PERFORMANCE EVALUATION AND SIMULATION OF ECOLOGICAL HOUSE

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ABSTRACT

The LESCOM program using the Response Factor Method developed by the authors was applied to the direct gain system and calculation of fluctuations in room temperature. Regarding the solar water collector, the efficiency straight line was obtained from the measured values. The one-dimensional thermal stratification was applied to the water storage tank. It was discovered from the measured values that relations between the amount of solar radiation on the solar cells and the amount of power generation in photovoltaic power generation could be formulated in the linear equation. In conclusion, simulation programs for typical systems of the ecological house were drawn up and verified.
The accuracy of the simulation programs was found to be comparatively high.

INTRODUCTION

The authors designed an ecological house for an experimental purpose in Kawasaki city, Kanagawa prefecture with a view to improving the quality of life and saving energy. To discover its comfort and energy-saving, performance tests were conducted on the systems installed in the house where one family was living. In addition,simulation programs were worked out for comparative verification of measured values and theoretical ones.

OUTLINE OF EXPERIMENTAL HOUSE

Figure 1 shows the ground plan of the ecological house and Table 1 indicates its specifications.
The house with a total floorage of 180 square

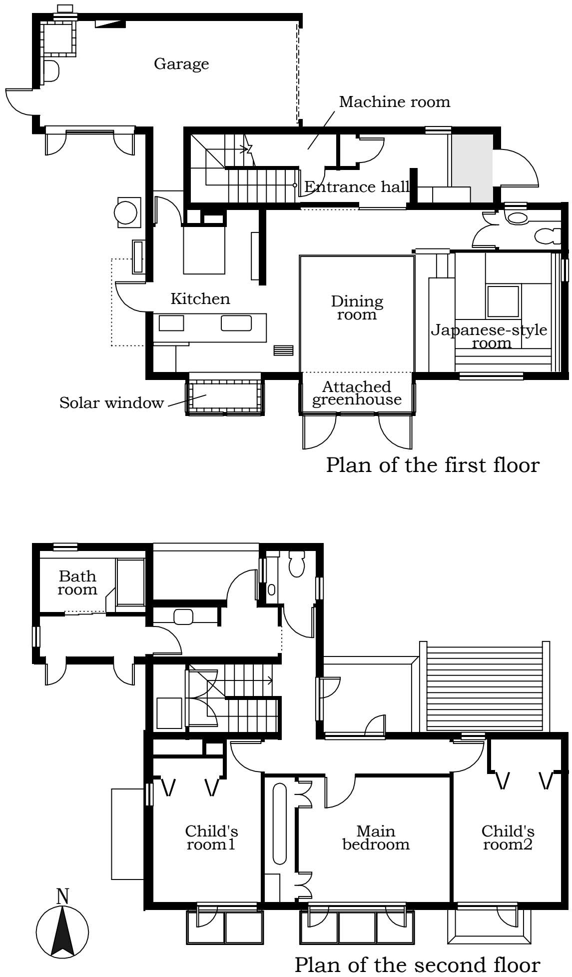

Figure1 Ground Plan of Ecological House

Table1 Specifications of Ecological House

	Details
Thermal insulation	Outer wall : Rockwool 150mm Roof : Polystyrene foam 200mm
Attached greenhouse	Glass : Low-emissivity double glazing(3-6-3mm) Shade : Roll screen installed outside
Heat storage floor	Concrete 150mm
Rock bed	Rubble : Depth 250mm Surrounding insulation : Polystyrene foam 200mm
Solar air collector	Module of collector : 900mm×1000mm Area : 13.2m²
Solar water collector	Area : 8.8m² Capacity of hot water storage tank : 300 l
Solar cells (single crystal)	Module of sollar cells : 900mm×1000mm Area : 26.3m² Capacity of solar cells : 3.18kw

meters was built by the two-by-four method and completed in 1995. Five family members have been living since June 1995. The following is the outline of the systems used in the house.

