.3.1 Understanding Design Requirements of Low Energy Housing with Validated Effectiveness on p.026).

Location 1	:	High-density, high-rise location in which sunlight is hard to utilize
Location 2	:	High-density location in which sunlight can be utilized with ingenuity
Location 3	:	Suburban location in which sunlight can be easily utilized

- At sites such as those in Location 1 which is surrounded by high-rise buildings and sunlight hours are extremely short (dense, high-rise location), as well as Location 2 which is a narrow urban site with short distances between the adjacent buildings (dense location), daylight utilization can sometimes be difficult. Nevertheless, selecting a method that suits the site conditions achieves energy saving effects to some extent.

2) Daylighting conditions

- Table 1 shows the indoor daylighting conditions of a house using Condition 0 (equivalent to the Building Standard Law of Japan) to Condition 3 as a guideline by considering the necessity of daylight in habitable rooms (used for extended periods of time) and non-habitable rooms (not used for extended periods of time).

Table 1　Guideline for daylighting conditions

	Living/dining rooms	Senior's/children's rooms	Other habitable rooms	Non-habitable rooms (Kitchen, hallway, entrance, washing room, bathroom, toilet)
Daylighting condition 0 (equivalent to the Building Standard Law)	Mono-directional daylighting	Mono-directional daylighting	Mono-directional daylighting	–
Daylighting condition 1	Bi-directional daylighting	Mono-directional daylighting	Mono-directional daylighting	–
Daylighting condition 2	Bi-directional daylighting	Bi-directional daylighting	Mono-directional daylighting	–
Daylighting condition 3	Bi-directional daylighting	Bi-directional daylighting	Mono-directional daylighting	Mono-directional daylighting for all

- Mono- or bi-directional daylighting shown in Table 1 refers to the number of daylight utilization methods adopted. Daylight utilization methods discussed in this document (see Table 3 on p.068) are classified into methods that can be regarded and methods that cannot be regarded as daylighting surface.

Methods that can be regarded as daylighting surface	Cases in which daylighting is implemented according to (1) Planning positions and shapes of openings shown in Method 1: Direct daylight utilization methods (daylighting methods)*
	Cases in which daylight guiding is implemented according to (1) Design ingenuity with spatial structures such as transom windows and light wells shown in Method 2: Indirect daylight utilization methods (daylight guiding methods)
Methods that cannot be regarded as daylighting surface	Other methods

* Although skylights are not evaluated as the daylighting surface for Zone VI due to solar shading considerations, they can be included in the daylighting surface evaluation if either they are installed on the north side of the house or if a sun control device is installed.

- Details of each method are explained in 3.2.4 Daylight Utilization Methods.

Glossary: Senior's/children's rooms
This refers to a room in which occupants spend long hours during the day.

3. How to achieve target levels

1) How to achieve target levels

- The relationship between the energy conservation target levels for daylight utilization and the daylighting conditions by location is shown in Table 2.
- Level 0, the reference level, refers to a house located in a dense area surrounded by high-rise buildings (Location 1) with the level of daylight utilization that barely meets the Building Standard Law of Japan.

Table 2 Target levels for daylight utilization and how to achieve them

Target level	Energy saving effect (Lighting energy reduction rate)	Daylighting conditions (application of methods)		
		Location 1	Location 2	Location 3
Level 0	0	Daylighting condition 0 (equivalent to the Building Standard Law) Mono-directional daylighting Floor area x 1/7	–	–
Level 1	Approx. 2 - 3%	Daylighting condition 3	Daylighting condition 2	Daylighting condition 1
Level 2	Approx. 5%	–	Daylighting condition 3	Daylighting condition 2
Level 3	Approx. 10%	–	–	Daylighting condition 3

- The lighting energy estimated here includes energy during the night. Therefore, if we consider the lighting energy during the day only, we can expect more significant reduction effects.
- At a suburban site in Location 3, daylight utilization equivalent to Level 1 can be achieved without special design ingenuity. However, if sunlight utilization is difficult on a dense site in Location 1 or 2 it is necessary to actively consider methods for introducing daylight.

2) Types of daylight utilization method and light environment characteristics

- Daylight utilization methods discussed in this document are aimed at not only introducing more light into the room but also increasing the uniformity of the indoor light, i.e. illuminance of the areas where light is hard to reach, in addition to reducing the contrast in lighting. Table 3 shows the degree of effectiveness in terms of an increased amount of guided light, enhanced light uniformity, and reduced contrast in lighting when each method is used.

Table 3 Light environment characteristics of daylight utilization methods

Details of methods					Increased amount of light	Enhanced uniformity	Reduced contrast in lighting
Method 1	Direct daylight utilization methods (daylighting methods)	(1) Positions and shapes of openings	Side window	Direction	○	○	○
				Shape	△	○	–
				Height	△	◎	○
			Top side window		○	◎	○
			(Skylight: Zone V only)		(○)	(◎)	(◎)
		(2) Sun control devices	Bamboo blind, screen, paper sliding door, curtain		△	△	◎
			Louver, blind*		○	○	◎
			Overhang, awning*		△	△	○
Method 2	Indirect daylight utilization methods (daylight guiding methods)	(1) Spatial structures	Transom window, etc.		○	△	–
			Light well		○	◎	○
		(2) Reflection on finished surfaces			△	○	○
		(3) Devices	Horizontal reflector, etc.		○	○	–
			(Light duct, etc.: Zone V only)		(◎)	(◎)	(○)

◎: Effective, ○: Effective depending on plan, △: Not very effective
* Sun control devices including louvers and overhangs can be also used as daylight guiding method.

3.2.3 Steps for Examining Daylight Utilization Technology and Prerequisites

1. Steps for examining daylight utilization technology

- Confirmation of the site conditions and sunlight conditions is an important prerequisite for examining daylight utilization methods.
- Next, direct daylight utilization methods (daylighting methods) can be examined. During this step, it is important to also consider factors such as future changes in the surrounding environment and the possibility of partial sale of the site.
- At the same time, indirect daylight utilization methods (daylight guiding methods) that suit the daylighting methods should also be examined.

Step 1 Confirming site and sunlight conditions

1) Study the seasonal site and sunlight conditions from a floor planning perspective and consider a location that will continue to ensure sunlight in the future.
2) Study the seasonal site and sunlight conditions from a sectional planning perspective and consider a framework of the three-dimensional building shape, including the number of stories, that will continue to ensure sunlight in the future.

▼

Step 2 Examining direct daylight utilization methods (daylighting methods) – Method 1

1) Examine the positions and shapes of openings that enable daylighting. Thoroughly consider the relationship between the daylight utilization and the wind utilization.
2) Examine the sun control systems around the openings. Thoroughly consider the relationship between the daylight utilization and the solar shading.

▼

Step 3 Examining indirect daylight utilization methods (daylight guiding methods) – Method 2

1) Examine daylight guiding methods according to the spatial structures and daylighting methods.
2) Make the daylight guiding plan feasible for the entire space as much as possible by fully examining the spatial connection, use of partition walls and their types.

▼

Step 4 Identifying areas lacking daylight and incorporating this into lighting systems

1) Identify the areas lacking light during the day and incorporating Section 5.5 Lighting System Planning.

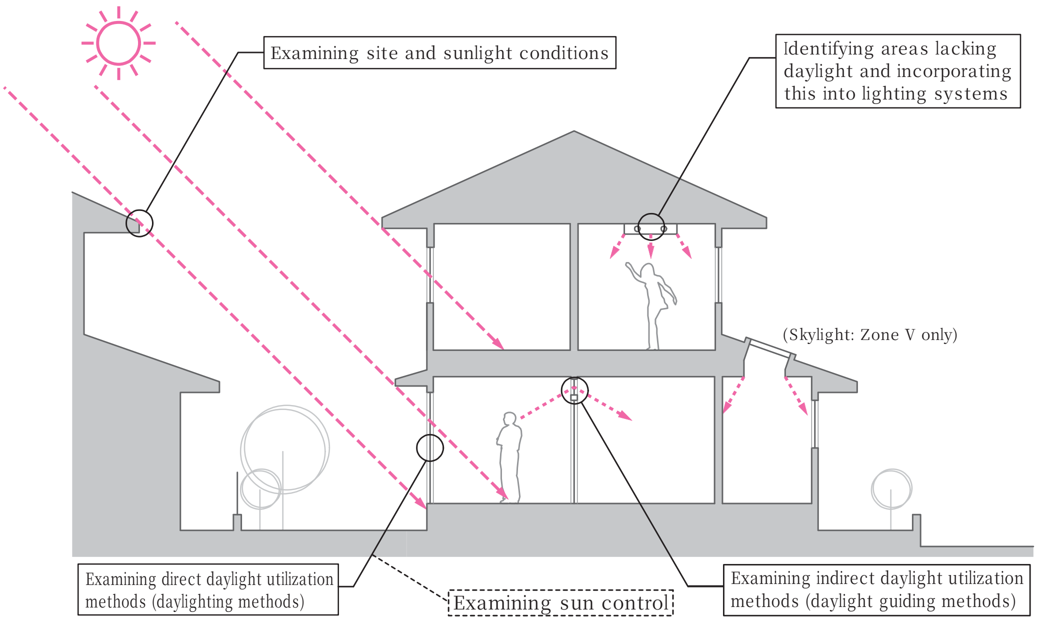


Fig. 1 Overview of daylight utilization technology

2. Prerequisites (site and sunlight conditions) and points to note for planning

1) Points to note for floor planning based on site conditions

First, perform a floor plan check for outline planning.

How surrounding buildings and other objects cast a shadow over the site can be studied using a sun shadow diagram. For season, closely examine when the shortest sunshine hours (winter solstice) are in winter when sunlight needs to be secured, in addition to when the longest sunshine hours (summer solstice) are in summer (Fig. 2 and Fig. 3). Since the position of the sun and shadows caused by it varies in the morning, noon and afternoon, checking it carefully by the hour leads to a pleasant and bright indoor environment. If there is a possibility of buildings being developed around the site in the future, it is important to predict the situation.

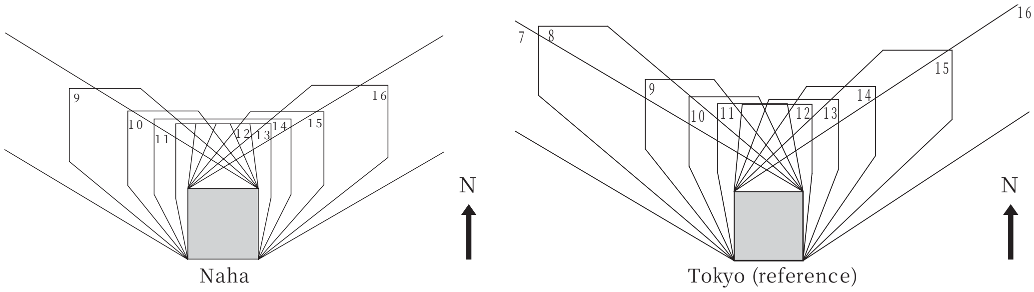


Fig. 2 Sun shadow diagram (bungalow) at winter solstice (December 21)

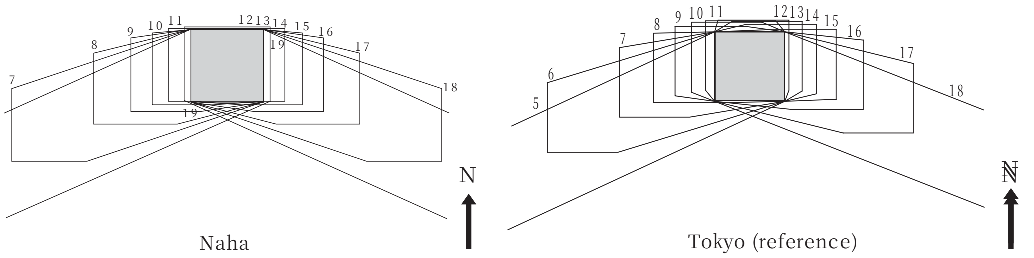


Fig. 3 Sun shadow diagram (bungalow) at summer solstice (June 21)

Once the position and time of day at which sunlight is secured are identified, use ingenuity in floor plan layouts from long-term perspectives, such as which time of the day sunlight is required and the lifestyle of occupants.

2) Points to note for sectional planning based on site conditions

Next, perform a three-dimensional shade check for specific planning.

For example, the solar altitude in the due south position for Naha should be treated as 40.4° at the winter solstice, 87.3° at the summer solstice, and 64° at the spring and fall equinox. The seasonal solar altitude and state of shadows caused by it can indicate the extent of floor area covered in shadow by the buildings on the south of the house through the south-facing windows on the first floor. It also enables consideration for the window positions and opening shapes (described later in this section), thereby allowing a more specific, three-dimensional spatial image (Fig. 4).

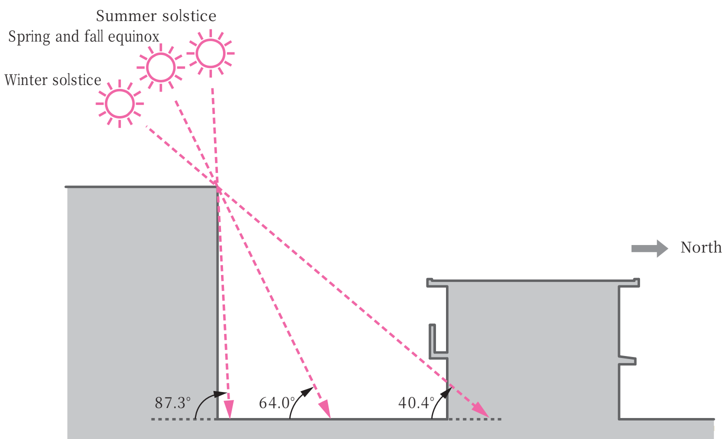


Fig. 4
Three-dimensional shade check
(Solar altitude in Naha)

Key Point

Differences in indoor illuminance due to site conditions

A floor illuminance distribution simulation was conducted on the first floor assuming the existence of a two-storey building on the south, a building site in which the space between adjacent buildings is narrow in one case and wide in another (Fig. a and Fig. b), as well as the existence of two-storey buildings surrounding the site (Fig. c). Results show the possibility of receiving direct daylighting from the opening is high when the space between buildings is wide.

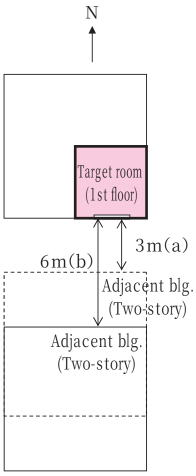
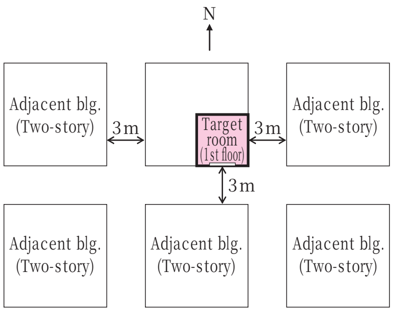


Fig. a
Floor illuminance distribution with narrow space between buildings (3 m)

Fig. b
Floor illuminance distribution with wide space between buildings (6 m)

Conditions a, b of space between buildings on south



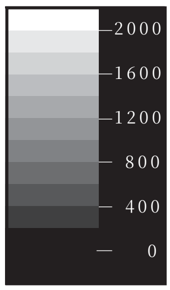
Conditions c of surrounding buildings (c)

Fig. c
Floor illuminance distribution with surrounding buildings (3 m)

■ Conditions (Naha)

Adjacent building: Two-storey
8 m x 8 m x 6 m (height)
Target room: South-facing first floor
4 m x 4 m x 2.5 m (ceiling height)
Window dimensions: 200 cm x 200 cm (patio door)
Season and time: Spring and fall equinox; noon

Illuminance (lx) level



Comment ● Is lighting energy consumption in hot humid region highest in Japan?

As the hot humid region is located in the south of Japan, people tend to think the lighting energy consumption is low because of its long sunshine hours. However, sunshine hours are actually short because of the high precipitation level, and the lighting energy consumption is very high compared to other regions in Japan. For example, in Naha, the number of sunshine hours was 1,621 in 2006, ranking 12th in terms of the short sunshine hours among the capital cities of all 47 prefectures. Despite the short sunshine hours, the solar radiation level is high and people tend to close curtains or blinds and use lighting in an effort to ensure solar shading and reduce cooling load in the summer. Furthermore, it is considered that the lighting energy consumption is very high because shutters and other coverings are used for openings to protect them from typhoons.

3

Chapter 3
Natural Energy
Application Technology
(Elemental Technology
Application Method 1)

3.2.4 Daylight Utilization Methods

Method 1: Direct daylight utilization methods (daylighting methods)

- Although daylighting from openings is the first stage of the daylight utilization methods, effects of daylighting vary depending on the location of the openings. Appropriate daylighting methods need to be selected for planning according to the site conditions and living space characteristics.
- At the same time, wind utilization should be considered.
- Even when the positions and shapes of openings have been determined, daylighting through openings alone leads to problems such as solar radiation heat directly entering the room and direct sunlight being too bright, which significantly impair the comfort of occupants. To avoid these problems, solar shading and sun control should be planned together so that an appropriate level of daylight is achieved.

1. Planning positions and shapes of openings

1) Planning side windows

Average side windows installed in the exterior walls have a simple window structure and it is also easy to install flashing to these windows. Although often overlooked, another great advantage of side windows is their ease of opening and closing as well as cleaning.

From the perspective of daylight utilization, it is important to be aware of the following characteristics of openings.

(1) The higher the position of the window, the further the light reaches in the room and the greater the uniformity of the indoor illuminance.

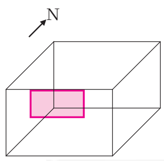
(2) The higher the position of the window, the easier the protection of privacy and the greater the tendency of opening curtains, etc.

(3) The higher the position of the window, the further it is from the center of the visual field and the easier the glare reduction.

Key Point

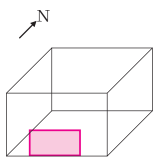
Differences in indoor brightness due to window height

- This section shows, as a reference, the indoor floor illuminance of a room with windows that are the same shape but are installed at a different height.
- In general, the higher the window position, the greater the illuminance uniformity. As shown in Fig. a, the light reaches further into the room. This increases the illuminance at the back of the room as well as the illuminance uniformity of the entire room. Other advantages of high windows are that they are less prone to be influenced by the surroundings and that they can reduce glare. However, these windows receive direct solar radiation and require the use of sun control devices as described later in this section.



a: Height to window sill 150 cm

Fig. a Floor illuminance distribution with high window

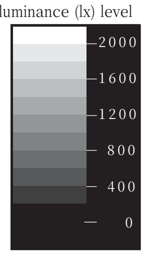


b: Height to window sill 0 cm

Fig. b Floor illuminance distribution with low window

■Conditions (Naha)
Target room: South-facing first floor
4 m x 4 m x 2.5 m (ceiling height)
Window dimensions: 200 cm x 100 cm
Season and time: Spring and fall equinox; noon

Illuminance (lx) level



* This chapter shows the verification results of brightness characteristics using a simulation software called "Inspirer".

2) Planning top side windows

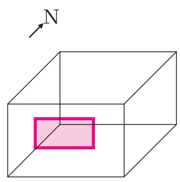
If the space between buildings is narrow and the possibility of daylighting from side windows is extremely low, or if there is a north-facing room that requires more light, it is effective to plan efficient daylighting using top side windows. As mentioned previously, windows that are located high enable efficient daylighting for the back of the room to increase illuminance and uniformity, and provide other advantages such as improved ventilation performance. The way in which maintenance is to be performed should be taken in to account when using top side windows. Careful consideration is required not only in cleaning and inspecting these windows but also in using the sun control devices mentioned hereafter, especially because solar shading is essential for south-facing top side windows in the summer.

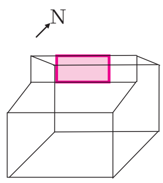
Key Point

Differences in indoor brightness between side windows and top side windows

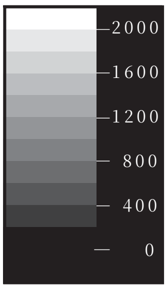
- The differences in the indoor floor illuminance distribution and the luminance distribution, which represent the condition of light in the entire room (perception of light), are shown below as a reference.
- Top side windows brighten the ceiling and walls at the back of the room that were darker with side windows.

■Conditions (Naha)
Target room:
South-facing first floor
4 m x 4 m x 2.5 – 3.5 m (ceiling height)
Window dimensions:
200 cm x 100 cm
Season and time:
Spring and fall equinox; noon





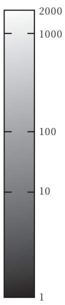
Illuminance (lx) level



Floor illuminance distribution

Floor illuminance distribution

Luminance (cd/m²) level



Condition of indoor light (Luminance distribution)

Fig. a Indoor brightness with side window

Condition of indoor light (Luminance distribution)

Fig. b Indoor brightness with top side window

Illuminance (lx) level
An amount of light that reaches a particular point (incident light). The unit of illuminance is lux (lx).

Luminance
An amount of light that represents the brightness on a surface seen from a particular direction.
The unit of luminance is the candela per square meter (cd/m2).

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

2. Planning sun control devices

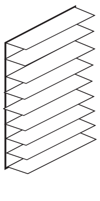
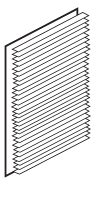
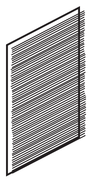
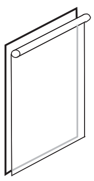
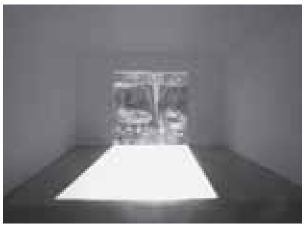
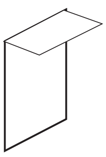
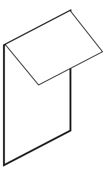
Introducing daylight into the room leads to a tremendous reduction in lighting energy consumption in Zone VI. However, since solar shading is important in order to reduce cooling load, particularly in the summer (see Section 4.2 Solar Shading Methods for Zone VI), there is a need for ensuring both indoor brightness and solar shading.

A device that blocks direct sunlight is generally known as “solar shading device”. Considering the light in addition to the heat, it is required to install a device not only for shading to block the heat but also for adjusting the brightness, that is, a “sun control device”.