(1) Direct gain system using an attached greenhouse (Figure 2)

Solar heat taken into a greenhouse and kept in a heat storage floor radiates at night. Roll screens designed to block solar radiation are installed outside to prevent room temperature from rising in summer. Low-emissivity double glazing is used in the greenhouse. The concrete of the heat storage floor is 150 millimeters thick.

(2) Solar air heating system(Figure 3)

During the heating season, air is warmed by a solar air collector installed in the western part of the southern roof, and is sent by a fan through a duct to a rock bed under the floor on the first floor for radiant heating. An air conditioning system installed in the middle of the duct heats air if the amount of heat is short. Air blown from the floor on the first floor circulates to the upper part of the greenhouse to the second floor to the inlet of the ceiling to the solar air collector on the roof. During the cooling season, air over a specified temperature is exhausted outside.

(3) Solar water heating system(Figure 4)

Heat is collected by a solar water collector installed in the upper center of the southern roof. Through an antifreeze solution, heat exchange is conducted in a hot water storage tank and tap water is warmed. If a specified temperature is not gained, gas as auxiliary heat source is used to heat water.

(4) Photovoltaic power generation system(Figure 5)

Sunlight is converted into electricity by solar cells set up in the eastern part of the southern roof, and is utilized through an inverter as a household power source. Surplus power is sold to a power company. Figure 6 shows the roof area occupied by each system.

MEASUREMENT

Measurement is automatically done by a data logger and computer. The mean of values measured for ten minutes at 15 seconds intervals is recorded in a magnetic optical disc. Measurement has been done for two years since June 9, 1995.

VERIFICATION AND SIMULATION OF EACH SYSTEM

(1) Direct gain system using an attached greenhouse
[Verification]

The LESCOM program using the Response Factor Method developed by the authors was applied to calculation of room temperature fluctuations. The LESCOM program consists of one main routine and 50 sub routines. Figure 7 shows the comparison between calculated temperatures and those