This section discusses the characteristics of sun control devices that are installed outside (Table 4) and inside (Table 5) including how they relate to solar shading effects. Furthermore, using overhangs and blocks

Table 4　Characteristics of sun control devices 1 (installed outside)

High ▲ Solar shading effect ▼ Low

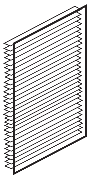
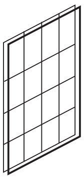
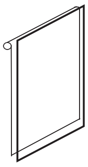
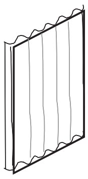
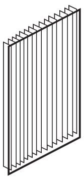
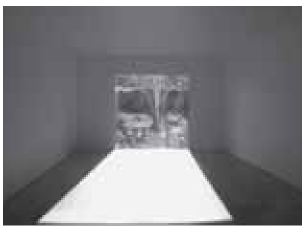
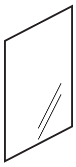
		**Horizontal louver** Direction/season/time: Appropriate for southeast to south to south west and high solar altitude. View: Varies depending on the blade spacing and angle. Direct light diffusion: Hardly any Remark: Blade setting according to the purpose is important. Direct sunlight reflected on the top of blades enters the ceiling, brightening the room.
		**Horizontal blind** Direction/season/time: Works for all directions. View: Varies depending on the blade spacing and angle. Direct light diffusion: Slight, depending on the blade angle. Remark: Appropriate adjustment according to the outside conditions and purpose is important. Possible to guide the light reflected on the blades to the ceiling.
		**Bamboo blind** Direction/season/time: Appropriate for east and west and low solar altitude. View: Not very good Direct light diffusion: Yes Remark: Inexpensive and easy to install. Visual effects of natural material.
		**Roller blind** Direction/season/time: Appropriate for east and west and low solar altitude. View: Not very good, although depends on the material. Direct light diffusion: Very high, although depends on the material. Remark: Effective for blocking the view from outside. Appropriate for creating a soft light environment.
		**Overhang** Direction/season/time: Appropriate for south and high solar altitude. View: Good Direct light diffusion: None Remark: Inappropriate for blocking the afternoon sun as direct sunlight easily enters when the solar altitude is low.
		**Awning** Direction/season/time: Appropriate for any directions except north. View: Good Direct light diffusion: Hardly any, although depends on the material. Remark: Works even when the solar altitude is low unlike the fixed overhang. Some materials allow diffuse transmission of direct sunlight.

with decorative openings as examples, it explains the methods for reducing the contrast in lighting between openings and surroundings using sun control devices to prevent the room from looking dark.

Regarding the ease of adjusting the light environment, auxiliary devices installed inside such as indoor horizontal blinds have superior performance. On the other hand, outside devices provide a higher solar shading effect and overhangs and blocks with decorative openings are more effective, considering their ability to protect against heavy wind and rain.

It is necessary to understand the characteristics of each sun control device and select the one that suits the period of use, direction to be installed and purpose.

Table 5 Characteristics of sun control devices 2 (installed inside)

Solar shading effect (High ▲ … ▼ Low)	Photo	Device	Characteristics
High			**Horizontal blind** Direction/season/time: Works for all directions. View: Varies depending on the blade spacing and angle. Direct light diffusion: Slight, depending on the blade angle. Remark: Appropriate adjustment according to the outside conditions and purpose is important. Easy to adjust the blade angle, roll up, etc.
			**Paper sliding door** Direction/season/time: Appropriate for low solar altitude. View: Not good Direct light diffusion: Very high, although slightly varies depending on the material. Remark: Effective for blocking the view into the building, but hard to see the outside environment. Can create a soft light environment.
			**Roller blind** Direction/season/time: Appropriate for east and west and low solar altitude. View: Not very good, although depends on the material. Direct light diffusion: Very high, although depends on the material. Remark: Effective for blocking the view from outside. Appropriate for creating a soft light environment. Easy to roll up and down for adjustment.
			**Sheer curtain** Direction/season/time: Appropriate for low solar altitude. View: Depends on the material. Direct light diffusion: Depends on the material. Remark: Material selection is important according to the purpose, such as whether the priority is on the view or glare control.
			**Vertical blind** Direction/season/time: Works for all directions. View: Varies depending on the blade spacing and angle. Direct light diffusion: Slight, depending on the blade angle. Remark: Appropriate when direct sunlight enters the room with an angle against the window.
Low			**None** Direction/season/time: View: Good Direct light diffusion: None Remark:

■Some photos in Tables 4 and 5 are available in color in Appendix 2 on p.390.

3

Chapter 3
Natural Energy Application Technology (Elemental Technology Application Method 1)

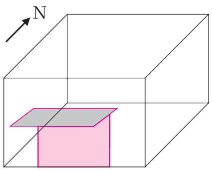
1) Sun control effect of overhangs

Overhangs often used in hot humid regions have a different solar shading effect depending on the depth. The sun control effect also depends on the overhang depth. However, unlike solar shading, this effect varies depending on the perception of light.

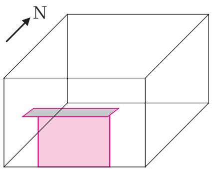
Key Point

Differences in indoor light condition due to depth of overhangs

- The luminance distribution diagrams representing the condition of indoor light indicate the differences in effects of overhangs.
- Fig. a and Fig. b show the differences in perception of light from the south-facing opening at noon according to the depth of the overhang. Since the solar altitude is high, the deep overhang of Fig. b creates a large shady area and the glare (contrast) of the opening is small.
- Fig. c and Fig. d show the differences in perception of light from the east-facing opening at 9:00 a.m. according to the depth of the overhang. Since the solar altitude is lower than that of noon, the sun shines on the floor, but the deep overhang of Fig. d can reduce the glare (contrast) by decreasing the glare area.



Deep overhang



Shallow overhang

■Conditions (Naha)
Target room:
South-facing first floor (a, b); east-facing first floor (c, d)
4 m x 4 m x 2.5 m (ceiling height)
Window dimensions:
200 cm x 200 cm
Overhang depth:
80 cm (a, c); 150 cm (b, d)
Season and time:
Spring and fall equinox at noon (a, b); 9:00 a.m. (c, d)

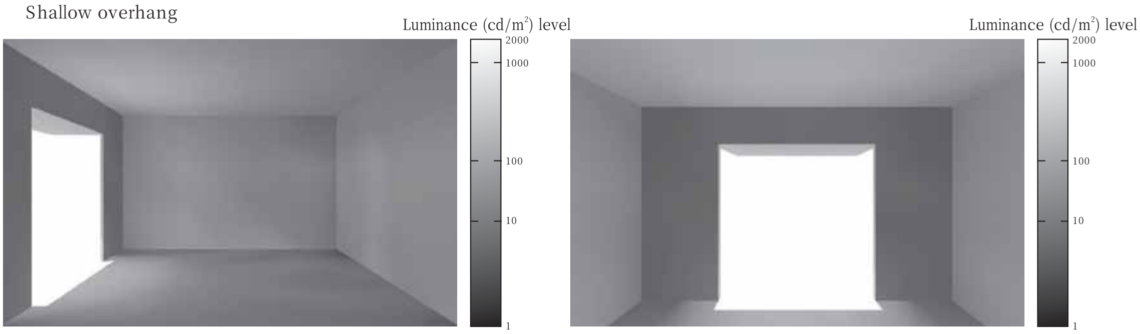


Fig. a Shallow overhang (South-facing opening, noon) Light on side and opening directions (luminance distribution)

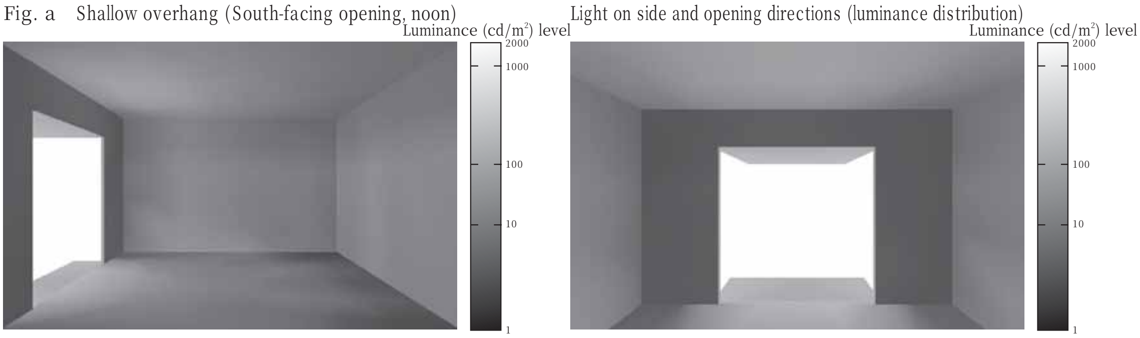


Fig. b Deep overhang (South-facing opening, noon) Light on side and opening directions (luminance distribution)

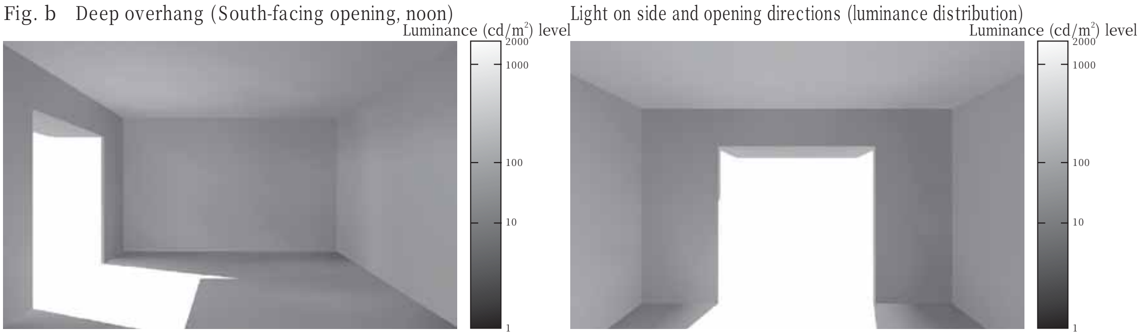


Fig. c Shallow overhang (East-facing opening, 9:00 a.m.) Light on side and opening directions (luminance distribution)

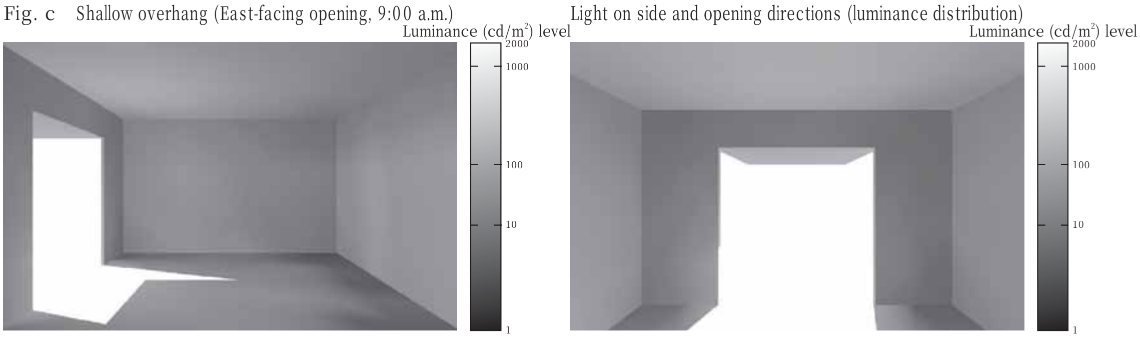


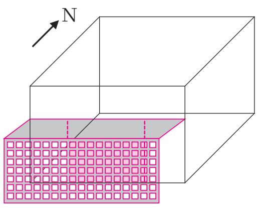
Fig. d Deep overhang (East-facing opening, 9:00 a.m.) Light on side and opening directions (luminance distribution)

2) Sun control effect of blocks with decorative openings

Blocks with decorative openings are frequently used in Zone VI in order to help protect against heavy wind and provide aesthetic landscaping. Although these blocks also work as an effective solar shading device against the afternoon sun, a combined use with overhangs can achieve a significant effect in terms of sun control.

Key Point

Indoor light condition provided by blocks with decorative openings



- The luminance distribution diagrams expressing the condition of indoor light below shows the effect of blocks with decorative openings.
- Fig. a and Fig. b show the differences in perception of light from the west-facing opening at 3:00 p.m. with or without blocks with decorative openings.
- In Fig. a, which has an overhang but none of these blocks, the afternoon sun directly shines into the room and the opening and wide area of the floor seem too bright. Even though a sufficient amount of daylight is actually secured, the room seems relatively dark.
- In Fig. b, which has both an overhang and blocks with decorative openings, the afternoon sun is softened by the sun control effect of the blocks and the amount of daylight is limited. However, as the contrast in lighting is reduced the back of the room does not seem very dark.
- In short, blocks with decorative openings effectively prevent the back of the room from looking dark by securely blocking solar radiation including the afternoon sun.

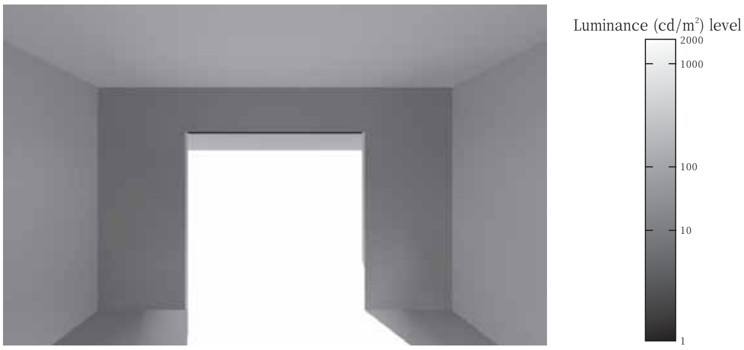


Fig. a
Indoor light condition without blocks with decorative openings (luminance distribution)
Luminance (cd/m2) level

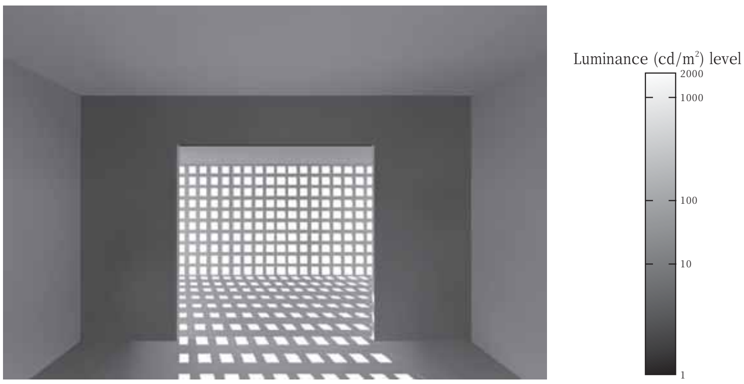


Fig. b
Indoor light condition with blocks with decorative openings (luminance distribution)
Luminance (cd/m2) level

■Conditions (Naha)
Target room: West-facing first floor 4 m x 4 m x 2.5 m (ceiling height)
Window dimensions: 200 cm x 200 cm
Size of decorative openings of blocks: 16 cm x 16 cm x 15 cm (thickness)
Overhang depth: 150 cm
Blocks with decorative openings/overhang width: 4 m
Reflectance: Ground 0.2; back of overhang/blocks with decorative openings 0.3; ceiling 0.7; wall 0.5; floor 0.3
Season and time: Spring and fall equinox; 3:00 p.m.

* Hiding one of the figures (Fig. a or Fig. b) makes the effect of contrast in lighting between the opening and the room easier to see

Comment ● The principle of *hiruandon* which means unnecessary lighting during the day

There is a term ***hiruandon*** (literally, a paper shade lamp in daylight) in Japanese. This is a famous reference to the outer guise of Oishi Kuranosuke, who was the leader of forty-seven masterless samurai whose story is the national epic of Japan . It is used to ridicule someone who is dull or useless, such as "You are like a paper shade lamp in broad daylight". Why is ***hiruandon*** (daytime lighting) useless? That is because the daylight is bright and a paper shade lamp is completely ineffective and wasteful. But think about this: the same amount of light is coming from the paper shade lamp regardless of day or night. Why is the same amount of light effective at night but not in the daytime?

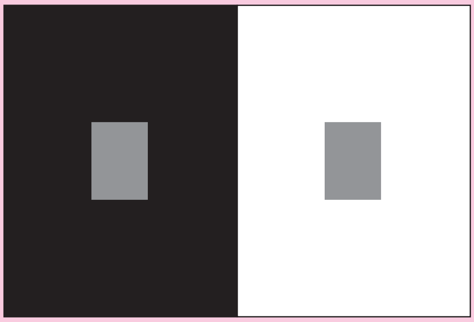


Fig. Simultaneous contrast of brightness

The reason for this is that the effectiveness of light depends on its relationship with the surroundings as well as the amount of light. There is hardly any light around the paper shade lamp at night, but a large amount of light exists during the day. The above figure represents the condition of a paper shade lamp at night and in the daytime. The light emitted from the paper shade lamp is shown in gray, the surrounding light at night is in black and the surrounding light in the daytime is in white. Please look closely at this figure. Don't the small gray squares look different?

This figure expresses the "simultaneous contrast of brightness" phenomenon which is determined by the contrast between the "brightness" of a particular color and its surroundings. In the case of light surrounding the paper shade lamp, the difference between the night and day is far greater than that of the black and white area in the figure. Moreover, since the area around the lamp is much larger this effect is further heightened.

Taking this concept a step further, you can see that this figure is the same as when looking at the window from inside the room in terms of perception of light (Photo 1). If there is no light in the room, the window looks very bright and dazzling. On the contrary, since the window is very bright the area around the window looks dark even though there is light in the room.

Because of this, we tend to turn on a paper shade lamp, i.e. lighting, in order to add light to the dark area even in the daytime (Photo 2). This results in daytime lighting in which we attempt to make the dark area look brighter but it is actually waste of lighting considering the presence of large amount of light.

The sun control and other daylight utilization methods explained in this document reduce the contrast in lighting. These methods are very effective in preventing daytime lighting by keeping the room from looking dark as well as in reducing lighting energy in hot humid regions where the sunlight is so intense that windows look too bright.

Photo 1 Stark contrast in lighting between window and inside of room

Photo 2 Example of how impression of darkness created by contrast with windows can result in use of daytime lighting

Method 2: Indirect daylight utilization methods (daylight guiding methods)

- By guiding the light received from an opening into the back of the room (daylight guiding), brightness and other visual comforts can be increased. Even if there is a house that cannot achieve sufficient daylighting, daylight guiding makes the optimum use of the light obtained by daylighting.
- Daylight guiding methods consist of three methods: daylight guiding using spatial structures, reflection on finished surfaces, and devices. The desirable priorities are that architectural daylight guiding using spatial structures and interior finish are fully examined before adopting daylight guiding using devices to supplement insufficient lighting.
- A combination of daylight guiding methods may further increase the effects.

1. Daylight guiding using spatial structures

Daylight guiding using spatial structures refers to the creation of a passage of light through ingenuity in the floor and elevation planning.

1) Daylight guiding using transom windows and other means

A transom windows that is installed in the upper partition wall as a cross ventilation opening can also guide light into the next room with poor daylighting conditions. As the lower area of the transom windows is covered by the wall, which blocks a view, it can introduce light into the room while maintaining an independent space. Moreover, in hot humid regions where the solar altitude is high, a daylight guiding effect tends to be low and it is important to efficiently use the light reflected in the room which is discussed later in this section.

Daylight guiding using transom windows is also effective in designing exterior openings for non-habitable rooms that tend to be one step behind. Even when it is difficult to plan windows in all the non-habitable rooms such as washing rooms, toilets and bathrooms, sufficient daylighting in one of these rooms and daylight guiding using transom windows in the surrounding spaces creates pleasant spaces with natural lighting.

Similar to transom windows, an efficient use of glass blocks and glass screens in the partition wall guides daylight into the entire space, achieving the same effects.

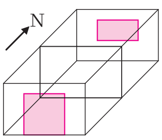
Key Point

Daylight guiding effects of transom windows

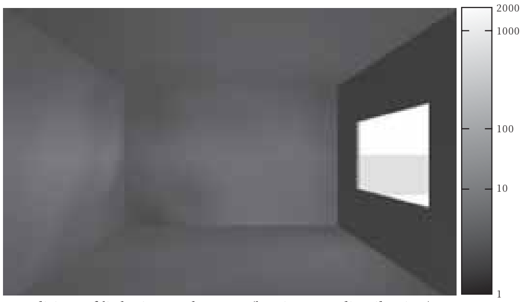
- The difference in the condition of light in the north room and the floor illuminance (including the south-facing room) with or without a transom window is shown below for reference purposes.
- Although the indoor floor brightness is hardly different between the two rooms, areas in the ceiling and walls that are related to the perception of light look brighter when there is a transom window.

■Conditions (Naha)
Target room:
North-south consecutive rooms on the first floor
South room:
4 m x 4 m x 2.5 m (ceiling height)
South room window dimensions:
200 cm x 200 cm (patio door)
North room:
4 m x 4 m x 2.5 m (ceiling height)
North room window dimensions:
200 cm x 100 cm (waist-level window)
Dimensions of transom window between north and south rooms:
200 cm x 50 cm
Season and time:
Winter solstice; noon

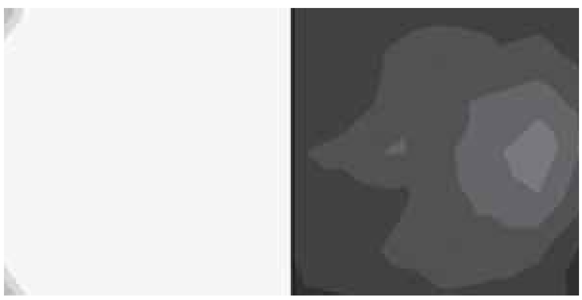
Fig. a
Without transom window
(Winter solstice, noon)



Luminance (cd/m²) level



Condition of light in north room (luminance distribution)



Floor illuminance distribution (left: south room; right: north room)

Illuminance (lx) level

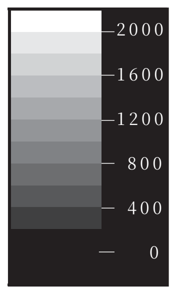
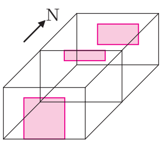
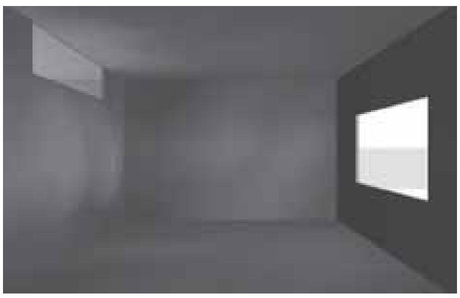


Fig. b
With transom window
(Winter solstice, noon)





Condition of light in north room (luminance distribution)

Floor illuminance distribution (left: south room; right: north room)

2) Daylight guiding using light wells

Planning a light well to create a passage of light through from the upper to the lower floor of the house can guide the light into the lower floor (Fig. 5). The effect of the light well can be obtained even in the staircase by taking into account the light transmittance and reflectance of components. A light well is used in combination with top side windows and other means (skylights are also possible in Zone V). Since it is not direct daylighting through top side windows and other means, a solar shading effect can be expected to some extent.

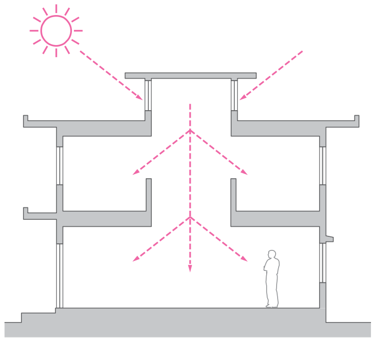


Fig. 5 Example of light well planning

2. Daylight guiding using reflection on finished surfaces: Reflection on outside surfaces, back of eaves and indoor surfaces

Daylight guiding using reflection on finished surfaces is a method used often in traditional Japanese buildings and can be effectively applied to modern houses. The fundamentals of this method are that light reflected on the ground is reflected further on the back of eaves and ceiling around the openings in order to guide the light into the back of the room. However, as the reflection of the light is strong and windows become too bright in hot humid regions, thorough solar shading and sun control are prerequisites.

Fig. 6 is an actual example of effective light guiding which prevents solar radiation and glaring of the openings by skillfully using the reflection on the outside surfaces as well as on the finished surfaces such as the back of the overhang and ceiling. Amahaji (semi-outdoor space with a deep overhang) works to efficiently guide the indirect daylight into the room.

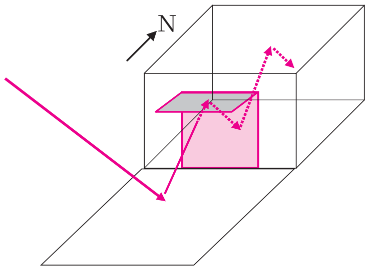
If it is desired to open windows for cross ventilation and view, a combination of the outside surfaces with low reflectance and indoor finished surfaces with high reflectance is an extremely effective method for daylight guiding which makes the most of the reflection on finished surfaces.

Fig. 6 Daylight guiding using reflection on ground, back of eaves and ceiling by means of amahaji

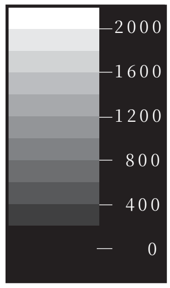
Key Point

Daylight guiding effect using outside surfaces with low reflectance and indoor finished surfaces with high reflectance

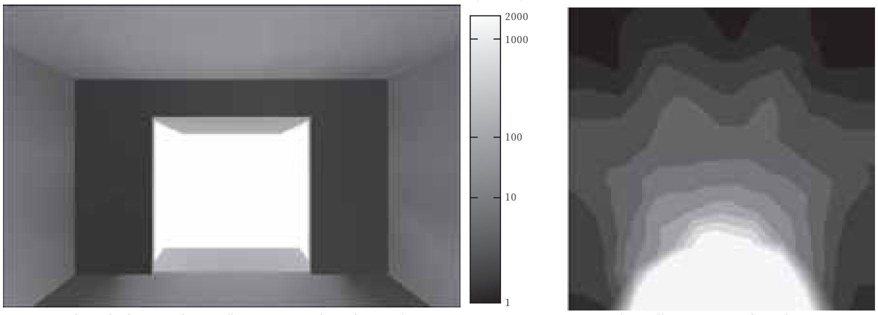
- The indoor light condition (luminance distribution) and floor illuminance distribution of the outside surfaces and indoor finished surfaces with different reflectances are shown as a reference.
- When both the ground and indoor reflectance are low (Fig. a), the entire room looks dark (low luminance distribution) and indoor light itself decreases (low illuminance distribution). On the other hand, when the ground reflectance is low but the indoor reflectance is high (Fig. b), the room seems bright (high luminance distribution) while somewhat controlling the contrast with the opening in terms of perception of light and the light reaches the back of the room (high illuminance distribution).
- When the ground reflectance is high but the indoor reflectance is low (Fig. c), the contrast is the greatest and the window seems too bright (high luminance distribution), but the light does not reach as further into the room as Fig. b (low illuminance distribution).
- When both the ground and indoor reflectance are high (Fig. d), the entire room looks bright and the light fully reaches the back of the room (high illuminance distribution), but the entire room seems extremely bright and solar radiation is intense.
- From the above, a combination of the outside surfaces with low reflectance and indoor finished surfaces with high reflectance (Fig. b) is most effective.



lluminance (lx) level



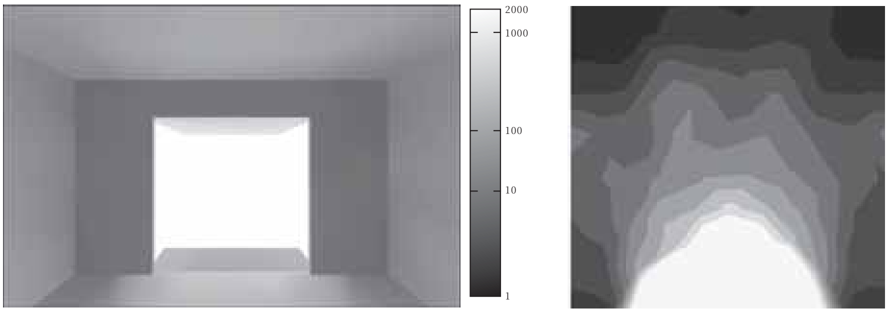
Luminance (cd/m²) level



Indoor light condition (luminance distribution) Floor illuminance distribution

Fig. a When both ground and indoor reflectance are low

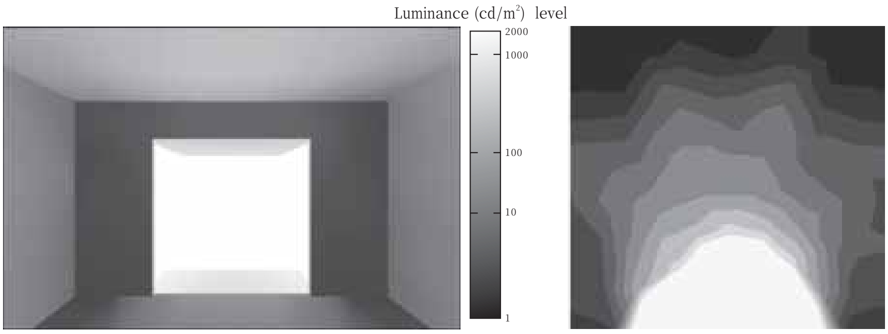
Luminance (cd/m²) level



Indoor light condition (luminance distribution) Floor illuminance distribution

Fig. b When ground reflectance is low but indoor reflectance is high

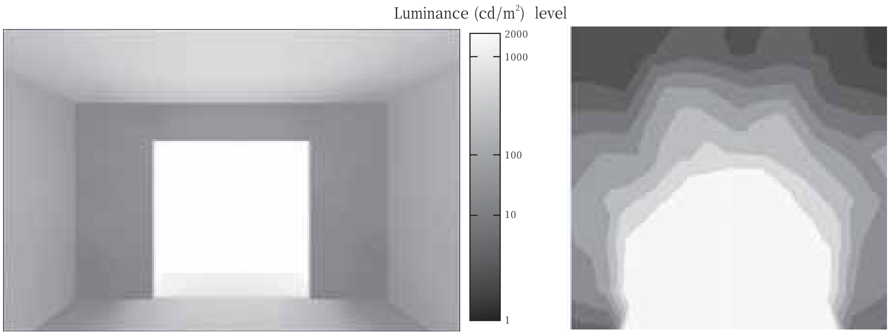
Luminance (cd/m²) level



Indoor light condition (luminance distribution) Floor illuminance distribution

Fig. c When ground reflectance is high but indoor reflectance is low

Luminance (cd/m²) level



Indoor light condition (luminance distribution) Floor illuminance distribution

Fig. d When both ground and indoor reflectance are high

■Conditions (Naha)
Target room: South-facing first floor
4 m x 4 m x 2.5 m (ceiling height)
Window dimensions: 200 cm x 200 cm
Overhang depth: 150 cm
Season and time: Spring and fall equinox; noon

a. Reflectance (low - low)
Outside surface: 0.2; back of overhang: 0.2; ceiling: 0.5; wall: 0.3; floor: 0.1

b. Reflectance (low - high)
Outside surface: 0.2; back of overhang: 0.8; ceiling: 0.9; wall: 0.7; floor: 0.5

c. Reflectance (high - low)
Outside surface: 0.8; back of overhang: 0.2; ceiling: 0.5; wall: 0.3; floor: 0.1

d. Reflectance (high - high)
Outside surface: 0.8; back of overhang: 0.8; ceiling: 0.9; wall: 0.7; floor: 0.5

The table below shows the reflectance of major finishing materials (including outside surfaces) for reference purposes.

Reference
Table: Reflectance of major finishing materials

Component	Finishing materials	Reflectance (%)	Component	Finishing materials	Reflectance (%)
Ceiling and wall	Japanese cypress (new)	55～65	Floor	*Tatami* mat (new)	50～60
	Cedar (new)	30～50		Light-colored vinyl tile, Astile	40～70
	Colored lacquer, varnish	20～40		Dark-colored vinyl tile, Astile	10～20
	Light-colored wallpaper, typical *fusuma* paper.	40～70		Light-colored flooring	20～30
	Dark-colored wallpaper, typical *fusuma* paper	20～40		Dark-colored flooring	10～20
	White plaster wall (new)	75～85	Outside surface	White gravel	20～40
	Typical white wall	55～75		Gravel, concrete, pavement stone	15～30
	Earth wall top coat , typical light-colored wall	40～60		Asphalt pavement	15～20
	Typical dark-colored wall	15～25		Lawn (grass)	5～15
	Japanese sand wall (green and other dark colors)	5～15		Earth (wet earth)	3～7

3. Daylight guiding using devices

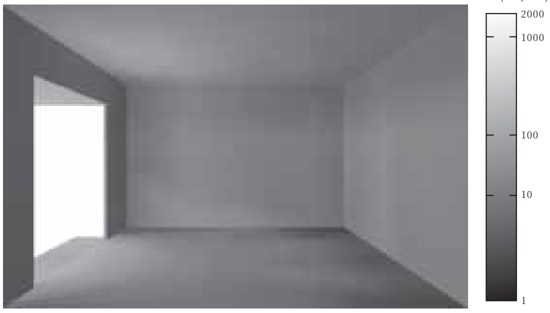
The daylight guiding using devices consists of two methods. The first method reflects the light at the upper surface of a light shelf installed above the window and guides the light into the back of the room using the reflection from the ceiling. The second method also utilizes the reflection from the ceiling in the same manner by using sun control devices installed on windows (p.074) that have blades with a high reflecting effect (e.g. louvers).(In Zone V, the use of mechanical devices, e.g. light ducts, is also effective as it guides the light into the areas where the light normally does not reach (See p.083).)

It is desirable that the light shelf is installed at a higher position than the eye level in order to secure a view. When designing a house with a low ceiling, it is necessary to incline the ceiling so that it is higher toward the openings. Employing such techniques for an opening in a living room with a relatively high ceiling is efficient as it enables a large opening above the light shelf.

Key Point

Daylight guiding effects of light shelves

- The differences in the indoor light condition (luminance distribution) and floor illuminance distribution with or without a light shelf are shown as a reference.
- When there is a light shelf, the upper surface of the light shelf and the ceiling have a high reflectance and the entire room is very bright.
- A light shelf is a type of overhang designed to guide direct sunlight to the ceiling. By installing a window above the light shelf, the direct sunlight is reflected on the upper surface of this overhang, entering the ceiling and expanding into the back of the room. If there is no overhang, the direct sunlight enters only the floor near the window, causing a stark contrast in brightness with the back of the room. However, an ordinary overhang blocks direct sunlight only and does not solve the contrast in brightness between the near the window and the back of the room. Light shelves can guide direct sunlight to the ceiling and brighten the back of the room, reducing the contrast between the near the window and the back of the room and creating a pleasant light environment.
- Since light shelves increase the entry of solar radiation heat, it is required to adopt proper solar shading in the summer, such as installing an overhang or blind to the window above the light shelf.



Indoor light condition (luminance distribution)

Floor illuminance distribution

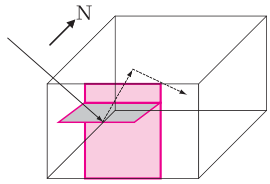


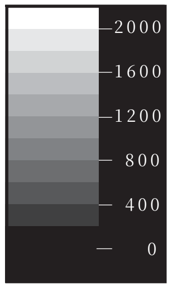
Fig. a　Without light shelf

Indoor light condition (luminance distribution)

Floor illuminance distribution

Fig. b　With light shelf

Illuminance (lx) level



■Conditions (Naha)
Target room: South-facing first floor
4 m x 4 m x 2.5 m (ceiling height)
Window dimensions:
200 cm x 200 cm (patio door);
200 cm x 50 cm (high window)
Light shelf depth: 150 cm
Reflectance: top of light shelf 0.8;
ceiling 0.9
Season and time:
Spring and fall equinox; noon

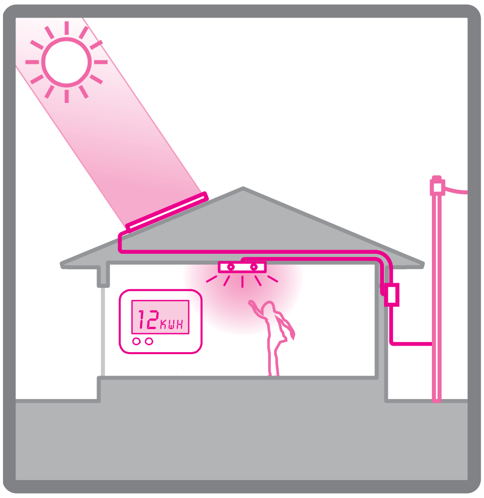
Comment ● Possibility of new daylight guiding methods including light ducts in hot humid region (Zone VI)

There are new daylight utilization methods for the areas where a daylighting path cannot be secured, such as a light duct system which guides light into the building by combining a light collector with ducts made of high reflectance materials, and a method which guides light into the building by combining a sun-tracking light collector and optical fibers. These methods are very effective when a light path can be relatively flexibly designed and daylight cannot be utilized by other means. Photos below are an example of daylight guiding for a hallway, where daylight is unavailable, and an example of introducing daylight by vertically guiding it into a room with a side window.

However, a very high daylight guiding effect also means a high solar heat gain. In Zone VI, one of the hot humid regions, it is necessary to decrease the area for collecting light, such as skylights, in order to reduce solar radiation. Moreover, due to some cost related issues for small houses, daylight guiding is not adopted except in some large-scale spaces, such as the light duct system seen in Citizen's Square within the Okinawa prefectural government building.

Therefore, technologies which can secure a wide radiating area and achieve sufficient indoor light conditions using a small light collecting area are required for Zone VI. If such technologies are developed in the future, the light duct system and other technologies will also be useful in Zone VI.

3.3 Photovoltaic Power Generation (Sunlight Utilization 2)



Photovoltaic power generation is a system that supplies the electricity consumed in a house by generating electricity using sunlight during the day. Although this requires electricity to be purchased during the night, any surplus electricity produced during the day can be sold. This improves the total power balance thereby enabling an extremely low running cost.

3.3.1 Purpose and Key Points of Photovoltaic Power Generation

- A type of photovoltaic power generation system used in houses is called a grid-connected power system (which buys and sells electricity in connection with commercial electric power systems). The amount of photovoltaic power generation largely varies depending on the weather and time of day, but it is possible to purchase electricity during the night and sell it during the day so that running costs can be reduced.
- Photovoltaic power generation provides the largest amount of power generation during the daytime in the summer when the load at power stations is the highest and sells the surplus electricity. This leads to a reduction of the load at power stations and contributes to the reduction of environmental impact from a macro perspective.
- Since solar cells used in the photovoltaic power generation system do not have a driving part it does not require any consumable supplies. The typical service life of solar cells is over 20 years for a power module that has a surface protected by tempered glass, which is extremely long compared to other equipment and devices.
- The amount of power generation depends on the site conditions, such as the duration of shady hours, and careful consideration is required for planning.
- Various verification studies are currently being conducted regarding the age deterioration of the power generation performance and efficiency of photovoltaic power generation systems (e.g. power conditioners and power modules); however such a tendency has not been identified.
- Photovoltaic power generation system distributors generally set a design life of approximately 15 years for power modules and approximately 10 years for power conditioners and provide approximately 10 years of warranty for the entire system.

* Even though the definition of design life varies among manufacturers, 90% of the nominal value is guaranteed in many cases.

3.3.2 Energy Conservation Target Levels for Photovoltaic Power Generation

The energy conservation target levels for photovoltaic power generation refer to the following levels 1 and 2 and indicate the reduction in annual primary energy consumption per household.

Level 0	:	No photovoltaic power generation
Level 1	:	Reduction in annual primary energy consumption; 33.7 GJ (approx. 3 kW of solar cell capacity)
Level 2	:	Reduction in annual primary energy consumption; 45.0 GJ (approx. 4 kW of solar cell capacity)

- The reduction here refers to the amount of photovoltaic power generation, i.e. the amount of power generation which corresponds to the capacities of solar cells (approximately 3 kW and 4 kW) that are assumed for levels 1 and 2. However, with regular residential photovoltaic power generation systems, any surplus electricity generated during the day is sold and electricity is bought during the night.

- The reduction (amount of power generation) varies from region to region and the previously-mentioned data are the values for Naha (photovoltaic panels with a tilt angle of 20°). See Table 1.

3.3.3 Photovoltaic Power Generation

1. Regional solar radiation level

The amount of sunlight (amount of solar radiation) influences the annual photovoltaic power generation. In other words, compared to the Seto Inland Sea and Pacific side of Japan, which has a large number of sunny days, the Sea of Japan side provides slightly lower power generation. It is said that, in areas such as Sapporo in Hokkaido, where there is no rainy season, the power generation is higher than Tokyo.

However, the regional difference in the power generation is approximately 10%, which means photovoltaic power generation can be adopted in any region in Japan. This is related to the fact that photovoltaic power generation is not influenced by outside air temperature unlike solar heat utilization.

Fig. 1 shows normal values of the annual mean global solar radiation and Table 1 lists examples of annual power generation in major cities (when a system with 3 kW and 4 kW of solar cell capacity is installed).

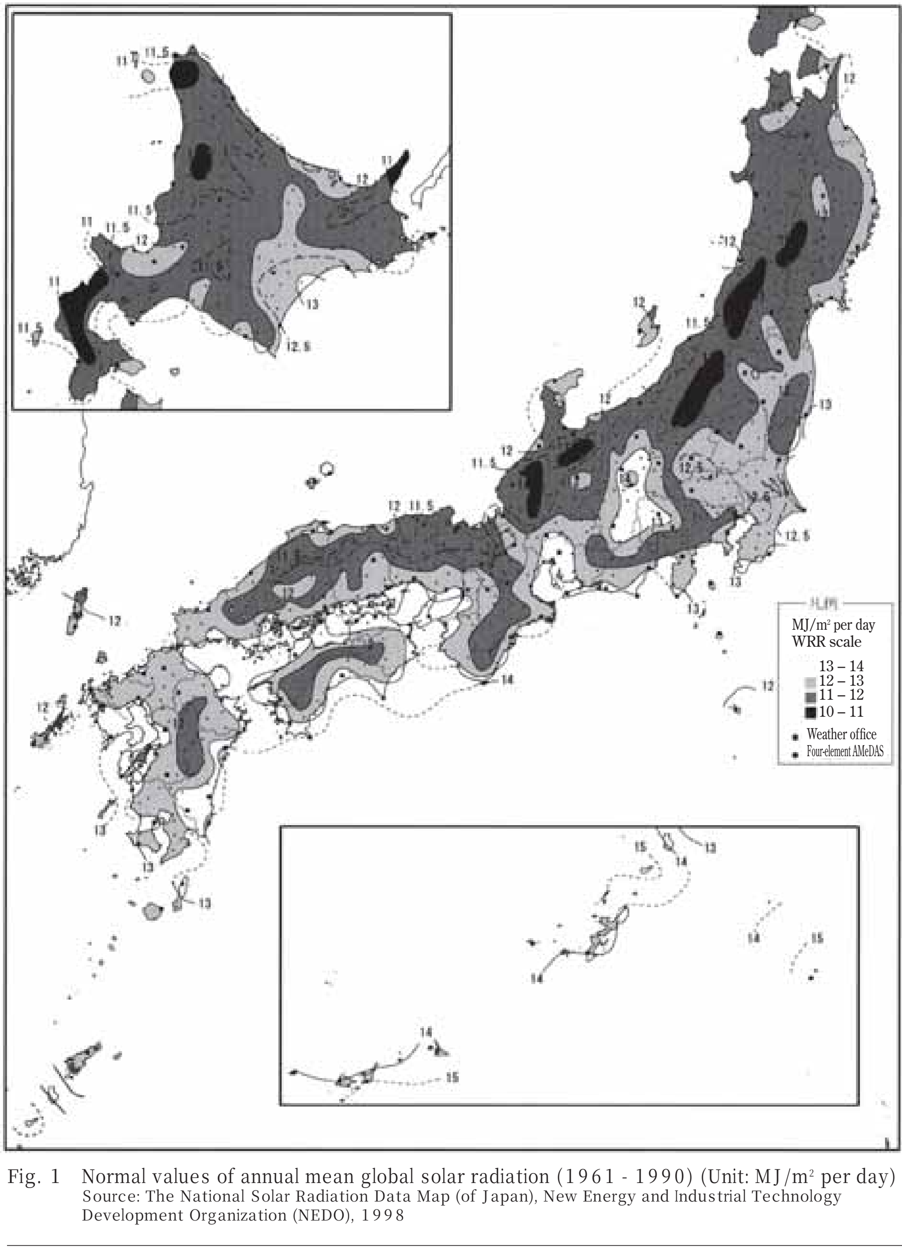


Fig. 1 Normal values of annual mean global solar radiation (1961 - 1990) (Unit: MJ/m² per day)
Source: The National Solar Radiation Data Map (of Japan), New Energy and Industrial Technology Development Organization (NEDO), 1998

Table 1 Examples of annual power generation in major cities
(Unit: GJ; primary energy conversion value)

City	Tilt angle	Solar cell capacity 3 kW	4 kW
Kochi	30°	35.3	47.1
Miyazaki	30°	34.9	46.5
Kagoshima	30°	32.7	43.6
Naha	30°	33.3	44.3
Naha	20°	33.7	45.0
Miyakojima	30°	34.0	45.3
Miyakojima	20°	34.7	46.3
Ishigakijima	30°	33.6	44.8
Ishigakijima	20°	34.2	45.6
Tokyo (reference)	30°	30.6	40.8
Sapporo (reference)	30°	31.9	42.6

Note 1: Using the Residential Solar Power Generation Simulation (June 2008) available on the Kyocera's website, the calculation was performed for a system with a capacity of 3.15 kW under the conditions of the direction (due south) and the tilt angle (30° or 20°), which was translated into 3 kW and 4 kW based on a simple ratio conversion.

Note 2: Figures in Table 1 are primary energy conversion values, and this can be converted to power generation (secondary energy conversion values; unit: kWh) by using the following formula:

$$1\text{GJ} = \frac{1}{9.76}\ \text{MWh} = \frac{1}{9.76} \times 1000\text{kWh} = 102.4\text{kWh}$$

For example, 33.7 GJ for Naha (20°) using a 3 kW solar cell can be converted as shown below

$33.7 \times 102.4 = 3450\text{kWh}$

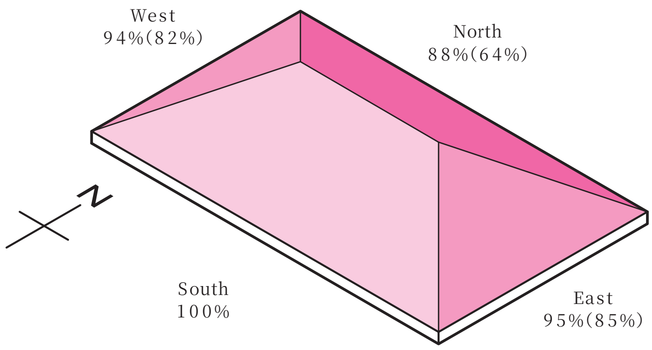
2. Direction of installation and tilt angle

The sunlight utilization efficiency depends on the installation direction and tilt angle of photovoltaic panels but it is also largely influenced by the latitude of the building site (Fig. 2, Table 2).