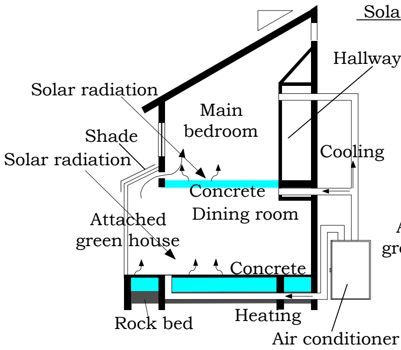

Figure2 Direct Gain System Using Attached Green house

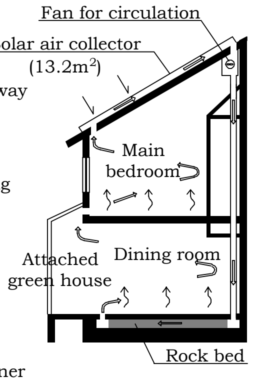

Figure3 Solar Air Heating System

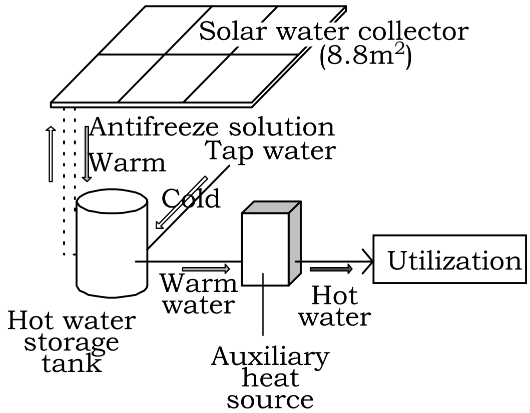

Figure4 Solar Water Heating System

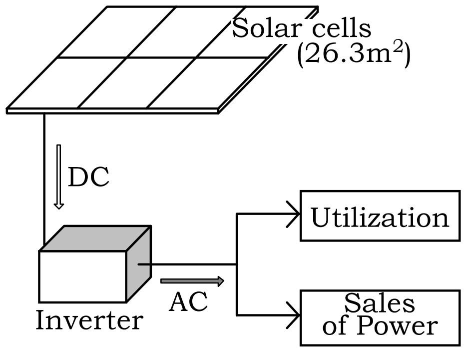

Figure5 Photovoltaic Power Generation System

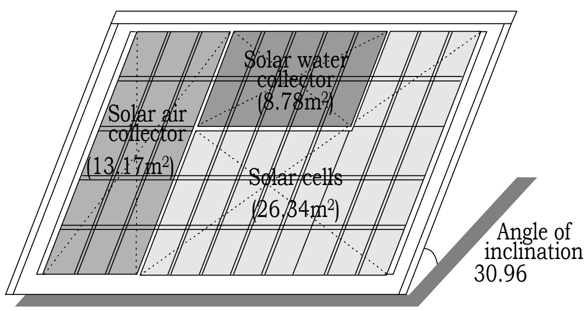

Figure6 Roof Area Occupied by Each System

measured every hour at a dining room in the intermediate season in an effort to confirm the credibility of the program. The program is regarded as highly reliable, as calculated values and measured ones are almost identical.

[Annual Simulation]

1) Conditions

Standard weather data for Tokyo(in the 1980s) were used. Questionnaires were sent out to set a life pattern similar to that followed by the family living in the ecological house. Based on the findings of the questionnaires, the authors determined when curtains were drawn and opened, generation of heat from the human body and the schedule of use of lighting and other machines. Space data were compiled on the assumption that the attached greenhouse was separate from the dining room and that the two were linked through mutual ventilation. Table 2 shows the calculation patterns.

2) Results

Figure 8 and 9 show the results of the calculation of cooling and heating loads. It is found that the ecological house can reduce the load by 25 percent throughout the year compared with Pattern 8(standard house). Pattern 5 with low-emissivity glass, which is installed as partitions between the attached greenhouse and the dining room and opened and closed when necessary, can curtail the load most sharply.

(2)Solar air heating system

[Verification]

Figure 10 shows the analysis method of the rock bed. Under the method, the rock bed is divided(into three segments) horizontally and the vertical one-dimensional heat conduction is applied. The following are heat balance equations for all segments.

Segment 1 :

$$\frac{V}{3}\rho_r \cdot C_r \frac{dT_1}{dt} = H_{a1} + H_{loss\,s} + H_{loss\,t} + H_{loss\,1} + H_{up\,1} \quad (1)$$

Segment 2 :

$$\frac{V}{3}\rho_r \cdot C_r \frac{dT_2}{dt} = H_{a2} + H_{loss\,s} + H_{loss\,2} + H_{up\,2} \quad (2)$$

Segment 3 :

$$\frac{V}{3}\rho_r \cdot C_r \frac{dT_3}{dt} = H_{a3} + H_{loss\,s} + H_{loss\,u} + H_{loss\,3} \quad (3)$$