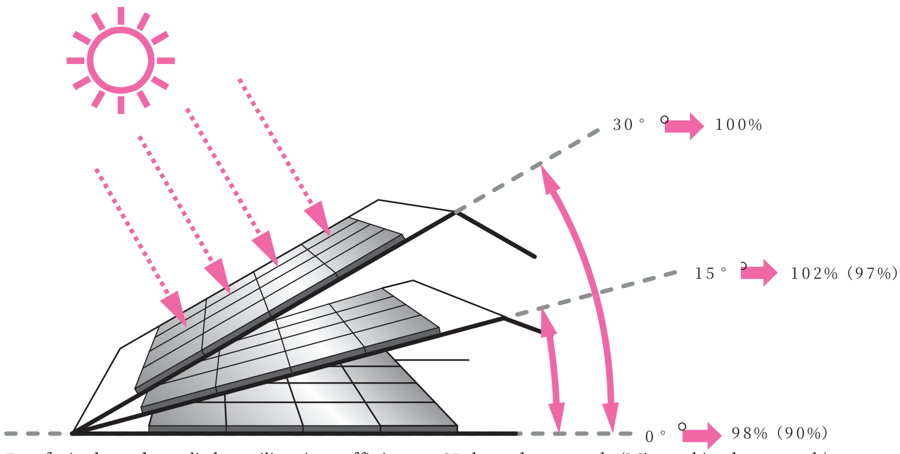
In Zone VI, the difference in utilization efficiency due to the direction of installation is not very significant. For example, in Naha, where the utilization efficiency is 100% for the system installed in due south, the sunlight utilization efficiency is 94 – 95% for east and west and approximately 88% for north installation (when the tilt angle is 20° on a roof). Additionally, with regard to the difference in utilization efficiency due to the tilt angle, the total annual power generation is predicted to become high with a tilt angle of approximately 20° when the system is installed on the south side of the roof. Even when the system is installed on a leveled surface (tilt angle of 0°), the decrease of power generation is estimated to be small.

On the contrary, in Zone V, there is a certain difference in power generation due to the direction of installation. For example, in Miyazaki, while the utilization efficiency is 100% for due south installation, it is approximately 82 – 85% for east and west and approximately 64% for north installation (when the tilt angle is 30° on a roof). This difference in power generation due to the direction is more significant when the tilt angle is larger. Moreover, regarding the difference in utilization efficiency due to the tilt angle, the efficiency becomes the highest with a tilt angle of approximately 30° when the system is installed on the south side of the roof. When this value is regarded as 100%, it is approximately 98% at a tilt angle of 20° and approximately 90% on a leveled surface. This difference is not as significant as that of the direction.

As described above, attentions should be paid to the direction and tilt angle of the panels when installing photovoltaic panels in high latitude regions. On the other hand, in low attitude regions, the roof pitch and direction can be relatively flexibly designed, as long as a sharp tilt angle is avoided, and it may be possible to install photovoltaic panels on the roof of preferred design.



Direction of installation and sunlight utilization efficiency: Naha 20° (Miyazaki 30°)



Roof pitch and sunlight utilization efficiency: Naha - due south (Miyazaki - due south)

Fig. 2 Direction of installation and tilt angle of photovoltaic panels

Table 2 Comparison of power generation by direction and tilt angle (Unit: %)

City	Upper: Latitude Lower: Longitude	Sunlight utilization efficiency by direction				Sunlight utilization efficiency by tilt angle (due south)					
		Due south	Due east	Due west	Due north	0 °	15 °	30 °	45 °	60 °	90 °
Kochi	33.6 133.6	100	83	80	60	88	97	100	98	91	63
Miyazaki	31.9 131.4	100	85	82	64	90	97	100	97	88	60
Kagoshima	31.6 130.6	100	84	83	66	91	97	100	97	88	59
Naha	26.2 127.7	100	95	94	88	98	102	100	93	83	52
Miyakojima	24.8 125.3	100	95	95	90	98	102	100	94	81	49
Ishigakijima	24.3 124.2	100	94	97	90	98	102	100	92	81	48
Tokyo (reference)	35.7 139.8	100	79	79	57	88	97	100	98	91	64

* The table above shows the calculation results based on the expanded AMeDAS weather data (1981 - 2000) issued by the Architectural Institute of Japan. The sunlight utilization efficiency by direction column shows the values calculated when the tilt angle is 20° for Naha, 15° for Miyakojima and Ishigakijima, and 30° for other cities. The utilization efficiency by tilt angle column shows the values calculated when the direction of installation is due south.

3. Local conditions

The outside brightness of the direct solar radiation on a sunny day is at least 15,000 lux, with 7,000 – 8,000 lux on a cloudy day and approximately 3,000 lux in the shade. Photovoltaic power generation is possible on a cloudy day but is impossible in the shade. Therefore, power generation may be lower than the estimated annual power generation shown in Table 1 on p.085 at sites with short sunshine hours, such as north-facing slopes and mountainous areas. It is necessary to check the seasons and time of day when the site is covered in shade and subtract the hours in which power generation is impossible.

Some sites such as mountainous areas are covered in shade in the morning and evening when the power generation efficiency is not high, so the effect may not be significant. However, in the dense urban areas, it is possible that high-rise buildings will be built in the adjacent area causing shade during hours when the power generation efficiency is high. Therefore, future development plans for the surrounding area should be also taken into consideration.

4. Cautionary advice on installing photovoltaic panels

When installing a photovoltaic panel on the roof in regions with heavy wind such as Okinawa, caution is required to prevent damage caused by storms. Consider the use of photovoltaic panels integrated into the roof or use ingenuity such as installing the panels flat on the deck roof. When using a frame, it is necessary to securely attach it to the roof (building envelope) with anchors or other means as well as to tightly fasten the main unit to the frame with bolts or other means. In regions where salt damage is a concern, rustproofing of metal parts such as frames and bolts is essential.

3

Chapter 3
Natural Energy Application Technology
(Elemental Technology Application Method 1)

* The solar cell capacity of a system refers to a total output of the solar cell module calculated according to the Japanese Industrial Standards (JIS). The output during actual use (generated output) varies depending on the solar radiation intensity, installation conditions (direction, installation angle, surrounding environment), regional differences, and temperature conditions. The maximum generated output is 70 – 80% of the solar cell capacity due to loss caused by increased temperature and other factors.

3.3.4 Test Calculation of Photovoltaic Power Generation Costs

Under the following conditions, power generation simulation was performed and calculation was conducted for Naha (Zone VI) and Miyazaki (Zone V) in order to determine the number of years it will take to recover the initial costs of installation (Table 3, Fig. 3 and 4).

Table 3 Conditions of simulation

Prerequisites	Solar cell capacity*: 3 kW (test calculation results f or an installation area of 21.9 – 23.6 m2 at 3.15 kW converted to 3 kW) Rated capacity of power conditioner: 4 kW Solar radiation data: Naha in Okinawa Prefecture, Miyazaki in Miyazaki Prefecture Data Creation and Research on Solar Radiation, NEDO and Japan Weather Association, March 1998 Module installation conditions: tilt angle; Naha 20°, Miyazaki 30°, angle of direction 0° (due south)
Conditions of test calculation	1) Loss due to increased element temperature (seasonal temperature loss): 10% (Dec. – Feb.); 15% (Mar. – May, Sep. – Nov.); 20% (Jun. – Aug.) 2) Loss rate due to wiring, soiled receiving surface, backflow preventing diode, etc.: 5.35% 3) Temperature correction factor of installation method: 1.00 (pitched roof) 4) Power conversion efficiency of power conditioner: 94.5% (replacement cost of the power conditioner is not included in this cost test calculation)

1) Test calculation results for Naha

The calculation for Naha indicates the estimated annual power generation to be 3,430 kWh (33.7 GJ).

The following shows the conversion of this amount into electricity costs (based on the unit price as of April 2009).

(1) 31.48 yen/kWh (hourly rate lighting service provided by the Okinawa Electric Power Company)
3,430 kWh x 31.48 yen/kWh = 107,976 yen

(2) 27.15 yen/kWh (meter rate lighting service provided by the Okinawa Electric Power Company)
3,430 kWh x 27.15 yen/kWh = 93,124 yen

Although not all the generated electricity is sold in reality, the calculation was performed to determine the number of years it will take to pay back the installation costs assuming that all the generated electricity is sold for simplification purposes.

If the installation cost is 2,753,000 yen (labor and material prices estimated under certain conditions; See p.356), the following number of years is required to pay back the initial costs:

(1) 2,753,000 yen / 107,976 yen = approximately 25.5 years (hourly rate lighting service provided by the Okinawa Electric Power Company)

(2) 2,753,000 yen / 93,124 yen = approximately 29.6 years (meter rate lighting service provided by the Okinawa Electric Power Company)

2) Test calculation results for Miyazaki

The calculation for Miyazaki indicates the estimated annual power generation to be 3,546 kWh (34.9 GJ).

The following shows the conversion of this amount into electricity costs (based on the unit price as of April 2009).

(1) 25.0 yen/kWh (Yoka Night 10 lighting service provided by the Okinawa Electric Power Company: rate for 80 kWh to 200 kWh)
3,546 kWh x 25.0 yen/kWh = 88,650 yen

(2) 25.0 yen/kWh (meter rate lighting service provided by the Kyushu Electric Power Company: rate for 120 kWh to 300 kWh)
3,546 kWh x 25.0 yen/kWh = 88,650 yen

Although not all the generated electricity is sold in reality, the calculation was performed to determine the number of years it will take to pay back the installation costs assuming that all the generated electricity is sold for simplification purposes.

If the installation cost is 2,546,000 yen (labor and material prices estimated under certain conditions; See

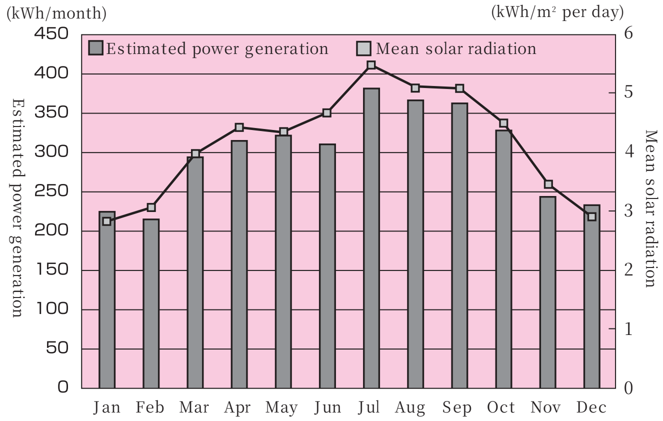


Fig. 3 Monthly mean solar radiation and simulation results of estimated photovoltaic power generation (Naha)

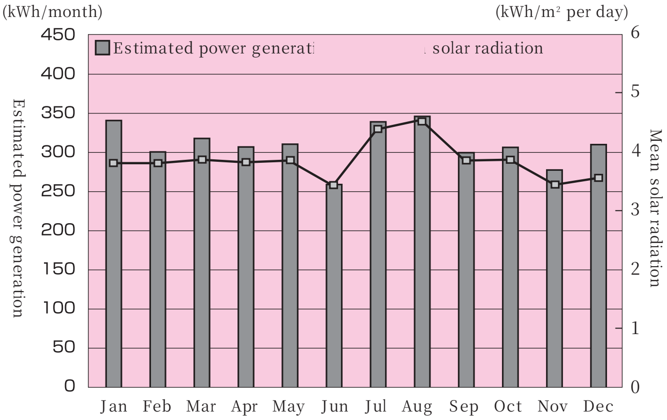


Fig. 4 Monthly mean solar radiation and simulation results of estimated photovoltaic power generation (Miyazaki)

p.362), the following number of years is required to pay back the initial costs:

(1) 2,546,000 yen / 88,650 yen = approximately 28.7 years (Yoka Night 10 lighting service provided by the Okinawa Electric Power Company: rate for 80 kWh to 200 kWh)

(2) 2,546,000 yen / 88,650 yen = approximately 28.7 years (meter rate lighting service provided by the Kyushu Electric Power Company: rate for 120 kWh to 300 kWh)

The above simulation results suggest that initial costs can be paid back in 25 to 30 years depending on the rate scheme; however electricity costs vary according to the year and electric power company, thus careful attention is required.

Subsidies are available that help reduce the initial costs. For example, the Ministry of Economy, Trade and Industry of Japan offers residential solar generation installation subsidies for fiscal year 2009 in accordance with the Implementation Guidelines for Subsidy for Assisting Residential Solar Generation Installation. This subsidy provides 70,000 yen per nominal output of a 1 kW solar cell module constituting an eligible photovoltaic power generation system that meets the requirements. There are also prefectural and municipal subsidies programs that vary locally, and by combining these programs a further reduction in initial costs can be achieved.

On February 24, 2009, the Ministry of Economy, Trade and Industry announced that it would introduce a new program that imposes a mandatory obligation on electric power companies to purchase the surplus electricity generated by photovoltaic power systems at prices nearly double that of the current level. The details including the electricity purchase price, commencing time and application period are to be determined, but if this program were implemented in 2010 for 10 years, it is expected that the number of years required for paying back the initial costs mentioned above would significantly be reduced and the number of installations would increase.

For example, if these subsidies and the electricity purchase program are applied in Naha and the annual estimated power generation is converted into electricity cost, the payback time is approximately 20.6 years as shown below, which is five to nine years less than the current level.

Current

3,430 kWh x 31.48 yen/kWh = 107,976 yen

When the electricity purchase price has doubled

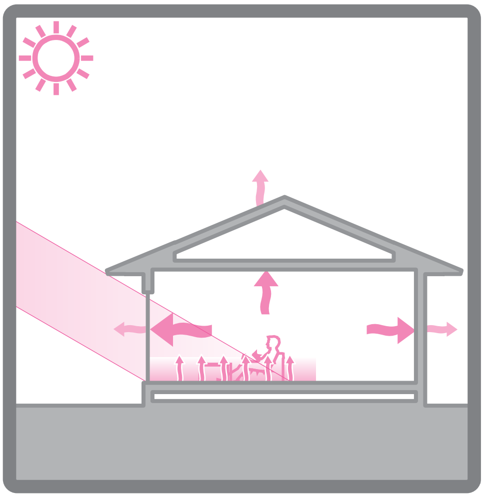
3,430 kWh x 0.5 x 31.48 yen + 3,430 kWh x 0.5 x 50.00 yen = 139,738 yen

Payback time of initial costs

(2,753,000 yen − 210,000 yen − 1,397,000 yen) / 107,976 yen + 10 years = approximately 20.6 years

* The hourly rate lighting service provided by the Okinawa Electric Power Company is applied to the electricity consumed at the house. The electricity selling price is set based on an assumption that half of the electricity produced by photovoltaic power generation is sold at double the electricity purchase price of the hourly rate lighting service for 10 years.

3.4 Solar Radiation Heat Utilization for Zone V (Solar Heat Utilization 1)



The basics of reducing heating energy are to decrease heat loss from buildings. Additionally, we can also reduce heating load by increasing the heat gained by buildings.

Solar radiation is the most significant cause of heat gain, and solar houses are designed to actively positively proactively utilize solar heat in heating. Of these solar heating plans, a method for obtaining natural heating effects using solar heat in buildings is called passive solar heating. Among those houses, a method for obtaining natural heating effects mainly by envelope design is called passive solar heating. It is important to design a house by maintaining the balance of the three architectural techniques—heat collection, thermal insulation of openings and heat storage—while taking into account the regional climate characteristics and site conditions. Solar heat utilization technology is not applicable to Zone IV, which is warm in winter.

3.4.1 Purpose and Key Points of Solar Radiation Heat Utilization

- Utilization technology of solar radiation heat is effective in reducing heating energy consumption in winter. Here, we will discuss architectural technology that obtains solar heat from openings and effectively utilizes it.
- Solar heat radiation gain and utilization can be achieved using the three methods: increasing the amount of heat gain (heat collection), controlling heat gain loss (insulation), and effectively utilizing heat gain while preventing a decrease in room temperature (heat storage). It is vital to efficiently combine these methods according to the regional climate characteristics and site conditions and minimize the room temperature variation in an effort to maintain the heat balance of buildings.
- Major components that obtain solar radiation heat are glass window openings. In order to increase solar heat gain, it is necessary to make floor and opening planning based on the directions and sizes, such as placing major openings on the south.
- Glass windows are heat collection areas as well as significant heat loss areas in general. Expanding the heat collection window area to increase solar heat gain results in the dilemma of increasing heat loss. Therefore, the specification for the openings needs to consider the heat balance. Glazing has a high solar transmittance and the greater the insulation performance of glazing and frames, the better heat balance.
- In winter, most heat gain occurs during the day when solar radiation is available, and heat loss continues all day. Generally, heat loss is lower during the day than at night when the outside air temperature decreases. Therefore, in order to maintain stable room temperature, it is effective not only to retain the heat balance all day but also to supplement the heat loss at night by receiving the heat gain that exceeds the heat loss during the day. This requires heat storage technology that carries heat over from the day to the night.
- Although solar radiation gain and utilization technology provides heating effects in winter, it is important to plan opening areas that allow for both solar radiation gain and shading as we also need to consider the cooling energy reduction effects using solar shading schemes in summer (See Section 4.3 Solar Shading Methods for Zone V on p.188 for solar shading).

3.4.2 Energy Conservation Target Levels for Solar Radiation Heat Utilization

1. Definition of target levels

• Energy conservation target levels for solar radiation heat utilization are divided into the following levels 1 to 4 and indicate the reduction rate of energy consumed by heating systems.

Level 0	:	Heating energy reduction rate	None
Level 1	:	Heating energy reduction rate	Approx. 5%
Level 2	:	Heating energy reduction rate	Approx. 10%
Level 3	:	Heating energy reduction rate	Approx. 20%
Level 4	:	Heating energy reduction rate	Approx. 40%

• The typical heating energy consumption in 2000 was 5.0 GJ (approximately 7% of total energy consumption) (See Section 6.1 on p.339).

• Any target level can be achieved by combining the regional climate characteristics, site conditions (influence of obstruction of sunlight), building direction (direction of opening serving as heat collection area), and methods for utilizing solar radiation heat to be adopted.

2. Requirements for achieving target levels

1) Regional climate characteristics (Passive solar zone classification)

• Effectiveness of solar radiation heat gain and utilization is largely related to regional climate characteristics. Here, we focus on solar radiation characteristics and coldness in winter among regional climate characteristics. The passive solar zone classification (PSP) refers to the classification of regional solar radiation characteristics based on solar radiation level and temperature in winter. This categorizes Japan into five zones from Zone A to Zone E. Zones C to E, which have high solar radiation levels, belong to Zone V. Zone V includes Zones C to E, which have high solar radiation levels.

Zone A	:	Very cold region with low solar radiation level
Zone B	:	Cold region with low solar radiation level
Zone C	:	Cold region with high solar radiation level
Zone D	:	Region with high solar radiation level
Zone E	:	Warm region with high solar radiation level

• Passive solar zone classification map (PSP classification map) showing distribution of the PSP classification and corresponding prefecture and municipality list are provided in Appendix 1 Zone Classification Data on p.384.

Key Point

Passive Solar Potential (PSP)

• PSP refers to the ratio of the mean solar radiation levelheating degree days in January (sum of the difference between 18°C room temperature and mean outside air temperature of days in which daily mean outside air temperature falls below 18°C) to the heating degree daysmean solar radiation level in January (sum of the difference between 18°C room temperature and mean outside air temperature of days in which daily mean outside air temperature falls below 18°C), and indicates the possibility of solar radiation utilization in the region.

• PSP is the highest in warm regions with less heating degree days and high solar radiation and the lowest in cold regions with more heating degree days and low solar radiation.

• Compared to the regional classification created based on heating degree days, PSP classification is clearly influenced by solar radiation level. Zone V and pacific side of Zone IV, which are classified in the 1999 energy conservation standard, are areas with some of the highest solar radiation levels in the world and solar radiation can be easily utilized for heating. In Zone A of the PSP classification, we cannot expect much solar heat to be used for heating while solar heat utilization is highly effective in Zone E.

* The PSP classification was changed with the original five zones consolidated into three based on the amendment of the energy conservation standard in April 2009. However, in this document we use the five zones which conform to the original standard that was issued in 1999.

3

Chapter 3
Natural Energy Application Technology
(Elemental Technology Application Method 1)

2) Site conditions (influence of obstruction of sunlight)

- Effectiveness of solar radiation heat gain and utilization is greatly linked to the influence of obstruction of sunlight received by the building, i.e. sunshine hours of the planned building.
- If solar radiation is obstructed in winter because of tall buildings around the building site, it is difficult to gain and utilize solar radiation. It is necessary to investigate prior to the design process any factors causing obstruction of sunlight to the planned building, such as objects blocking the sun, topography and influences of trees.
- Here, we have divided the building site into the following three categories according to the influence of obstruction of sunlight (Table 1).

Table 1 Site classification by influence of obstruction of sunlight

Classification	Degree of obstruction of sunlight	Guideline for sunshine hours (winter solstice)
Site 1	Site with large influence of obstruction of sunlight (approx. 50%) where solar radiation heat utilization is difficult	At least 3 hours (e.g. only 3 hours of sunlight between 10:30 and 13:30)
Site 2	Site with small influence of obstruction of sunlight (approx. 25%) where solar radiation heat utilization is possible	At least 5 hours (e.g. 5 hours of sunlight between 9:30 and 14:30)
Site 3	Site with no influence of obstruction of sunlight (0%) where solar radiation heat utilization is easy	Sunlight can be received all day

* Degree of obstruction of sunlight (%) refers to a ratio of the solar radiation level that is blocked by buildings and other objects and cannot be used to the solar radiation level that is not blocked by surrounding buildings and other objects and can be used (total solar radiation) during a winter day (8:00 – 17:00).

- If the building site is applicable to Site 1 classification, hardly any heating effects can be expected even when methods for utilizing solar radiation heat are adopted.

Key Point

How to check sunshine hours

- Sunshine hours can be checked by taking the following steps after surveying the position and height of surrounding buildings.
  ①Create a sun shadow diagram (or sky diagram) using a sun-shadow simulation tool.
  ②Read sunshine hours at the point that is estimated as the major opening surface position of the planned building using a sun shadow chart (sunshine curve measurement scale).
- The central area of the height of the first floor opening (approximately 1.5 m from the ground level) is considered appropriate for the height of the measuring point of sunshine hours here.
- The diagram below is a sun shadow diagram of ground level plus 1.5 m in height at winter solstice using a two-storey house as an example. It was confirmed that at least 5 hours of sunlight (equivalent to Site 2 classification) can be received at point (C) which is set approximately 5.5 m in recess of the north lean-to roof of the house.

■Measurement conditions
Measurement date: Winter solstice
Measurement place: Kagoshima (Zone E)
Measurement time: 8:00 – 17:00
Measurement height: Ground level + 1.5 m

■Building conditions
Maximum height: Approx. 7.4 m (eaves)
Eave height: Approx. 6.0 m (upper roof)
Approx. 3.3 m (lean-to roof)
Width x depth:
10.32 m x 7.735 m (5.46 m for second floor)

Table: Sunshine hours at specific points

Point	Recess distance	Sunshine hours	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h
A	4.5 m	Approx. 2.5 hrs.										
B	5.0 m	Approx. 4.5 hrs.										
C1	5.5 m	Approx. 6.5 hrs.										
C2	5.5 m (4 m to west)	Approx. 6.5 hrs.										
C3	5.5 m (4 m to east)	Approx. 5.5 hrs.										

* Lines indicate shady hours.

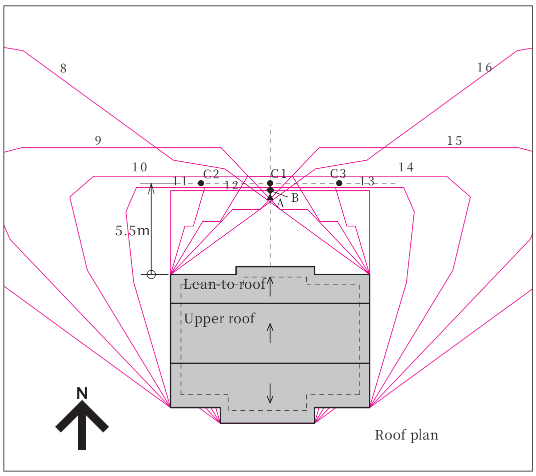


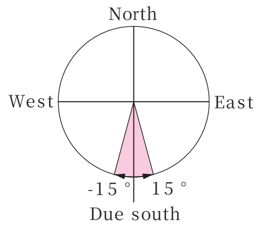
Fig. Example of sun shadow diagram of two-storey house

3) Building direction (direction of opening serving as heat collection area)

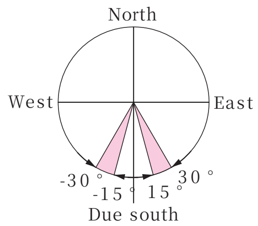
- Effectiveness of solar radiation heat gain and utilization is largely related to the direction of opening which serves as the heat collection area.
- Direction of opening* is effective in terms of heat collection, if it is within 30° east or west of due south, regardless of the regional classification. If it exceeds 30° from due south the heat collected from the opening drastically decreases.
- Therefore, the direction of opening aimed for heat collection must be within 30° of due south and the following two categories within this range are used with due south as the baseline:

Direction 1	:	Due south ±15 °
Direction 2	:	Due south ±30 ° (excluding range of Direction 1)

* "Direction of opening" refers to the orientation of the normal line from the opening toward the outside (i.e. from the interior to the exterior in a direction perpendicular to the straight line connecting both ends of the opening).



Direction 1



Direction 2

4) Methods for utilizing solar radiation heat

- This document covers the following methods for utilizing solar radiation heat that are effective in reducing heating energy.

Method 1	:	Insulation method for openings (enhanced insulation performance of openings)
Method 2	:	Method for collecting heat from openings (enlarged opening area for heat collection)
Method 3	:	Heat storage method (use of heat storage material)

- Of the three methods, Method 2 is not very effective if used alone. On the other hand, Method 1 and Method 3 are somewhat effective even when used alone, however a combination of these methods achieve higher energy saving effects. In order to obtain energy saving effects, it is necessary to adopt one of the following methods (or combinations).
  - Method 1
  - Method 3
  - Method 1 + Method 2
  - Method 1 + Method 3
  - Method 1 + Method 2 + Method 3
- Details of each method will be explained in Section 3.4.4 Solar Radiation Heat Utilization Methods.

3. How to achieve target levels

- Energy conservation target levels for solar radiation heat utilization are determined by site conditions (influence of obstruction of sunlight), building direction, and the use of methods for utilizing solar radiation heat.
- Tables 2 - 4 on p.094 show the correspondence between target levels and methods for each passive solar zone classification. Methods that have energy saving effects and energy reduction rate vary depending on the region.
- The heating energy reduction rate of each level is based on heating energy consumption in respective region. Even when the target level is the same, heating load is higher in Zone D of Table 3 and Zone C of Table 4 than Zone E of Table 2.

- In order to achieve the target level for low energy housing with validated effectiveness (LEHVE), the following conditions a and b need to be satisfied in terms of housing insulation level and opening area for heat collection:
  a. Housing insulation level: at least Level 3 (equivalent to the 1999 energy conservation standard
     (See Section 4.1 Insulated Building Envelope Planning for Zone V for details of insulation levels.)
  b. Opening area for heat collection: at least 10% ratio of opening area for heat collection to total floor area
     (The direction of openings for heat collection must be within 30° east or west of due south.)

Table 2 Target levels for solar radiation heat utilization and how to achieve them (Zone E: Kagoshima)

Target level	Energy saving effect (heating energy reduction rate)	Method to be adopted			
		Site 3: 0% obstruction of sunlight		Site 2: 25% obstruction of sunlight	
		Direction 1 Due south ±15 °	Direction 2 Due south ±30 ° (excluding Direction 1)	Direction 1 Due south ±15 °	Direction 2 Due south ±30 ° (excluding Direction 1)
Level 1	Approx. 5%		Method 3	Methods 1 + 3	
Level 2	Approx. 10%	Method 3	Method 1	Methods 1 + 2	Methods 1 + 2 + 3
Level 3	Approx. 20%	Method 1 Methods 1 + 2 Methods 1 + 3	Methods 1 + 2 Methods 1 + 3	Methods 1 + 2 + 3	
Level 4	Approx. 40%	Methods 1 + 2 + 3	Methods 1 + 2 + 3		

Table 3 Target levels for solar radiation heat utilization and how to achieve them (Zone D)

Target level	Energy saving effect (heating energy reduction rate)	Method to be adopted			
		Site 3: 0% obstruction of sunlight		Site 2: 25% obstruction of sunlight	
		Direction 1 Due south ±15 °	Direction 2 Due south ±30 ° (excluding Direction 1)	Direction 1 Due south ±15 °	Direction 2 Due south ±30 ° (excluding Direction 1)
Level 1	Approx. 5%*			Method 1 Methods 1 + 3	Methods 1 + 2
Level 2	Approx. 10%*	Method 1	Method 1	Methods 1 + 2 + 3	Methods 1 + 2 + 3
Level 3	Approx. 20%*	Methods 1 + 2 Methods 1 + 3	Methods 1 + 2 Methods 1 + 3 Methods 1 + 2 + 3		
Level 4	Approx. 40%*	Methods 1 + 2 + 3			

* Indicated values are based on Nagasaki and heating load is estimated to be 1.5 times higher than Kagoshima.

Table 4 Target levels for solar radiation heat utilization and how to achieve them (Zone C)

Target level	Energy saving effect (heating energy reduction rate)	Method to be adopted			
		Site 3: 0% obstruction of sunlight		Site 2: 25% obstruction of sunlight	
		Direction 1 Due south ±15 °	Direction 2 Due south ±30 ° (excluding Direction 1)	Direction 1 Due south ±15 °	Direction 2 Due south ±30 ° (excluding Direction 1)
Level 1	Approx. 5%*			Method 1 Methods 1 + 3	Methods 1 + 2
Level 2	Approx. 10%*	Method 1	Method 1 Methods 1 + 3	Methods 1 + 2 Methods 1 + 2 + 3	Methods 1 + 2 + 3
Level 3	Approx. 20%*	Methods 1 + 2 Methods 1 + 3 Methods 1 + 2 + 3	Methods 1 + 2 Methods 1 + 2 + 3		

* Indicated values are based on Fukuoka (Hakata-ku) and heating load is estimated to be 1.6 times higher than Kagoshima.

3.4.3 Steps for Examining Solar Radiation Heat Utilization Technology

Step 1 Checking and examining possibility of solar radiation heat gain and utilization

1) Check regional climate characteristics (passive solar zone classification)
2) Check site conditions (influence of obstruction of sunlight)
3) Check building direction (direction of opening serving as heat collection area)

▼

Step 2 Checking and examining possibility of solar radiation heat gain and utilization

1) Ensuring housing insulation level (at least Level 3)
2) Ensuring opening area for heat collection (at least 10% of total floor area)

▼

Step 3 Considering insulation method for openings (Method 1)

• Enhanced insulation performance of openings (e.g. adoption of low heat transmission coefficient)

▼

Step 4 Method for collecting heat from openings (Method 2)

• Enlarged opening area for heat collection (at least 20% of total floor area)

▼

Step 5 Heat storage method (Method 3)

• Use of heat storage material (adoption of materials and construction methods that can provide heat capacity increase)

3.4.4 Solar Radiation Heat Utilization Methods

Method 1: Insulation method for openings (Enhanced insulation performance of openings)

- The lower the heat loss from buildings, the lower the solar radiation heat that needs to be collected. Therefore, if we can secure sufficient insulation performance the possibility of solar radiation utilization increases.
- In order to reduce the heat loss from buildings, it is necessary to increase the level of insulated building envelope planning for the entire building. In particular, insulation methods for openings that are at high risk of being areas of significant heat loss are important.

1) Points to note when choosing materials for openings

① Glazing specification

- Glazing is required not only to minimize heat loss but also to increase heat gain. Because of this, it is generally believed that it is effective to choose glazing that is high in insulation performance (low heat transmission coefficient) as well as in solar transmittance.

② Frame specification

- In order to enhance insulation performance of window frames, it is also effective to make fittings and fixtures using wood, resinvinyl or other less heat conductive materials that are high in insulation performance.
- As air tightness of sashes affect heat loss from openings, it is desirable to use airtight sashes.

2) Insulation performance requirements for openings (heat transmission coefficient of openings)

- Table 5 shows heat transmission coefficients of openings and examples of opening specifications that are required for adopting Method 1. All openings are considered here, in principle.

Table 5 Requirements for insulation performance of openings (Method 1)

Heat transmission coefficient of openings*	Example of frames and glazing
2.91 (W/m²・K) or below	・Wood or plastic sash + double glazing (A12) ・Metal frame with thermal break + low-E double glazing (A12)

* For insulation performance (heat transmission coefficient) of openings, see Section 4.1 Insulated Building Envelope Planning for Zone V on p.153.

Key Point

Relationship between regional climate characteristics and glazing specification

- In terms of the relationship between glazing specification and regional climate characteristics, it is generally desirable in many cases to choose double glazing that has medium insulation performance and high solar transmittance in Zones D and E where solar radiation level is high, and low-E double glazing that has high insulation performance in Zones A and B where solar radiation level and outside air temperature are low.
- It is necessary to examine the specifications for glazing while considering solar shading schemes in summer. Solar radiation should be controlled in both winter and summer using solar shading schemes including overhangs, eaves, and curtains and other window coverings, for example (See Section 4.3 Solar Shading Methods for Zone V). However, if the curtain and other window coverings are open, energy saving effects through solar radiation heat utilization will further increase.

Comment ● Space structuring method in consideration of heat balance

By separating the heat collection space and heat collection components from the living space, it is easy to control the indoor heat balance. A buffer space such as a roofed veranda or sunroom is an example of separating the heat collection space from the living space.

It is also very effective to locate auxiliary rooms, such as bathrooms, washing rooms or storage rooms, where thermal environmental performance is not as critical as that of the living space, in the north as areas for preventing cold air.

Method 2: Method for collecting heat from openings (enlarged opening area for heat collection)

- Although openings lead to significant heat loss, south-facing openings often have a positive daily heat balance and it is effective to enlarge opening area that serves as a heat collection area. However, as this is related to the regional climate characteristics and glass window specifications, it is desirable to consider these factors.
- Table 6 shows the required opening area for adopting Method 2. Here, we will discuss openings facing due south ±30° that can serve as heat collection area.

Table 6 Requirements for opening area for heat collection (Method 2)

Opening area for heat collection	Remarks
At least 20% of total floor area	• Applicable to openings facing due south ±30° that can serve as heat collection area

- The opening area referred to here is based on "sash inside width x sash inside height" similar to when calculating the effective daylighting area according to the Building Standard Law of Japan.

Key Point

Relationship between regional climate characteristics and opening area

- In terms of the relationship between regional climate characteristics and opening area, it is generally more effective to enlarge the opening area in Zones D and E where solar radiation level is high. On the other hand, as the opening area becomes larger, the heat balance tends to be unfavorable in Zone A where solar radiation level is low.

Key Point

Relationship between direction and size of opening

- Consideration for the direction of opening also influences the size of opening. If the opening area is enlarged but the amount of solar radiation gain is low, heating load will increase due to heat loss from the openings. Therefore, the larger the opening, the more necessary it is to design the direction of the opening to be as close as possible to due south and adopt schemes to effectively obtain solar radiation. On the other hand, the smaller the opening, the less influence the direction of the opening has.

3

Chapter 3
Natural Energy Application Technology
(Elemental Technology Application Method 1)

Glossary: Heat capacity
This refers to the amount of heat that is required to raise the temperature of the material by the unit temperature. Generally, heat capacity of a uniform material can be obtained from the multiplication of specific heat and volume or weight.

Method 3: Heat storage method (Use of heat storage material)

- Heat storage is technology which effectively maintains a stable room temperature. It prevents the overheating of the room by absorbing heat during the day and the decrease of room temperature by releasing the absorbed and stored heat at night. Conversely, it stores cool air (cold storage) at night in summer and provides cooling effects during the day.
- Building components that are effective in heat storage include floors, exterior walls, partition walls and ceilings.
- Furniture, equipment and other living necessities are used in the house and the heat capacity of these objects also brings about heat storage effects.

1) Materials for heat storage components

- It is appropriate to use the materials for heat storage components which have the following characteristics:
  ① Having large heat capacity (volumetric specific heat);
  ② Being heat conductive; and
  ③ Quick heat absorption and emission from the surface.
- The most important characteristic of the above is the heat capacity. The larger the heat capacity of the heat storage component, the more stable and less variable the room temperature. Although this is the same as when heating is used, the room is less likely to be heated if materials with large heat capacity are used. However, once the room is heated these materials keep the room from losing heat.
- The heat capacity can be obtained using the following formula:
  Heat capacity (kJ/°C) = volume of heat storage component (m^3)
  x volumetric specific heat of heat storage material (kJ/m^3・°C)
- The volumetric specific heat of major materials is shown in Table 7 for reference purposes.

Table 7 Volumetric specific heat and effective thickness of major materials

Material	Effective thickness (m)*		Volumetric specific heat (kJ/m^3・°C)
Concrete	Regular concrete	0.20	2013
	Lightweight concrete	0.07	1871
Plastering material	Mortar	0.12	2306
	Lime plaster	0.13	1381
	Plaster	0.07	2030
	Wall clay	0.17	1327
Lumber	Pine	0.03	1624
	Cedar	0.03	783
	Japanese cypress	0.03	933
	Lauan	0.04	1034
	Plywood	0.03	1113
Gypsum, etc.	Plasterboard	0.06	854
	Perlite board	0.06	820
	Flexible board	0.12	1302
	Wood wool cement board	0.06	615
Other	Tile	0.12	2612
	Rubber tile	0.11	1390
	Linoleum	0.15	1959

* Materials have an "effective thickness" which can be considered as part of heat storage component. When calculating the volume of a material, if the actual thickness of the material is greater than the effective thickness, the maximum level we can include in the calculation is the effective thickness. This indicates that heat storage effects of a material having a thickness greater than the effective thickness are low. The more heat conductive the material, the greater the effective thickness.

2) Requirements for heat storage components (heat capacity)

- Table 8 shows the heat capacity of heat storage components which is required for adopting Method 3.

Table 8 Requirements for heat storage components (Method 3)

Heat capacity of heat storage components
Use materials that are expected to have heat capacity increase of at least 170 (kJ/°C・m²) for heat storage components per unit floor area

- In the case of wooden houses, in order to satisfy the requirements shown in Table 8, for example, mud-plastered walls are used for exterior and partition walls and slab on grade floors can be designed using materials with large heat capacity. The calculation examples of using mud-plastered walls and slab on grade floors as heat storage components are shown below for reference purposes:

Heat capacity = heat storage component area volume x volumetric specific heat of heat storage material

$$= 210\ (m^2) \times 0.07\ (m) \times 1327\ (KJ/m^3 \cdot °C)$$
$$+ 20\ (m^2) \times 0.15\ (m) \times 1327\ (KJ/m^3 \cdot °C)$$
$$= 25{,}546\ (KJ/°C)$$
$$> 25{,}500 = 150\ (m^2) \times 170\ (KJ/m^2 \cdot °C)$$

■ Calculation conditions

Total floor area	150 m²
Heat storage component	Exterior/partition walls: mud-plastered wall (area: 210 m², thickness: 70 mm) Slab on grade floor: concrete floor (area: 20 m², thickness: 150 mm)

3) Points to note when designing heat storage components

- In order to ensure heat storage effects, it is important to pay attention to the following points when designing a house:

①Position of heat storage components

- Heat storage effects become more apparent if the heat storage component receives direct solar radiation and the amount of solar radiation heat increases. However, heat storage effects can be expected even if the component does not receive direct solar radiation.

②Area of heat storage components

- The greater the area of heat storage components, the higher the heat storage effects. It is desirable to design a wide and shallow heat storage area.

③Thickness of heat storage components

- When considering the thickness of heat storage components, keep in mind that the heat storage performance of a material will not change if the thickness exceeds the effective thickness. For example, it is effective to choose 15 – 20 cm of thickness when using stone or concrete.
- Even if the thickness of the heat storage component is small, a certain level of heat storage effects can be achieved. If cork is used for floors as a finish, heat storage effects although slightly lower are observed.

Comment ● Systems for heat storage

There are two heat storage systems: direct and indirect heat storage systems.

①Direct heat storage system

This system directly gives and receives heat via radiation and convection using floors, walls, ceilings and other heat storage components within the living space. It consists of a direct gain system which uses the same surface for heat absorption and emission and a trompe wall system in which the heat absorbed from a surface penetrates through the heat storage component and emitted from the opposite surface.

②Indirect heat storage system

In this system, the heat collection section is separated from the heat storage section and heat is transferred in-between these sections. This system is available in different varieties, such as a stationary greenhouse type in which the heat collection section belongs to the living space, and an outdoor air-collecting type that is installed independently on the roof. Other varieties include a method in which a water bag is installed between wood joists and a method which sends indoor air to the crawl space and stores heat on the slab on grade floor.

3.4.5 Estimating Effects of Adopting Solar Radiation Heat Utilization Methods

1. Trial calculation methods

This section shows the trial calculation results of the heating load reduction effects achieved by the three methods using Solar Designer ver. 5.0. These three methods improve the indoor thermal environment in winter and save heating energy by utilizing solar radiation heat as explained in Section 3.4.4.

Seven cities are selected from Zones C, D and E of different PSP classification, which all belong to Zone V (Table 9), and heating load calculation is performed using the standard building model (Fig. 1, Table 10). Heating hours and other conditions are shown in Table 11. Additionally, in order to examine the influence of obstruction of sunlight and building direction, we performed the calculation by combining two conditions of obstruction of sunlight; 0% and 25% and three conditions of building direction; 0°, 15°, 30° from due south.

Table 9 PSP classification and regions

PSP classification	City
Zone E	Kagoshima
Zone E	Miyazaki
Zone E	Kochi
Zone D	Nagasaki
Zone D	Yatsushiro
Zone C	Fukuoka (Hakata)
Zone C	Shimonoseki
Zones VI, D	Tokyo (reference)

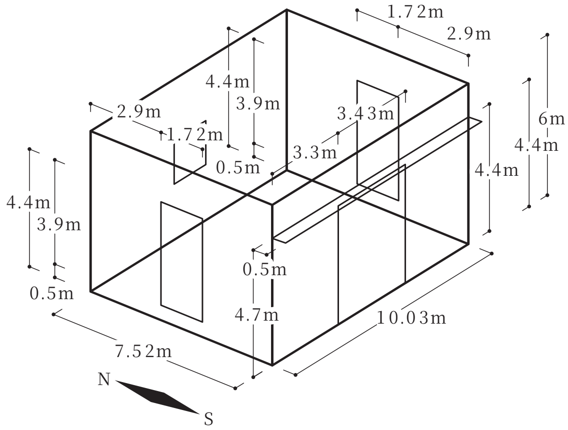


Fig. 1 Outline drawing of standard building

Table 10 Specifications of standard building

Specifications			
Building direction		Due south	
Building shape		Width: 10.03 x Depth: 7.52 x Height 6.0 (m)	Raised floor
Total floor area		151.0 (m²)	
Overhang		Depth: 0.5 (m), Height: 4.7 (m)	
South opening	Size	Depth: 3.43 x Height 4.40 (m)	
	Position	Spanerel wall height: 0 (m)	Distance from west wall: 3.3 (m)
East opening	Size	Depth: 1.72 x Height 3.90 (m)	
	Position	Spanerel wall height: 0.5 (m)	Distance from south wall: 2.9 (m)
West opening	Size	Depth: 1.72 x Height 3.90 (m)	
	Position	Spanerel wall height: 0.5 (m)	Distance from north wall: 2.9 (m)
Opening glazing	Heat transmission coefficient	4.65 (W/m²·K)	
	Solar transmittance	0.83	
	Sash ratio	0.85	
Floor finish	Thickness	Cedar	
	Thermal conductivity	0.12 (W/m²·℃)	0.1032 (kcal/m²·h·℃)
	Volumetric specific heat	783 (kJ/m²·℃)	187.0 (kcal/m²·℃)
Floor	Heat storage thickness	Plywood	
	Insulation thickness	0.1420 (m)	
Wall	Heat storage thickness	Plasterboard	
	Insulation thickness	0.0950 (m)	
Roof*	Heat storage thickness	Concrete	
	Insulation thickness	0.1980 (m)	
Indoor solar absorptance		0.2	
Outdoor solar absorptance		0.9	
Opening area not used for heat collection		2.69 (m²)	
Insulation	Thermal conductivity	0.043 (W/m²·℃)	0.037 (kcal/m·h·℃)
	Volumetric specific heat	33.5 (kJ/m²·℃)	8.0 (kcal/m²·℃)

* Specifications for standard building roof are calculated by adding the heat capacity of furniture, equipment and other living necessities to the heat capacity of roof and converting it into concrete.

Table 11 Heating and other system mode settings

Mode setting			
Heating	Temperature setting 18℃		
	Duration	7:00-10:00 12:00-14:00 16:00-23:00	
Air change rate		0.5 ACH (24h)	
Indoor generated heat	Daily total	57.348 MJ/day (13,700 kcal/day)	
	Breakdown by time period	0.2326kW [200kcal/h]	14:00-16:00
		0.3488kW [300kcal/h]	13:00-14:00 16:00-17:00
		0.4652kW [400kcal/h]	10:00-12:00
		0.5814kW [500kcal/h]	00:00-07:00 09:00-10:00
	0.6977kW [600kcal/h]	08:00-09:00	12:00-13:00
			17:00-18:00
		0.8140kW [700kcal/h]	07:00-08:00
		1.0465kW [900kcal/h]	18:00-00:00

2. Detailed settings of methods

1) Insulation method for openings (Method 1)

Four types of specifications, A to D, have been set for openings (Table 12).