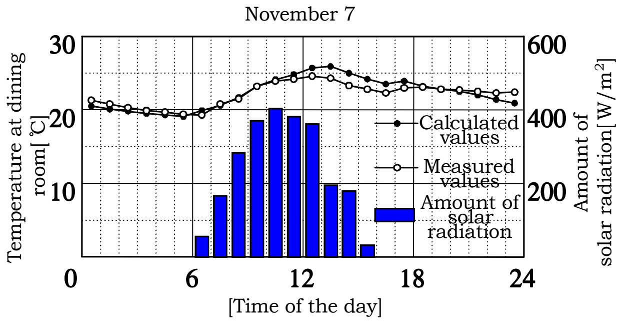

Figure7 Comparison between LESCOM-Calculated Values and Measured Values

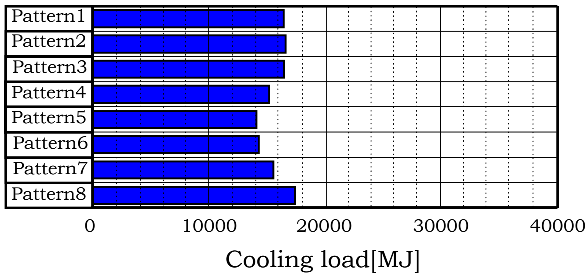

Figure8 Simlation of Cooling Load

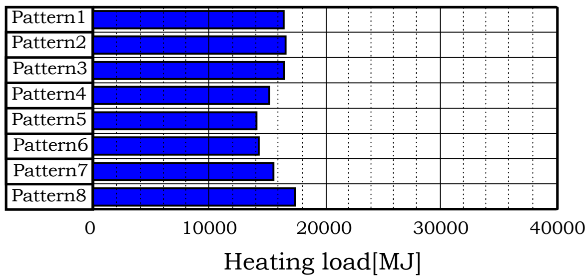

Figure9 Simlation of Heating Load

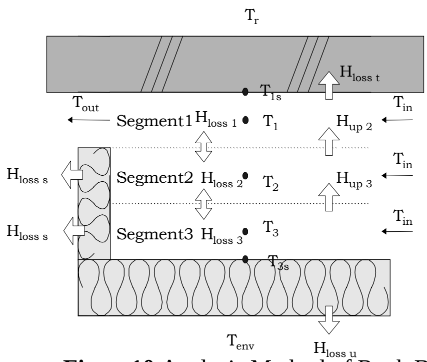

Figure10 Analysis Method of Rock Bed

Table2 Simulation Patterns

	Specifications of outer walls	Specification of floors	Attached green house	Members for partitions
Pattern 1 (Ecological house)	High insulation Rock wool 150mm	Heat storage floor Concrete 150mm	With	
Pattern 2			With With partitions (Open between 6:00 a.m and 7:00 p.m in summer) (Open between 7:00 a.m and 5:00 p.m in winter)	Plywood×2
Pattern 3				Plywood×2 with rock wool 50mm
Pattern 4			With With partitions (Open between 7:00 p.m and 6:00 a.m in summer) (Open between 7:00 a.m and 5:00 p.m in winter)	Plywood×2
Pattern 5				Low-emissivity glass
Pattern 6		Standard floor		
Pattern 7		Heat storage floor Concrete 150mm	Without	
Pattern 8 (Standard house)	Standard insuration Rock wool 55mm	Standard floor		

Nomenclature:
H_a-Amount of heat of inlet air
$H_{loss\ t}$-Heat transfer to upper and lower segments
$H_{loss\ b}$-Heat loss to the lower soil
C_r-Specific heat
H_{up}-Amount of heat of air ascending from lower segments
$H_{loss\ s}$-Heat loss to the side soil
V-Capacity
Figure11 shows the comparison between theoretical values and measured ones. They are almost identical.

(3) Solar water heating system

[Verification]

1) Performance straight line of solar heat collector

Figure 12 shows measured values between July 1995 and April 1996.

Based on the least square method,

$$Y=-0.348X+0.556 \qquad (4)$$

Performance straight line of solar collector

X-axis: $\dfrac{\left(\dfrac{T_{in}+T_{out}}{2}-T_{env}\right)}{I_T}$

Y-axis: $\dfrac{Q_u}{A \cdot I_T}$

Nomenclature:
T_{in}-Inlet temperature of solar collector
T_{out}-Outlet temperature of solar collector
T_{env}-Outdoor temperature
I_T-Solar radiation on solar collector surface
Q_u-Amount of heat obtained by solar collector
A-Area of solar collector

Figure 13 shows theoretical values based on Formula(4) and measured ones. They are almost identical when a pump is in operation in the daytime.