2) Method for collecting heat from openings (Method 2)

There are two types of ratio, 10% and 20%, for the ratio (Ag/Af) of the south-facing opening area for heat collection (Ag) to the total floor area of a house (Af) as shown in Table 13.

3) Heat storage method (Method 3)

Two types of volumetric specific heat, equivalents of plasterboard and mud-plastered wall, have been set for the indoor heat collection storage components (Table 14).

Table 12 Opening specifications for examination

	Heat transmission coefficient (W/m²・K)	Heat transmission coefficient (kcal/ m²・h・K)	Solar transmittance	Example specifications
A	6.51	5.5986	0.90	Metal frame + single glazing
B	4.65	3.9990	0.83	Metal frame + double glazing
C	2.91	2.5026	0.70	Metal frame with thermal break + low-E double glazing
D	1.80	1.5480	0.66	Wood sash + low-E double glazing + insulating shutter

* Specifications B are for basic building

Table 13 Opening area for heat collection for examination

Ag/Af	Opening area for heat collection (m²)	Opening width (m)	Distance from west wall (m)
10	15.10	3.43	3.30
20	30.20	6.86	1.58

* Ag/Af = 10 (%) is the specification for basic building.

Table 14 Settings for volumetric specific heat of heat collection storage component (wall)

Volumetric specific heat (kcal/ m³・°C)	Volumetric specificheat (kJ/m³・°C)	Estimated specifications
204	854	Interior plasterboard wall
316.9	1327	Mud-plastered wall

* Volumetric specific heat = 204 (kcal/ m³・°C) is the wall specification for basic building, and specifications shown in Table 10 should be used for floors and ceilings.

3. Results of trial calculation

Fig. 2 shows the results of trial calculation of annual heating load (unit: GJ) using solar radiation heat utilization methods for eight cities listed in Table 9. Obstruction of sunlight is set at 0% (Site 3) in all cities.

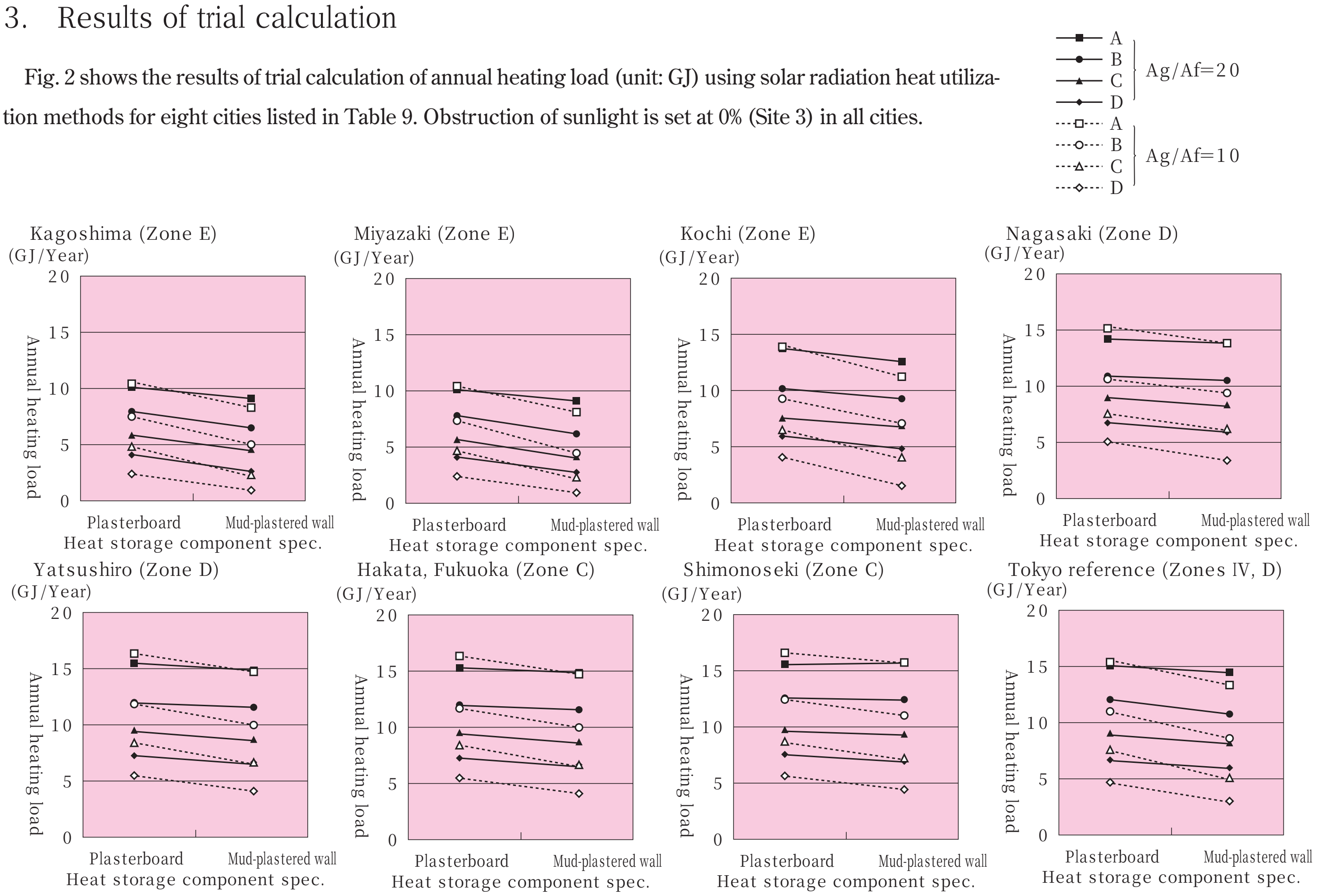
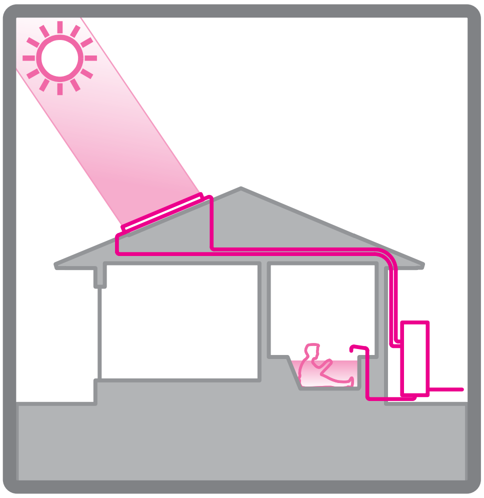


Fig. 2 Annual heating load using solar radiation heat utilization methods in major cities of hot humid regions

3

Chapter 3
Natural Energy Application Technology
(Elemental Technology Application Method 1)

3.5 Solar Water Heating (Solar Heat Utilization 2)



Water heating accounts for a very large portion of the total residential energy consumption, and the adoption of solar water heating systems that utilize natural energy is effective from an energy saving perspective.

3.5.1 Purpose and Key Points of Solar Water Heating

* This section explains solar water heating systems when a heat collection section is installed on the roof of a detached house. There are systems that use solar heat not only for the domestic hot water supply but also for space heating, but this document does not discuss such systems.

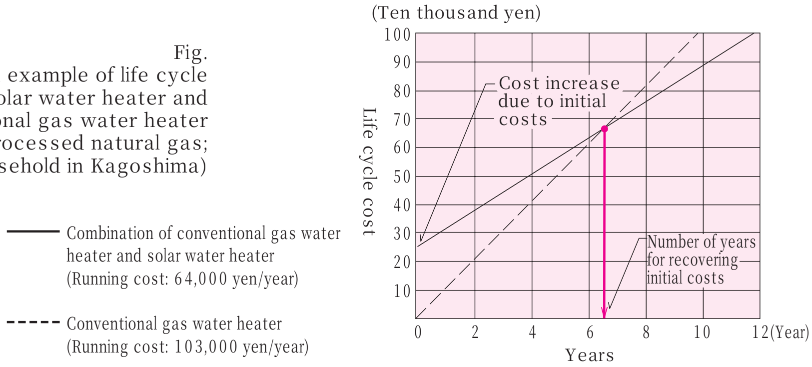
- Heat sources of domestic hot water system used in houses are classified into gas, oil, electricity and natural energy. Among these, solar water heating devices that utilize natural energy have a long history of achievements since the oil shocks of the 1970s, and are still one of the most effective energy saving means of water heating today.
- Compared to other systems, the initial costs of solar water heating are higher for the portion that is required for installing solar water heating devices. Nevertheless, once the installation is completed running costs can be drastically reduced and the appropriate installation enables the recovery of initial costs during the service life of the device.
- There are many different types of solar water heating devices but all of these devices consist of a heat collection section which collects solar heat and a hot water storage section which stores heated water. The area of the heat collection section has the most significant influence on the amount of heat collection. The larger this area the greater the amount of heat obtained, however, if it is too large compared to the usage amount of hot water, the device will be over capacity making it difficult to recover the initial costs.
- Since hot humid regions are warm as well as rich in solar radiation, a typical heat collection area of 3 – 4 m2 can cover more than half of the annual domestic hot water energy and solar water heating is an extremely effective energy saving method.
- Solar water heating devices are generally classified into "solar water heaters" and "solar systems" that are defined in the Japanese Industrial Standards (JIS A 4111). These devices use a different connection style between the heat collection section and the hot water storage section.
- Generally, it is common to plan solar water heating as an auxiliary heat source system by connecting it to gas or oil water heater. Appropriate connection is extremely important here in order to ensure energy performance of solar water heating.
- Solar water heating devices require heavy heat collectors to be installed on the roof and some models need a hot water storage tank. To ensure safety due attention must be given to design and installation.

Key Point

Number of years for recovering initial costs of solar water heating device

- The figure below is a graph showing the life cycle costs of a solar water heating device (solar water heater) and a conventional gas water heater by the number of years used. In this example, the solar water heater requires approximately 250,000 yen in initial costs (including installation cost) in addition to the gas water heater which is an auxiliary heat source. The annual running costs are reduced by nearly 40,000 yen and it takes approximately 6.4 years to recover the increase in the life cycle cost caused by initial costs. Generally speaking, the service life of solar water heating devices is over 10 years and it is possible to recover the initial costs during the life span.

Fig.
Test calculation example of life cycle costs of solar water heater and conventional gas water heater
(For using processed natural gas; four-person household in Kagoshima)



Key Point

Definition of terms

- Some terms used in the previous Design Guidelines for Low Energy Housing with Validated Effectiveness (issued in June 2005) have been reviewed and revised to comply with names and definitions employed by the Japanese Industrial Standards. The following table shows major changes.

Name and definition	Name and definition in previous guidelines	Name and definition in present guidelines
Solar water heater	System that supplies hot water directly from solar water heating device to faucet without auxiliary heat source	Type of solar water heating device with integrated heat collection and hot water storage section that collects heat through natural circulation
Solar system	System that uses both solar water heating device and auxiliary heat source	Type of solar water heating device that collects heat through forced circulation between heat collection and hot water storage sections
Device used for connecting solar water heating device and auxiliary heat source that mixes heated water and tap water and controls auxiliary heat source	Domestic hot water temperature control section	Solar connection unit

3.5.2 Energy Conservation Target Levels for Solar Water Heating

1. Definition of target levels

- The energy conservation target levels for solar water heating refer to the following levels 1 to 4 and indicate the reduction rates of energy consumed by domestic hot water systems.
- Any target level can be achieved by adopting solar water heating methods.

Level 0	:	Domestic hot water energy reduction rate	None
Level 1	:	Domestic hot water energy reduction rate	At least 10%
Level 2	:	Domestic hot water energy reduction rate	At least 30%
Level 3	:	Domestic hot water energy reduction rate	At least 50%
Level 4	:	Domestic hot water energy reduction rate	At least 70%

* The domestic hot water energy reduction rate is based on the typical hot water consumption of a four-person family.

- The typical domestic hot water energy consumption in 2000 was 13.8 GJ (approximately 21% of total energy consumption) for Zone VI and 19.2 GJ (approximately 28% of total energy consumption) for Zone V (See Section 6.1 on p.339).

2. How to achieve target levels

- This document discusses the following solar water heating methods that provide energy saving effects.

Method 1 : Securing heat collection area and other considerations	1a: Small effective heat collection area (below 3.5 m^2) 1b: Medium effective heat collection area (3.5 m^2 – 5.5 m^2) 1c: Large effective heat collection area (over 5.5 m^2)
Method 2 : Appropriate connection with auxiliary heat source	2a: Not connecting with auxiliary heat source 2b: Connecting with auxiliary heat source using a three-way valve 2c: Connecting with auxiliary heat source using solar connection unit
Method 3 : Adopting energy-efficient circulating pump	Solar systems only

- The corresponding relationship between the target levels and methods of energy conservation by solar water heating is as shown in Table 1.

Glossary: Effective heat collection area
The heat collector used to collect solar radiation in solar water heating does not utilize the entire unit for this task. The area that actually collects heat is referred to as an "effective heat collection area" in this document (See p.108 for details).

Table 1 Target levels of solar water heating and how to achieve them

Target level	Energy saving effect (domestic hot water energy reduction rate)	Method applied	
		Solar water heater	Solar system
Level 0	0	Use of conventional domestic hot water systems without energy saving method	
Level 1	At least 10%	Methods 1a + 2a	(Methods 1a + 2a)
Level 2	At least 30%	Methods 1a + 2c Methods 1b + 2b	Methods 1a + 2c Methods 1b + 2b
Level 3	Approx. 50%	Methods 1b + 2c	Methods 1b + 2c + 3
Level 4	Approx. 70%	Methods 1c + 2c	Methods 1c + 2c + 3

- Since weather conditions vary locally in the hot humid regions, Kagoshima is used as a typical example in this section.
- ( ) in Table 1 indicates uncommon method.
- The most important method is the securing of heat collection area and other considerations (Method 1), a prerequisite of which is that the heat collection section is installed in the appropriate direction and tilt angle.
- To increase energy performance, it is important to increase the solar heat utilization rate and an appropriate connection with an auxiliary heat source (Method 2) is required. In Table 1, Method 2a applies to solar water heating used for bathtubs only while Method 2b and Method 2c apply to all uses including the kitchen sink and wash basin. When comparing Method 2b and Method 2c, the use of a solar connection unit (Method 2c) generally has a higher solar heat utilization rate (The three-way valve method or Method 2b can also increase the solar heat utilization rate if operated properly; See p.112 for details).
- There is a loss in the energy saving effect of solar systems if the heat medium circulating pump consumes a large amount of electricity. When a high energy saving effect is desired, it is essential to select a device that uses energy-efficient circulating pump (Method 3).

3.5.3 Steps for Examining Solar Water Heating and Prerequisites

1. Steps for examining solar water heating

・The selection of solar water heating devices should be examined according to the steps shown below:

Step 1 Examining the feasibility of adopting solar water heating

1) Check the local weather conditions
2) Check the surrounding conditions of the building site
3) Check the building structures and other factors
4) Examine the installation location, direction, etc.

▼

Step 2 Examining the type, size and other elements of solar water heating

Select the type that suits the conditions and examine each method
1) Securing heat collection area and other considerations (Method 1)
2) Appropriate connection with auxiliary heat source (Method 2)
3) Adopting energy-efficient circulating pump: solar system/forced circulation type only (Method 3)

▼

Step 3 Making considerations for planning and using solar water heating

1) Considerations for planning
2) Considerations for efficient operation and controlling methods

2. Prerequisites

1) Local weather conditions

Solar water heating devices use natural solar heat energy and local weather conditions need to be fully examined. There is a possibility that solar heat cannot be sufficiently collected in the following regions:

・Regions with insufficient solar radiation
・Regions with severe winters (devices and pipes freeze and cannot be used)
・Regions with high snowfall or snow cover (devices and pipes are covered with snow and cannot be used)

As hot humid regions are warm as well as rich in solar radiation, solar heat collection can be expected. However, since the heat collection section is commonly installed on the roof, wind protection is required especially in the typhoon-prone regions. Specific measures will be discussed in Section 3.5.5 on p.116.

2) Surrounding conditions of the building site

If either of the following statements applies to the surrounding conditions of the building site, there is a possibility that solar heat cannot be sufficiently collected:

・There are many adjacent buildings that obstruct solar radiation on the roof
・There are trees and other elements that obstruct solar radiation on the roof

3) Building structures and other factors

In general, since the heat collection section of the solar water heating device is installed on the roof, the building structure and roof need to be designed by taking into account the weight of the device. Caution is required especially when using a device with an integrated heat collection and hot water storage section, as such devices are heavy (approximately 400 kg with a full tank for a device with a heat collection area of 4 m^2). Additionally, if there is piping through the roof it is important to take proper measures to prevent leakage.

3.5.4 Solar Water Heating Methods

There are a wide range of solar water heating devices and they have different features. It is necessary to select the appropriate type according to the house.

Solar water heating devices can be classified into the following items in general:

(1) Heat collection system (direct or indirect heat collection)
(2) Heat collection medium (water, antifreeze solution, air, or heat pipe)
(3) Heat medium circulating method (forced or natural circulation)
(4) Structure of heat collection and hot water storage sections (integrated or separate)
(5) Heat collection section shape (flat plate, vacuum tube, etc.)

Detailed structures of each solar water heating system will be explained in Section 3.5.6 on p.118.

Actual products consist of a combination of the above mentioned items. However, some combinations may not be available in actual products (**Table 2**).

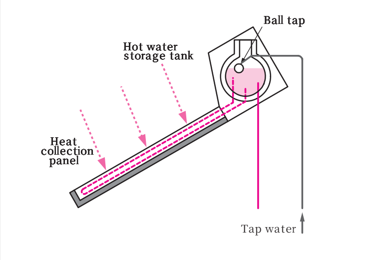
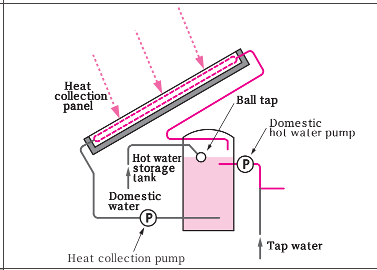
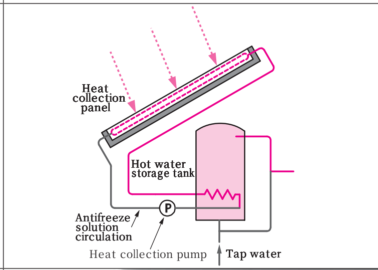
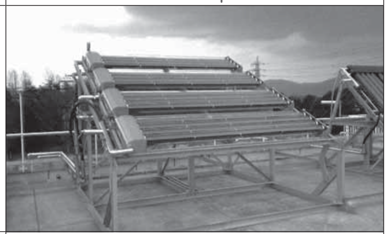
Table 2 Combination of heat collection section shapes, heat collection methods and hot water storage section

Heat collection section		Flat plate type		Vacuum tube type	
Hot water storage section		Integrated type	Separate type	Integrated type	Separate type
Direct heat collection (heat collection medium: water)	Natural circulation type (without pump)	◎	×	△ (vacuum hot water storage type)	×
	Forced circulation type (with pump)	×	△	×	△
Indirect heat collection (heat collection medium: antifreeze solution)	Forced circulation type (with pump)	△	○	×	○

◎: very common; ○: common; △: somewhat uncommon; ×: uncommon

Table 3 shows the structures and features of the typical solar water heater and solar systems in Japan. It is important to fully understand these characteristics and select the appropriate model.

Table 3　Structures and features of typical solar water heating devices

Item	Solar water heater	Solar system	
Heat collection type	Natural circulation type (direct heat collection)	Forced circulation type (direct heat collection)	Forced circulation type (indirect heat collection)
Hot water storage section	Integrated with heat collection section	Separate	Separate
Heat collection section	Flat plate type is mostly used in Japan	Flat plate type is mostly used in Japan	Flat type/Vacuum tube type
System diagram			
Heat collector appearance			
Heat collection area	• Commonly 3 – 4 m².	• Commonly 4 m².	• Adjustable (4, 6, 8, 10 m²).
Hot water storage amount	• Commonly 200 L.	• Adjustable, commonly 200 – 300 L (50 L per 1 m² of heat collection area as guideline).	• Adjustable, commonly 200 – 300 L (50 L per 1 m² of heat collection area as guideline).
Ease of antifreezing	× • Generally difficult to operate in cold regions.	× • Generally difficult to operate in cold regions.	× • Circulates the antifreeze solution.
Solar space utilization	× Impossible	× Impossible	× Possible
Burden on the roof/structure	× • Weight of both main unit and stored water.	○ • Weight of the heat collection unit and small amount of stored water only.	○ • Weight of heat collection unit and small amount of antifreeze solution only.
Direct connection with water supply system	× Impossible • Booster pump is essential for shower.	× Impossible • Booster pump is essential for shower as device ' s open structure does not allow use of water supply pressure.	○ Possible • Can use water supply pressure as it is directly connected with water supply system.
Power consumption	◎ • Not required for main unit. • Booster pump consumes electricity during domestic hot water supply.	△ • Pump consumes electricity both during heat collection and domestic hot water supply.	△ • Pump consumes electricity during heat collection.
Energy saving effect	• Many models have small heat collection area. • Radiation heat loss is significant in cold regions. • High energy efficiency for initial costs.	• Low hot water storage loss. • Power consumption can be issue.	• Heat collection area can be easily adjusted. • Low radiation heat loss. • Power consumption can be issue.
Initial cost	◎ • Has relatively simple structure. • Many manufacturers are available.	○ • Has slightly complex structure. • Many manufacturers are available.	△ • Circulation system for heat collector, hot water storage tank and antifreeze solution is required.
Ease of maintenance	○ • Fewer moving parts limit the replacement to ball taps, gaskets, etc.	× • System is complicated with many moving parts. • Necessary to replace pumps, valves, etc.	× • System is complicated with many moving parts. • Necessary to replace pumps, valves, etc. • Necessary to replace antifreeze solution once every three years.

The superiority descends in the order of ◎, ○, △ and ×.

Method 1 : Securing heat collection area and other considerations

1. Heat collection area

- The most important factor in sufficiently collecting solar heat is to secure a large heat collection area. Some devices have a small heat collection area of 2 m^2, but a heat collection area of 3 m^2 is required in order to achieve energy saving effects in hot humid regions.
- Table 4 shows the required heat collection areas for Method 1 by classifying them into the three categories according to the energy saving effect.

Table 4 Heat collection area requirements for Method 1

Method	Effective heat collection area	Energy saving effect
Method 1a	<3.5 m^2	Low
Method 1b	≥ 3.5 m^2, <5 m^2	Medium
Method 1c	≥ 5 m^2	High

- The "effective heat collection area" refers to the area of the heat collector that can actually collect solar heat. Although the Japanese Industrial Standards define the "effective heat collection area" (JIS A4111) for solar water heaters and "heat collection surface area" (JIS A1425) for photovoltaic system heat collectors, this document uses "effective heat collection area" for all devices.
- The total area of the heat collector is defined as the "total heat collector area" (JIS A1425).
- The effective heat collection area is described as the "maximum area of the transmitting body of the heat section that is projected onto the heat collection surface" (JIS A4111). Vacuum tube types and other devices with a gaps between the transmitting bodies have a smaller "effective heat collection area" in relation to the same "total heat collector area" than flat plate types and other devices that have a continuous heat collection surface.
- The effective heat collection area of an average heat collector is 1.5 – 2.0 m^2 and multiple heat collectors are connected and installed. Please check the information provided by manufacturers for details.

2. Direction of installation and tilt angle of heat collection section

- The prerequisite for successful implementation of Method 1 is that the heat collection section should be installed in the appropriate direction and tilt angle.

1) Direction of installation

- Although the heat collection section should be installed on the south side as much as possible, even if it is slightly off south it can still collect heat. The east side is less effective than the west side as it collects heat in the morning and has a great heat release loss before the night when the hot water usage is high. The north side has hardly any effect. It is also necessary to select a location that will not be in the shade due to adjacent buildings and other elements in the future.
- Use a frame for a north-south roof ridge so that the heat collector faces the south (Fig. 1).

2) Tilt angle

- Generally, the maximum annual heat collection can be reached when the installation angle (tilt angle) of the heat collection section is 30° in relation to a leveled surface. However, since there is no significant difference in heat collection due to the tilt angle in both hot humid and warm regions, please choose a tilt angle of up to approximately 60° by taking into account the roof pitch. A frame is required when installing heat collectors at an angle that is steeper than the roof pitch (Fig. 1).
- If the tilt angle of the heat collectors is steeper, the heat collection increases in the winter when the solar altitude is low and decreases in summer. Since water heating energy consumption is higher in the winter,

the use of a steep tilt angle for heat collectors increases the solar energy utilization rate, in general.

- In Okinawa, reinforced concrete flat roof houses are common. If heat collectors are installed horizontally on the flat roof, the amount of heat collection becomes too large in the summer and too little in the winter. For that reason, a flat surface frame needs to be used (Fig. 1).

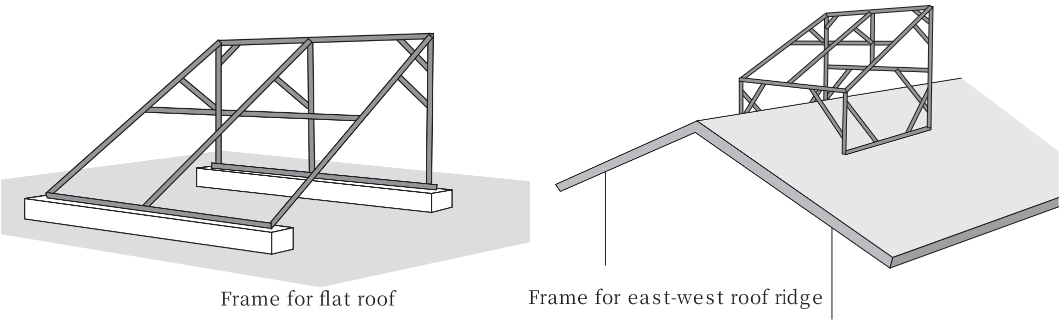


Fig. 1 Example of heat collector frame

Key Point

Energy saving effects of heat collection area

The figure on p.110 shows the results of calculating the ratio of the solar water heating energy to the total water heating energy by heat collection area at six representative locations in hot humid regions.

- The energy saving effect of water heating is high in hot humid regions where solar radiation is abundant and the tap water temperature is naturally high. In most locations the heat load halves with a heat collection area of 3 m^2. The energy saving effect further increases at 4 m^2 and the energy reduction rate is almost 70% in Okinawa. On the other hand, when the heat collection area exceeds 6 m^2, the reduction rate decreases in relation to the proportion of an increase in area. This is because the amount of heat collection becomes too large in relation to the heat load and the proportion of the effective heat collection decreases.
- From the above, it is considered that the appropriate heat collection area in hot humid regions is 3 – 4 m^2.

Key Point

Selecting the hot water storage section

- As solar water heaters have an integrated heat collection and hot water storage section, most models have a fixed capacity. The typical capacity of the hot water storage section is approximately 200 L.
- Some photovoltaic systems allow the capacity of the hot water storage section to be changed according to the heat collection area. Generally, the capacity is approximately 50 L per 1 m2 of a heat collection area. Therefore, if there is a heat collection area of 4 m2, the capacity of the hot water storage section is approximately 200 L.
- If the heat collection area is large, select the larger size of hot water storage section. Although 300 – 400 L is common, if the device also serves as a hot water storage tank for solar space heating it tends to be larger.

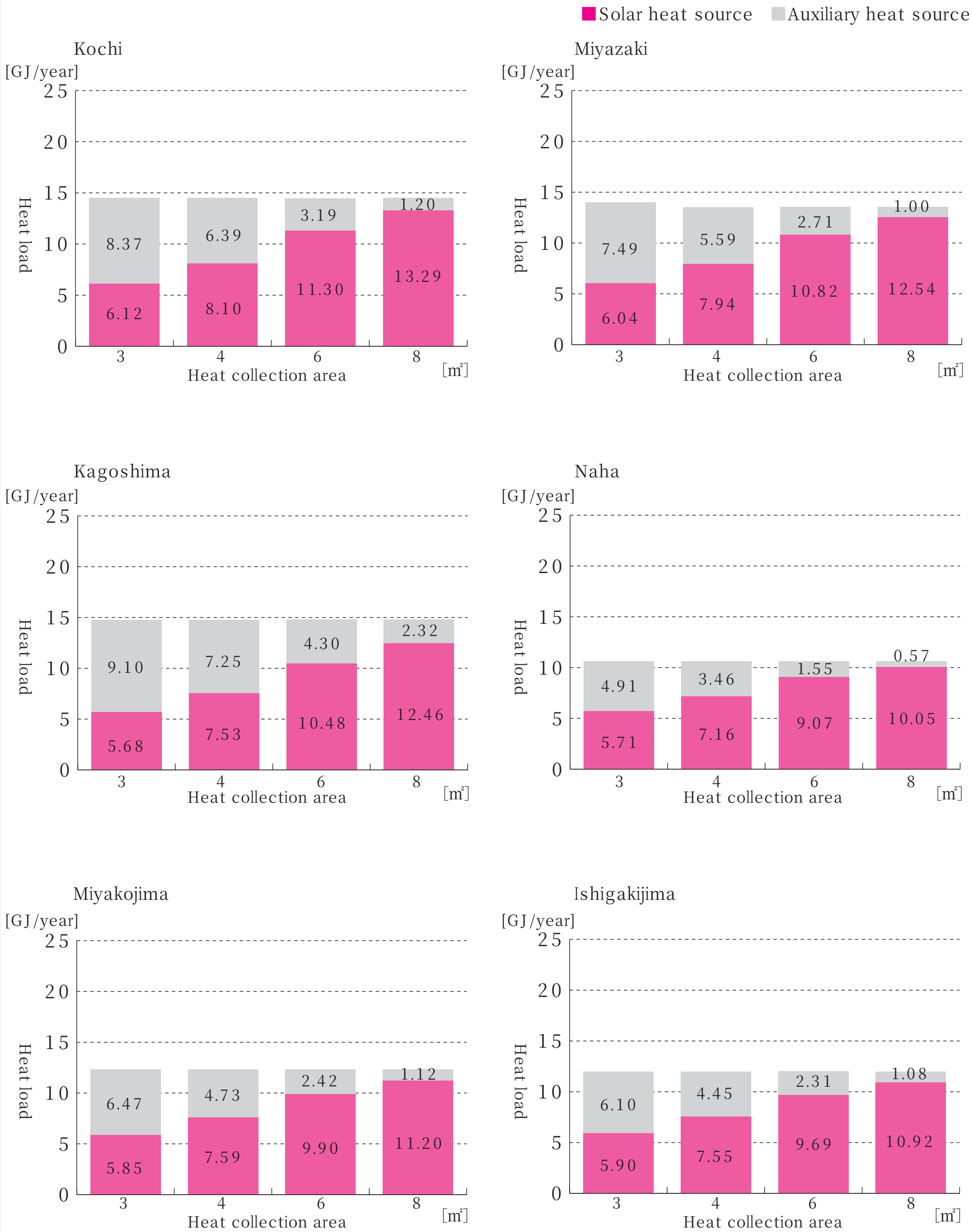


Fig. Domestic hot water energy saving effect of solar water heater (when installed due south with tilt angle of 30°)

■ Calculation conditions

- The calculation estimates the reduction effect of water heating load based on the monthly mean solar radiation by taking into account the efficiency of the heat collection section and system loss.
- The efficiency of the heat collection section is regarded as 40% throughout the year. This value is estimated from the experiment results of solar water heaters and indicates a combined efficiency of the heat collection and hot water storage sections. The results may be different for photovoltaic systems but the trend is predicted to be almost identical.
- The heat loss of the system caused by the piping and other sections is assumed to be 10%. This applies to when combining a solar connection unit with an auxiliary heat source. Compared to when using a three-way valve, it is thought that mixing hot water with cold water decreases the effective utilization rate of solar heat and the loss becomes greater.
- It is assumed that any hot water not used within the day becomes too cold to carry the heat to the next day.

Method 2 : Appropriate connection with auxiliary heat source

- Although solar water heaters achieve a high energy saving effect, they cannot collect heat under poor weather conditions and satisfy all the domestic hot water needs. Therefore, an auxiliary heat source that uses other types of energy is used at the same time. Gas and oil combustion are commonly available auxiliary heat sources.
- In order to help reduce energy consumption of water heaters, it is critical to increase the proportion of solar water heating over the other heat source. The adequate combination of a solar water heater and an auxiliary heat source such as a gas or oil water heater significantly increases the solar energy utilization rate. This document discusses three connection methods for these water heaters.
- In the past, the method of not connecting with an auxiliary heat source (Method 2a) was sometimes used, but this method provides a low solar heat utilization rate as it utilizes solar heat in the bathtub only.
- At present, connecting with an auxiliary heat source using a three-way valve (Method 2b) is most commonly practiced. This method provides an increased solar heat utilization rate if the switching of the three-way valve is properly performed, but if the switching is neglected solar heat cannot be used.
- Connecting with an auxiliary heat source using a solar connection unit (Method 2c) allows the unit to automatically control the solar water heater in order to increase the solar heat utilization rate. This provides both high energy efficiency and convenience as well as the superior safety.
- Table 5 summarizes characteristics of Methods 2a to 2c that are related to the methods for connecting solar water heating devices and auxiliary heat sources. When using a solar connection unit (Method 2c) initial costs are high yet other characteristics are extremely good. This method is expected to become more common in the future.

Table 5　Connection methods of solar water heating device and auxiliary heat source

Item	Method 2a Not connecting with auxiliary heat source	Method 2b Connecting with auxiliary heat source using three-way valve	Method 2c Connecting with auxiliary heat source using solar connection unit
Applications for which solar heat can be utilized	△ • For bathtubs only (solar heated water is sent to tub and reheated). • Solar heat cannot be utilized when automatically filling bathtub.	○ • Solar heat can be utilized for purposes other than bathtubs (reheating of the tub is impossible). • Depends on connection method whether solar heat can be utilized when automatically filling bathtub.	◎ • Solar heat can be utilized for purposes other than bathtubs (reheating of tub is impossible). • Solar heat can be utilized when automatically filling bathtub.
Convenience	× • Solar heated water needs to be sent to bathtub then reheated in bath boiler.	△ • Generally, as three-way valve is manually switched, solar heat utilization rate declines without proper operation. • Convenience increases if three-way valve is automatically switched by temperature sensor.	◎ • Highly convenient as unit automatically switches circuit. Users only need to set domestic hot water temperature of auxiliary heat source.
Solar heat utilization rate	× • Solar heat cannot be utilized for purposes other than use for bathtubs.	△ – ○ • Varies largely depending on whether three-way valve is properly used. Generally, since only one circuit changing switch is available in kitchen, it is difficult to switch at other places.	◎ • Unit automatically increase solar heat utilization rate.
How to increase solar heat utilization rate	• Solar water heating plays significant role for households in which bathwater accounts for large proportion of hot water consumption.	• Always appropriately operate three-way valve. • Use solar water heating circuit as much as possible even when temperature of solar heated water is slightly low.	• Lower domestic hot water temperature setting of auxiliary heat source. • Turn off auxiliary heat source during summer and in-between seasons when domestic hot water at fixed temperature is unnecessary (when using kitchen sink and wash basin).
Initial cost	○ • Least expensive.	△ • Three-way valve and piping costs.	△ • Additional cost of unit.
Safety	△ • Very hot solar heated water may be discharged particularly in summer.	△ • Very hot solar heated water may be discharged particularly in summer. Thermostat combination faucet is desirable for showers, kitchen sinks and wash basins.	◎ • Highly safe as unit automatically mixes solar heated water and tap water and maintains proper inlet water temperature even when operating auxiliary heat source.
Remarks	• This system is rarely used for new installations.	• This system used to be common.	• This system has recently become more common. • Model with built-in booster pump increases heated water pressure and improves discharging performance.

◎: Very advantageous; ○: advantageous; △: not very advantageous; ×: disadvantageous

This document covers three methods for connecting a solar water heating device with an auxiliary heat source. The following section provides a detailed explanation of each method.

1) Method 2a: Not connecting with auxiliary heat source

- In the past, there was a frequent use of the system which simply delivers the solar heated water into the bathtub and reheats it in the bath boiler without connecting the solar water heater with the auxiliary heat source (Fig. 2).
- This system is simple and inexpensive, and used to be effective when bathwater accounted for a majority of the domestic hot water consumption, but is now hardly used for new installations.

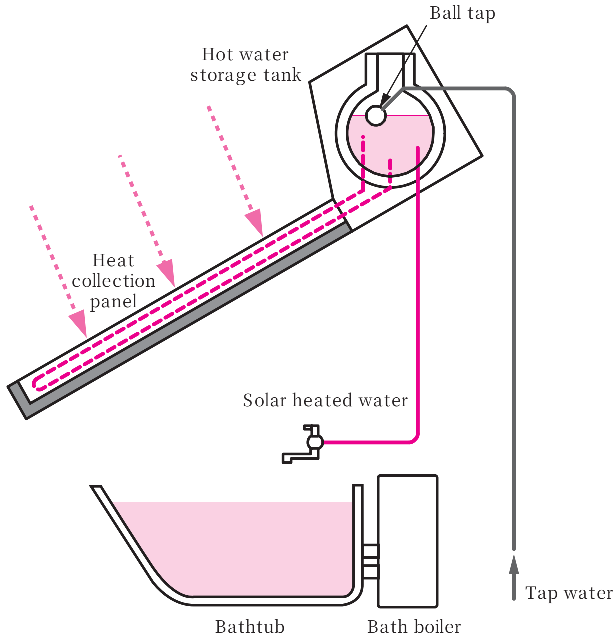
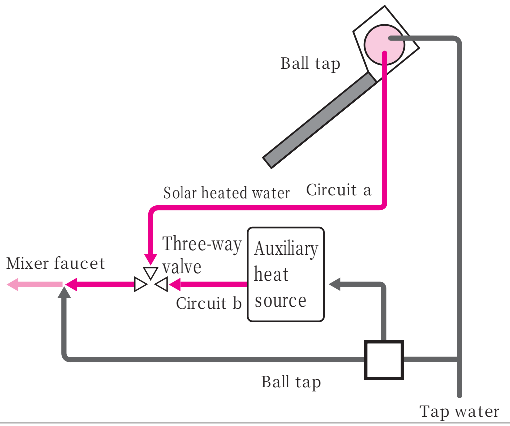
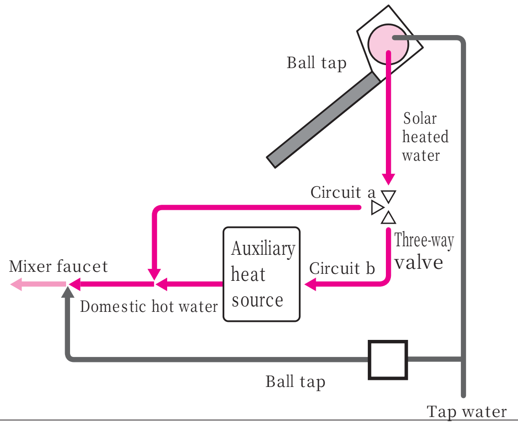
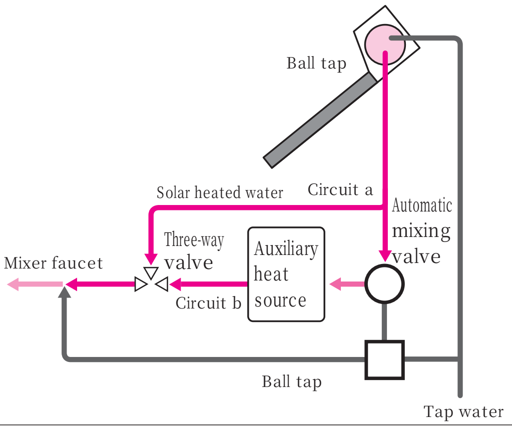


Fig. 2　Example of not connecting with auxiliary heat source (Method 2a)

2) Method 2b: Connecting with auxiliary heat source using three-way valve

- A system which uses a three-way valve for switching the solar water heater with the auxiliary heat source became widespread after Method 1a. There are many combinations of connecting the solar water heater with the auxiliary heat source. See Table 6 for the outline and characteristics of the major combinations.
- Three-way valves are relatively simple and can increase the solar heat utilization rate if operated properly. On the other hand, they are less convenient as they require the circuit to be switched manually according to the solar heated water temperature. If the circuit switching is neglected and the circuit for the auxiliary heat source is always used, the solar heat utilization rate may decrease.

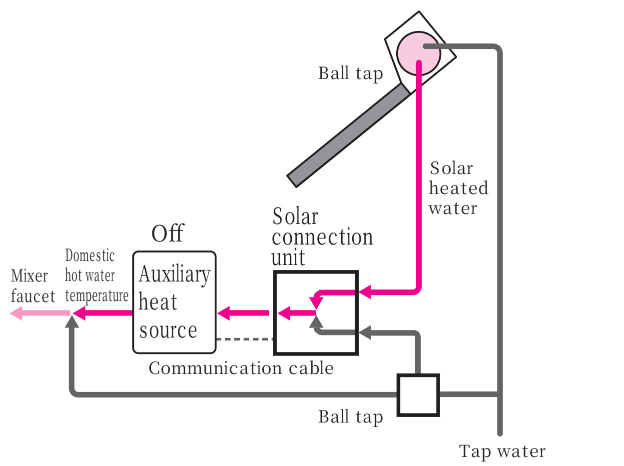
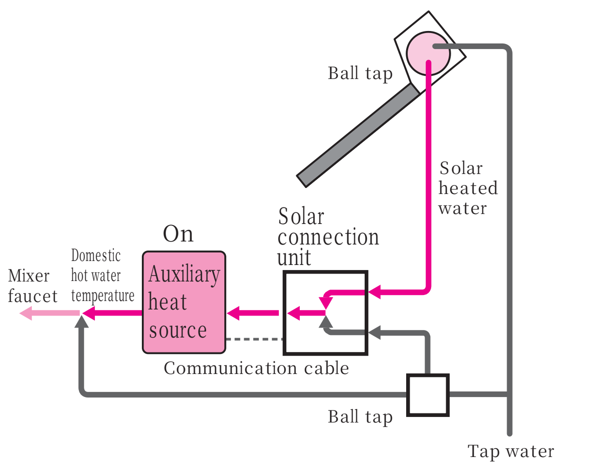
Table 6　Example of connecting with auxiliary heat source using three-way valve (Method 2b)

<table>
<tr><th></th><th>System diagram</th><th>Characteristics</th></tr>
<tr><td>Connection example 1</td><td>
</td><td>• When temperature is sufficiently high, solar heated water is used directly through circuit a.
• When solar heated water temperature is low, circuit is switched to circuit b and hot water supplied solely from auxiliary heat source is used.
• Any auxiliary heat sources can be used without giving particular consideration to connection with solar water heater.
• When circuit is switched to circuit b, solar heat higher than tap water temperature cannot be used at all.
• When solar heated water temperature is extremely high particularly in summer, use of facets other than thermostatic type may be dangerous.
• Solar heat cannot be used for automatically filling bathtub function of auxiliary heat source.</td></tr>
<tr><td>Connection example 2</td><td>
</td><td>• When temperature is sufficiently high, solar heated water is used directly through circuit a.
• When solar heated water temperature is low, circuit is switched to circuit b and solar heated water is reheated with auxiliary heat source for domestic hot water supply.
• Even when circuit is switched to circuit b, solar heat higher than tap water temperature can be used.
• Solar heat can be used for automatically filling bathtub function of auxiliary heat source.
• When solar heated water temperature from circuit b is relatively high, auxiliary heat source cannot limit its output and outlet hot water temperature may exceed preset domestic hot water temperature.</td></tr>
<tr><td>Connection example 3</td><td>
</td><td>• Although similar to example 1, auxiliary heat source is connected with solar water heater at inlet using automatic mixing valve so that solar heated water and tap water are mixed.
• Automatic mixing valve automatically adjusts mixing ratio of two inlet systems so that outlet temperature stays at constant level. Thermowax valve is commonly used for this purpose.
• Even when solar heated water temperature from circuit b is relatively high, it is safe as automatic mixing valve maintains low inlet temperature of auxiliary heat source.
• Even when circuit is switched to circuit b, solar heat higher than tap water temperature can be used.
• Solar heat can be used for automatically filling bathtub function of auxiliary heat source.</td></tr>
</table>

3) Method 2c: Connecting with auxiliary heat source using solar connection unit

- With the popularization of the central domestic hot water system, hot water became available in the kitchens and washing rooms. As the automatic filling of the bathtub by the auxiliary heat source became common, consumers began to seek out more convenient connection methods. As a result, solar connection units came on the market that enabled the automatic operation of the three-way valve and provided optimal control by communicating with the auxiliary heat source.
- The solar connection unit is installed on the auxiliary heat source inlet and connects the solar heated water with tap water at the unit inlet where they are mixed in an optimum ratio to increase the solar heat utilization rate. Since the solar connection unit and the auxiliary heat source should be connected with a dedicated communication cable, both the devices need to be compatible.
- Since all the control processes are automatically performed, this method provides great convenience and safety. Users can obtain hot water at a preset temperature by simply setting the domestic hot water temperature of the auxiliary heat source. Moreover, proper automatic control of the auxiliary heat source reduces unnecessary burning of the auxiliary heat source fuel, achieving further energy conservation (Table 7).
- As mentioned above, the use of the solar connection unit increases the solar heat utilization rate without performing special operations. When installing a solar water heating device for the first time, the solar connection unit is strongly recommended. This is why Method 2c is required for achieving the energy conservation target levels 3 and 4.