2) Theoretical formula of hot water storage tank

As Figure 14 shows, the tank is divided into five segments and the one-dimensional thermal stratification is applied. The heat balance equation for Segment "n" in the tank is:

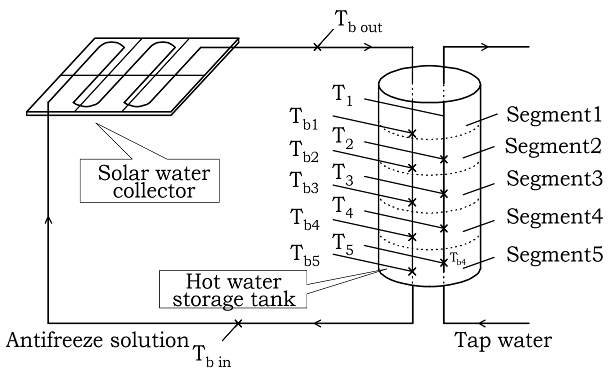

Figure14 Analysis Method of Hot Water Storage Tank

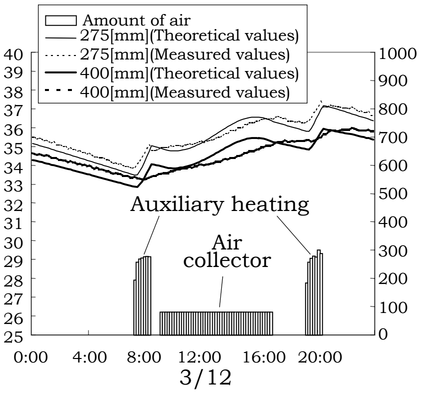

Figure11 Comparison between Theoretical and Measured Values of Rock Bed

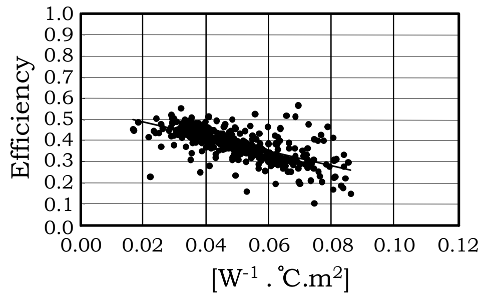

Figure12 Heat Collecting Efficiency

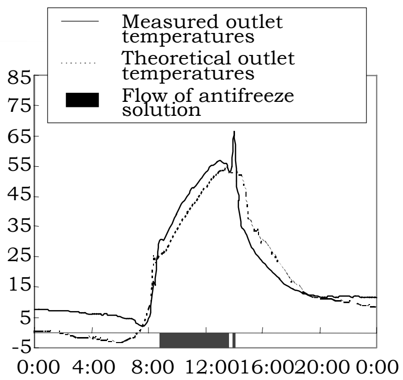

Figure13 Comparison between Theoretical and Measured Values of Solar Water Collector

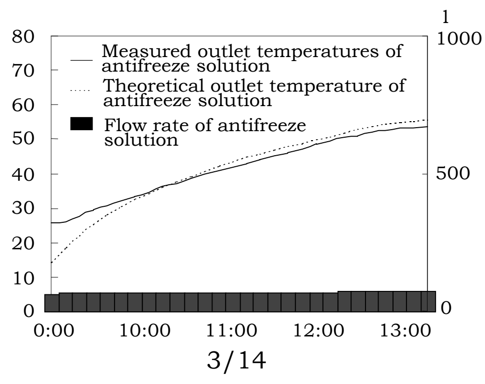

Figure15 Comparison between Theoretical and Measured Outlet Temperatures of Antifreeze Solution

$$M \cdot C_{pw} \frac{dT_n}{dt} = H_{bn} + H_{wn} + H_{loss\,n} \text{ [W]} \quad (5)$$

$$H_{loss\,n} = u \cdot A(T_{env} - T_n) + q_{\lambda}(T_n - T_{n\pm1}) \text{ [W]} \quad (6)$$

$$H_{bn} = \overline{KA}(T_{bn} - T_n) \text{ [W]} \quad (7)$$

$$H_{wn} = F_w \quad C_{pw}(T_{n+1} \quad T_n) \text{ [W]} \quad (8)$$

Nomenclature:

$H_{loss\ n}$-Heat loss to outdoor temperature and heat transfer inside tank

q -Diffusion coefficient

H_{bn}-Heat gain from antifreeze solution

T_n-Water temperature

H_{wn}-Heat loss from use of water

F_w-Rate of water flow

u-Coefficient of overall heat transmission of tank

C_p-Specific heat of water

$\overline{KA}$-Performance of heat exchanger

M-Amount of water

A-Side area

The assumption is:

q =0.463[W/℃]

u=0.276[W/m^2 ℃]

$\overline{KA}$=554.56[W/℃]

Figure 15 and 16 show the comparison between theoretical values and measured ones. They are almost identical.

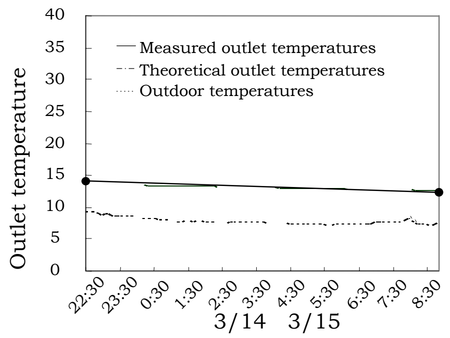

Figure16 Comparison between Theoretical and Measured Outlet Temperatures of Hot Water Storage Tank

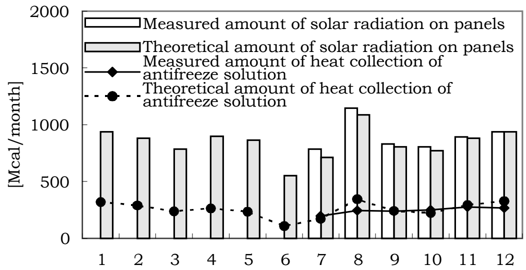

Figure17 Annual Simulation

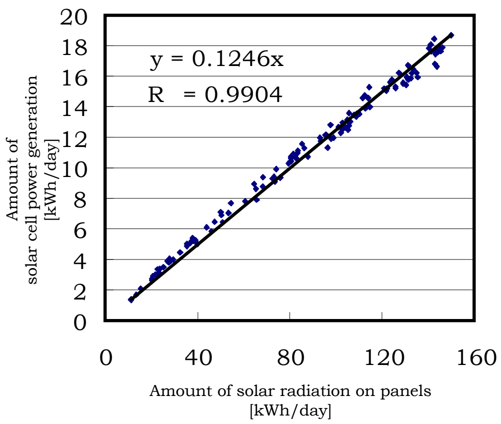

Figure18 Relationship between Amount of Solar Radiation on Panels and Amount of Solar Cell Power Generation

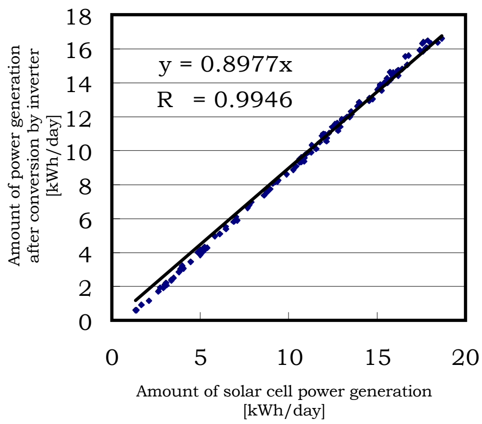

Figure19 Relationship between Amount of Solar Cell Power Generation and Amount of Power Generation after Conversion by Inverter