Table 7　Connection methods of solar connection unit (Method 2c) and general behaviors

Solar heated water temperature ≥ Preset domestic hot water temperature of auxiliary heat source	Solar heated water temperature < Preset domestic hot water temperature of auxiliary heat source
	
• Solar connection unit mixes solar heated water and tap water and sends it to auxiliary heat source. • Solar connection unit sends signal to auxiliary heat source not to ignite burner through the communication cable. • As auxiliary heat source does not perform unnecessary ignition, wasteful gas consumption is reduced. • Lowering domestic hot water temperature setting of auxiliary heat source further increases proportion of solar water heating. • Some models enable solar connection unit to perform mixing function only even when auxiliary heat source is turned off.	• Solar connection unit mixes solar heated water and tap water and sends it to auxiliary heat source so that it does not exceed upper tap water temperature limit of auxiliary heat source. • Auxiliary heat source sets upper limit of tap water temperature (generally 30 to 35 °C) in order to prevent domestic hot water temperature of auxiliary heat source from being too high. • When solar heated water temperature is below upper tap water temperature limit of auxiliary heat source, only solar heated water is supplied to that source. • Even when solar heated water temperature is low, if it is higher than tap water temperature, the surplus heat can be effectively utilized.

Key Point

Selecting auxiliary heat source

It is advisable to consider the following items when selecting the auxiliary heat source:

- A latent heat recovery device is desirable as the auxiliary heat source when the proportion of solar water heating is low in cases such as a small heat collection area and low solar radiation due to the surrounding environment. A wide range of latent heat recovery water heaters are currently available in both gas and oil (See Section 5.4 Domestic Hot Water System Planning on p.271). If the proportion of solar water heating is high because of the warm climate, conventional water heaters can be used.
- Some new models have an auxiliary heat source built into the hot water storage tank unit.

Method 3 : Adopting energy-efficient circulating pump (photovoltaic systems only)

- Whether it is a direct heat collection type which directly warms water or an indirect heat collection type which indirectly warms the water by heating the antifreeze or other solutions, the photovoltaic system requires a circulating pump which circulates the water and antifreeze solution if it is a forced circulation type.
- If the power consumption of the circulating pump is high, energy performance declines. Therefore, in order to fully demonstrate an energy saving effect, it is necessary to choose a model that operates the pump only when needed, uses a low power consumption pump or operates the pump using solar cell power.

Key Point

Power consumption of circulating pump

- Conventionally, pumps with power consumption of nearly 100 W have been commonly used. However, these pumps consume a large amount of electricity when operated during the day and result in significantly poor energy performance.
- In recent years, devices that use DC pumps and other power saving features have became available on the market. Models having pumps with a variable electrical input of 20 – 65 W operate the motor as needed thus achieving energy saving effects.

3.5.5 Solar Water Heating Planning and Considerations for Use

1. Considerations for sectional planning

1) Installing heat collectors (wind protection)

- Since hot humid regions are prone to typhoons, it is essential to protect against strong winds when installing heat collectors. As heat collectors installed on the roof may be blown upwards or slide sideways due to strong winds, it is necessary to firmly affix them.
- To prevent heat collectors from being blown away by strong winds, it is effective to fasten them as closely as possible to the roof and affix them at a gentle angle (Fig. 3). In the meantime, when using a frame in order to adjust the direction, heat collectors should be tightly affixed using wire and other means (Fig. 4).
- For safety reasons, it is important to carefully calculate wind load and examine how to affix heat collectors.

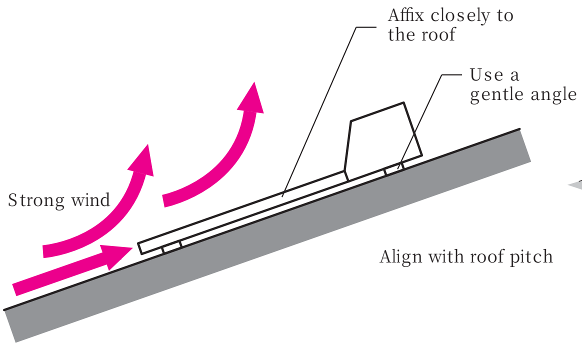


Fig. 3 How to install heat collectors in hot humid regions

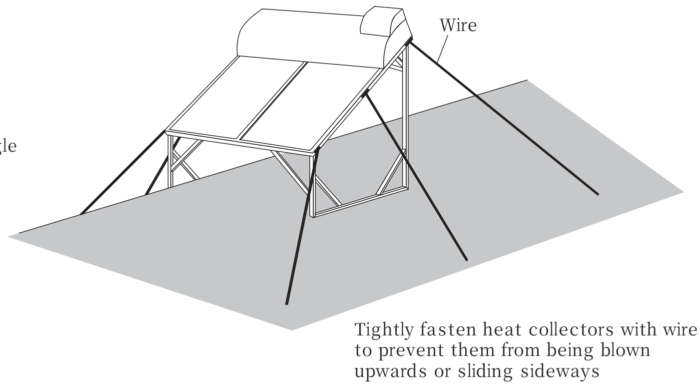


Fig. 4 Example of affixing heat collectors (using frame)

2) Installing hot water storage tank (separate type only)

- For a solar water heating system with separate heat collectors and a hot water storage tank, it is necessary to place the heat collectors, hot water storage tank and water heater as close together as possible.
- Although hot water storage tanks are generally installed outside, it is recommended to select a product that is properly insulated and install it indoors, even in unheated areas such as garages and utility rooms, in order to reduce heat loss.
- Particularly, since circulating pipes for the heat medium are installed outside, they should be as short as possible and must be insulated.

2 Considerations for efficient operation and control methods

Although solar water heating devices have very high energy performance, full advantage cannot be taken of their performance without understanding their characteristics and correct usage. The following section explains cautions to follow when using a system which connects a solar water heating device with an auxiliary heat source using a solar connection unit (Method 2c).

1) Preset temperature of water heater

When using a solar connection unit, the auxiliary heat source communicates with the solar connection unit via a communication cable and hot water is discharged according to the preset domestic hot water temperature of the auxiliary heat source remote control. As the system uses either the solar heat source or the auxiliary heat source according to this preset temperature, it is necessary to properly set this temperature in order to increase the system efficiency (Fig. 5, Table 8).

To increase the solar heat utilization rate, it is important to set the domestic hot water temperature of the auxiliary heat source as low as possible. The domestic hot water temperature should be raised only when very hot water is required and returned to the low setting afterward.

Table 8　Preset water heater inlet temperature and characteristics

Preset water heater inlet temperature	Characteristics
45 – 60 °C	• Mixing with tap water at faucet is prerequisite. Thermal mixing faucets are desirable. • As hot water can be used for shower at relatively high temperature, water pressure can be secured by mixing with water even when using thin hot water pipes. • In winter, solar heated water temperature does not often reach the preset domestic hot water temperature. Because of this, solar heat utilization rate is low and energy saving effects decline.
38 – 43 °C (recommended)	• Mixing with tap water at faucet is not prerequisite (common). • If hot water pipe diameter is thin, water pressure may not be sufficient for shower. • Solar heat utilization rate is high even in winter.

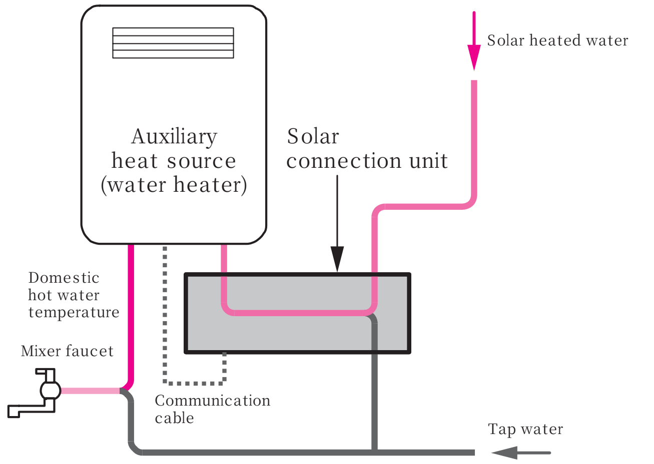


Fig. 5　Overview of solar connection unit

2) Adequate control of auxiliary heat source

- In a system using a solar connection unit (Method 2c), if the solar heated water temperature is lower than the preset domestic hot water temperature, it is reduced to the upper tap water temperature limit (30 – 35 °C) by mixing with the domestic water, and the domestic hot water is sent to the auxiliary heat source. The auxiliary heat source heats this water up to the preset domestic hot water temperature and discharges it. This process is intended to prevent the hot water discharge temperature from becoming too high due to the restriction in the lower capacity limit of the auxiliary heat source. However, this leads to an extremely low load operation of the auxiliary heat source and efficiency declines significantly.
- Additionally, even when sufficiently warm water is stored in the solar water heater, it takes a while before the solar heated hot water reaches the auxiliary heat source after it is discharged. During this period, even though short, the auxiliary heat source burns fuel. Even when solar heated water is supposed to handle all the domestic hot water needs, such as during the summer, the auxiliary heat source actually burns unnecessary fuel, resulting in low efficiency.
- For that reason, for usage in kitchen sinks and wash basins where a constant hot water temperature is not absolutely necessary and hot water discharge is often short and intermittent, turning off the auxiliary heat source stops unnecessary fuel burning and increases energy efficiency.
- Some solar connection units mix the solar heated water with the tap water even when the auxiliary heat source is turned off. As it mixes tap water when the solar heated water temperature is high, it provides enhanced safety.
- When the solar heated water temperate is lower than the preset domestic hot water temperature, the auxiliary heat source does not burn fuel and the domestic hot water temperature stays as is. It is often the case that this is sufficient for usage in kitchen sinks and wash basins. Turning on the auxiliary heat source only when the domestic hot water temperature is too low provides great energy saving benefits.
- In a system in which the hot water storage section and the auxiliary heat source are integrated, some models offer an energy saving mode as stated above (Fig. 6).

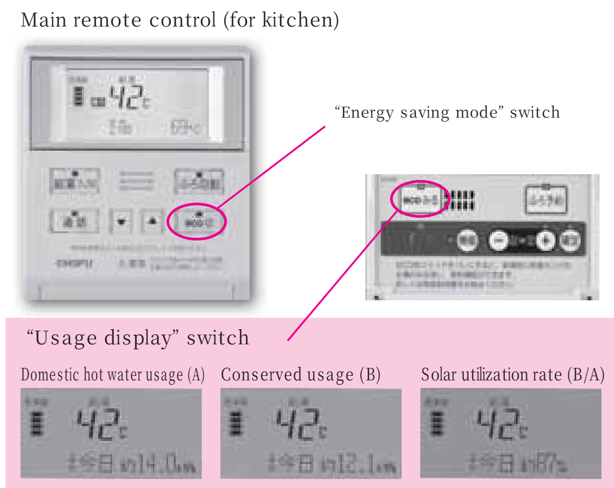


Fig. 6　Auxiliary heat source control panel

3

Chapter 3
Natural Energy Application Technology
(Elemental Technology Application Method 1)

3.5.6 Explanation of Solar Water Heating Systems

Characteristics of solar water heating devices were described in 3.5.4 on p.106 and detailed explanation of each system is provided in this section. Please use this as a reference for understanding products.

1. Solar heat collection system + heat medium circulation method

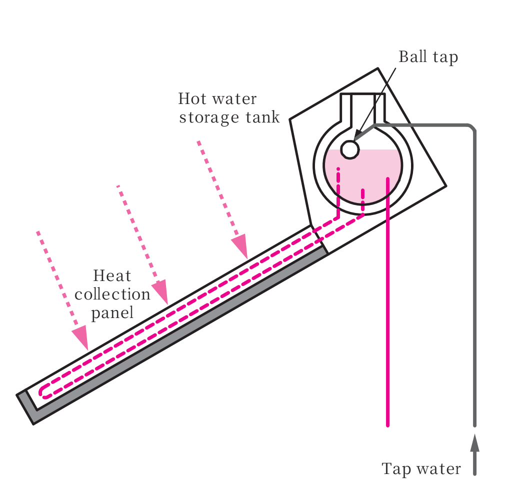
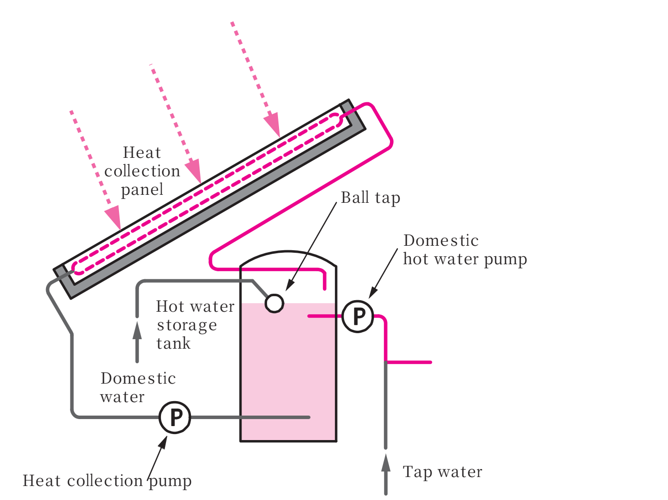
The solar heat collection system is regarded as the most important element that largely dictates the structures and characteristics of solar water heating devices. It determines factors such as weight and antifreezing of the heat collection section and water pressure. The following shows characteristics of each system.

1) Direct heat collection type (natural or forced circulation type)

Many of the direct heat collection devices are solar water heaters but some are photovoltaic systems. The direct heat collection is a system that directly sends water to the heat collection panels where it is heated for domestic hot water. There is a natural circulation type which circulates water by natural convection and a forced circulation type which circulates water with a pump (Table 9 (1) and (2)).

Because of its uncomplicated principles the system is often simple (particularly for the forced circulation type), and provides the benefit of high heat collection efficiency as it collects heat using water, which is used directly as domestic hot water. On the other hand, since the tap water carried to the heat collection section is considered unclean legally, it is necessary to cut off (release) from the water supply system in order to prevent a backflow into the tap water section. Additionally, the water pressure needs to be separately set during domestic hot water supply and antifreezing is difficult as the system circulates water.

Table 9 Principles and characteristics of solar water heating devices

<table>
<tr><th>(1) Direct heat collection type (natural circulation type)
"Solar water heater" system</th><th>(2) Direct heat collection type (forced circulation type)
Referred to as "water dripping photovoltaic system", etc.</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Operating principle
• Water is supplied to hot water storage tank by water supply pressure.
• Because of convection effect caused by change in water specific gravity due to temperature increase , low temperature water in tank descends to heat collection panels where it is heated. Once water becomes hot it ascends to hot water storage tank where it is stored.

Characteristics
• System has simple structure and is very common.
• As hot water storage section is installed next to heat collection panels on roof, radiation heat loss is significant at night.
• As hot water storage section is exposed to air, water supply pressure cannot be used during domestic hot water supply and hot water supply pressure is low.
• As antifreezing is difficult, system needs to be shut down and emptied of water during winter in cold regions.</td><td>Operating principle
• Water is sent to heat collection section by pump and heated during day when heat is collected. Heated water is drained back to hot water storage tank.
• Water is not allowed to flow when heat is not collected at night and other times.

Characteristics
• Open structure does not allow the use of water supply pressure. Booster pump is essential for shower.
• Low heat loss when heat is not collected.
• As separate pump is required for heat collection and domestic hot water supply, power consumption tends to be high.
• As it directly collects heat with water, the heat collection efficiency is relatively high. However, operation is difficult in winter in cold regions due to risk of freezing.</td></tr>
</table>

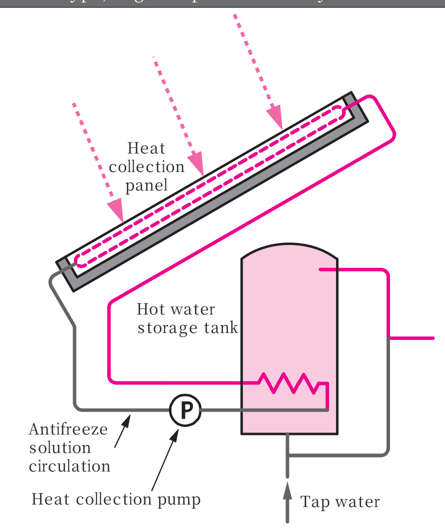
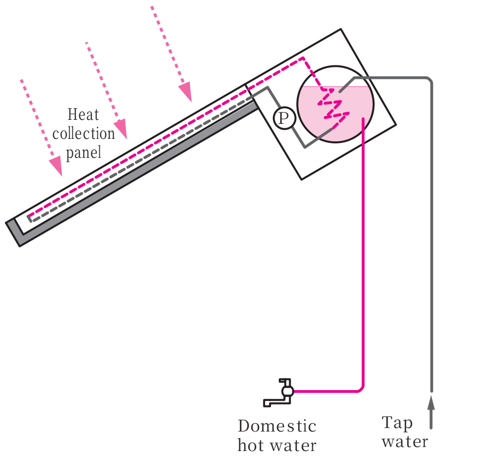
2) Indirect heat collection type (mostly forced circulation type)

Indirect heat collection is a system that circulates the antifreeze solution instead of water between the heat collection section and the hot water storage section. The heat collection section collects heat while the hot water storage section heats tap water using a heat exchanger located inside the hot water storage tank. Many of the photovoltaic systems are of this type. The circulation of antifreeze solution is mostly performed by forced circulation using a pump. The hot water storage tank is generally separate from the heat collection section, but there are a few models that have these sections integrated (Table 9 (3) and (4)).

Since it neither sends water directly to the heat collectors nor exposes it to the air, the water in the hot water storage tank is considered clean and is allowed to be connected directly to the water supply system. Therefore, the water supply pressure can be used during domestic hot water supply and the shower can be used at a comfortable water pressure even without a booster pump. Since the antifreeze solution is circulated through the heat collection and piping sections, it helps prevent freezing in these sections. However, the antifreeze solution has inferior thermal properties to water and the efficiency is slightly lower than the direct heat collection device because the system indirectly heats water.

Since the indirect heat collection system is complicated, initial costs tend to be high and cost recovery may be difficult in terms of the domestic hot water use alone. In Europe, it is common to use the same hot water storage tank for space heating. Separately, since the high power consumption of the pump circulating the antifreeze solution decreases energy performance, it is required to select a product that has energy-saving features. This includes operating the pump only when needed, using a pump with low power consumption, and pump operation using solar cell power.

Table 9 Principles and characteristics of solar water heating devices

(3) Indirect heat collection type (forced circulation/separate type)Regular "photovoltaic system"	(4) Indirect heat collection type (forced circulation/integrated type)
	
Characteristics ・As antifreeze solution is used in exposed outside pipes, system is resistant to freezing. ・As hot water storage section is closed, water supply pressure can be directly used and domestic hot water pressure is high. ・Separate space is required for installing hot water storage section. ・Circulating pump tends to have large power consumption. ・Complicated system makes it expensive.	Characteristics ・Appearance is close to that of solar water heater (hot water storage location is different). ・As hot water storage section is closed, water supply pressure can be directly used and shower can be comfortably used. ・This model is in-between solar water heater and separate photovoltaic system. ・As tap water pipes are exposed outside, system is less resistant to freezing. ・Model which performs pump circulation using solar cells provides high energy saving effect.

2. Layout of heat collection and hot water storage sections

The layout of the heat collection and hot water storage sections can be either integrated or separate, and is generally determined by the heat collection system mentioned earlier. It is common that solar water heaters have an integrated layout and photovoltaic systems have a separate layout (Table 10 (1) and (2)).

3 Shapes of heat collection section

In order to effectively collect solar heat, it is naturally required that the heat collection section has high performance. The performance of the heat collection section depends on its radiation properties and insulation performance.

With regard to the requirements for radiation properties, it should be not only easy for the solar radiation (short waves from a high temperature heat source) to be absorbed, but also difficult for infrared rays (long waves from a low temperature heat source) to be radiated. Although former models of solar water heaters often had a heat collection unit that was simply painted black, it was easy to heat and cool as it easily absorbed solar radiation while easily radiating infrared rays. In recent years, the mainstream of devices are solar water

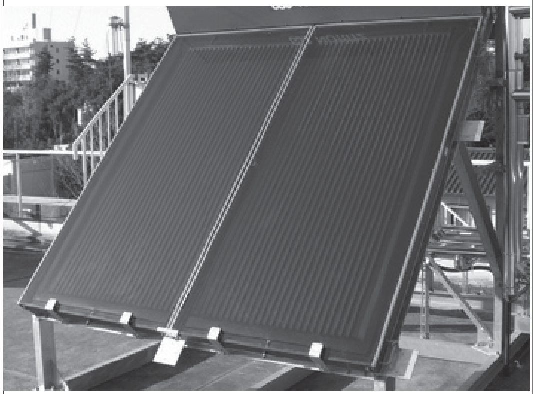
Table 10　Layout of heat collection and hot water storage sections

(1) Integrated type (direct heat collection and natural circulation are most common)	(2) Separate type
	Hot water storage tank   Heat collector
Characteristics • Most of solar water heaters and some photovoltaic systems are of this type. • Has simple structure and is generally inexpensive. • As weight of hot water storage section is on roof, it has structural disadvantage. • As heat collection and hot water storage sections are integrated, it offers little flexibility in system design.	Characteristics • Many of photovoltaic systems are of this type. • As only heat collection section is installed on roof, weight load is significantly reduced. • Layout flexibility of heat collection section and hot water storage tank is high. • Heat collection section has tidy and functional design. • As circulation between heat collection and hot water storage sections stops when heat is not collected, radiation heat loss is reduced. • Provides high system flexibility and can also be used for solar space heating and other systems. • Has complicated structure and is generally expensive. • As water, antifreeze or other solution is forcefully circulated by pump between heat collection and hot water storage sections, additional power consumption is required.

heaters boasting high heat collection efficiency using a "selective absorption membrane" that easily absorbs solar radiation but hardly radiates infrared rays. According to the Japanese Industrial Standards (JIS A 4111), at least 40% of heat collection efficiency is required (under outside air temperature conditions of at least 15°C).

Heat collection section shapes are largely classified into the insulation methods of the heat collection unit (black area coated with selective absorption membrane) and the transmission unit (glass). The flat plate type has a flat heat collection unit covered with insulation materials on the back and the transmission unit on the front. The vacuum tube type has a tubular heat collection unit that is protected by a tubular transmission unit and has vacuum gaps for reinforced insulation. The heat collection efficiency is not necessarily indicated in catalogs, but it is generally about 40 – 50% for the flat plate type and 50 – 60% for the vacuum tube type. In Japan, the flat plate type is most commonly used, but the vacuum tube type is often found outside Japan possibly because it is frequently installed in cold regions with poor weather. Both the flat plate and vacuum tube heat collectors are used in combination with various heat collection systems discussed earlier (Table 11 (1) and (2)).

Table 11 Shapes of heat collection section

(1) Flat plate heat collector	(2) Vacuum tube heat collector
	
Characteristics • Has simple structure and is inexpensive. • Very common in Japan. • White glass panels are highly efficient. • Difference between the gross area and effective heat collection area is insignificant. • Has slightly lower insulation performance and heat collection efficiency decreases in cold regions. • Suitable for heat collection of direct solar radiation and is highly efficient on sunny days, but is less efficient under diffused solar radiation on cloudy days.	Characteristics • As space between glass tube and heat collection section is vacuum insulated, it has high heat collection efficiency and freeze resistance even in cold regions. • Especially high efficiency for high temperature heat collection. • As heat collection section is tubular, ratio of effective heat collection area to gross area is limited (except those with external reflector). • As tubular sectional area is effective for heat collection, it is considered to be efficient on cloudy days. • No devices are produced in Japan. • Mainstream outside of Japan, such as in Europe and China. • Generally expensive, but inexpensive imported products have become available in recent years.