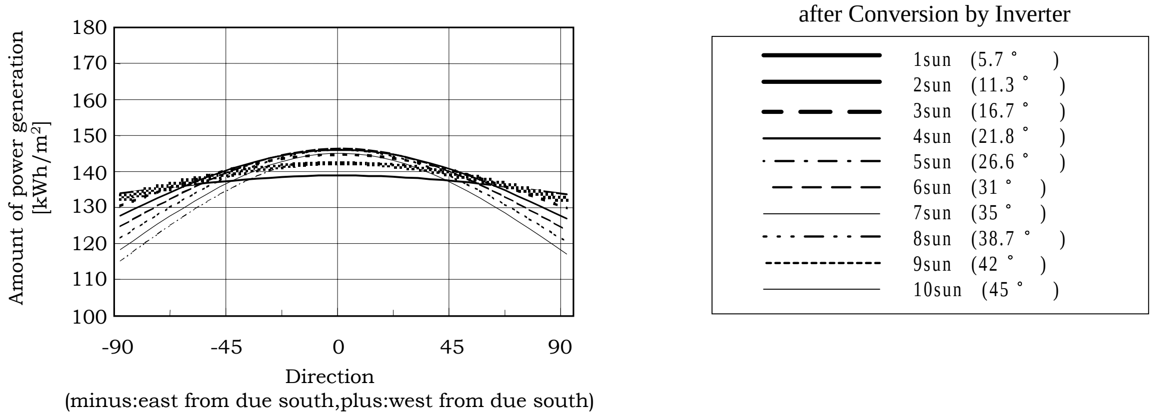

Figure20 Predicted Amount of Power Generation in Tokyo by Direction

[Annual Simulation]

Figure 17 shows the theoretical amount of heat collecition of an antifreeze solution(12.7GJ) based on weather data for Tokyo in 1995, and measured one. The simulation is considered to be highly accurate.

(4) Photovoltaic power generation sysytem

[Verification]

Figure 18 shows the relationship between the solar radiation amount on the panels and the solar cell power generation amount based on the measured values. Figure 19 shows the ralationship between the solar cell power generation amount and the power generation amount after the conversion by the inverter. As the relations in each of the two figures are almost one-dimensional, they are highly correlative. It is assumed, from the inclination of approximate straight line, that the efficiency of solar cell power generation is 12.46 percent and that of the inverter 89.77 percent

[Annual Simulation]

A simulation program using the Visual Basic Programming System was developed, as the photovoltaic power generation system can be applied widely. In the solar radiation of standard weather data for various regions, the authors input such conditions as regions, area of panels, azimuth, angle of inclination(roof pitch) and unit price of power, and calculated the monthly and yearly amount of power generation. Figure 20 shows the yearly amount of power generation per unit area in accordance with changes in azimuth and angle of inclination of panels in Tokyo. Table 3 shows the optimum placement of panels by region.

CONCLUSION

Simulation programs for the four typical systems of the ecological house were drawn up and verified. The accuracy of each of the programs was found to be high. The joint use of these programs and the LESCOM program has enabled the precise simulation of the ecological house under various conditions.

Table3 Optimum Conditions for Installing Panels by Region

Regions	Cities	Roof pitch (sun)	Direction (degree)	Annual amount of power generation
I	Sapporo	6	0	156.11
	Asahikawa	5	(+)5	135.38
	Nemuro	7	0	173.78
	Muroran	6	(+)5	146.80
II	Akita	4	(+)5	139.76
	Morioka	5	0	153.86
	Aomori	5	(+)5	145.84
	Hachinohe	6	(-)5	154.61
III	Sendai	6	0	155.49
	Yamagata	5	(+)30	145.20
	Fukusima	6	(-)5	161.99
	Niigata	4	(+)10	140.15
	Toyama	4	(+)5	144.63
	Matsumoto	5	0	168.20
IV	Tokyo	5	0	146.36
	Osaka	5	(+)5	133.66
	Nagoya	6	0	170.39
	Shizuoka	5	(-)5	160.82
	Yonago	4	0	153.48
	Fukuoka	4	(+)5	165.38
	Kumamoto	5	0	179.66
	Takamatsu	4	0	171.16
V	Kagoshima	5	(+)5	178.97
VI	Naha	3	(-)5	167.13

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