

EFFECTS OF TREES ON THE ROOM TEMPERATURE AND HEAT LOAD OF RESIDENTIAL BUILDING

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ABSTRACT

In summer, the shady planting is expected for providing shadow on building envelope and reducing reflected solar radiation from the front yard. The heat load simulation program which can take into consideration the shadow effects caused by trees including the effect of the long wave radiation exchange is developed by the authors. The program used to examine the effects of trees on the room thermal environment as well as heating and cooling loads of a model house. In the simulation, two kinds of trees, evergreen broad-leaved tree and deciduous broad-leaved tree were assumed. The simulation results for several cases of tree arrangements around the house showed that the cooling load was reduced by 15% - 20%. While the difference in cooling load was small, the heating load increased by 26% and 8.5% in case of the evergreen broad-leaved tree and the deciduous broad-leaved tree, respectively.

KEYWORDS

Heat Load, Shadow, Tree, Form Factor

INTRODUCTION

Whereas the role of planting trees in the yard may be considered for comfortable landscape, it is also expected the functions as shown below.

- Shading of solar radiation especially in summer.
- Cooling effects by evaporation from leaves.
- Preventing from seeing the inside of the building from adjoining site or passage.
- Interrupting the sound from surrounding.
- Protecting the fire from neighboring buildings.
- Reducing the effect of stormy wind.

Whereas shady planting reduces the heat island effect from the view point of improving residential area in a city, it also affects directly indoor environment such as room temperatures and heat load of the building. Trees or adjoining buildings effect on the room environment. While the heating load increases due to reduction of the incident solar radiation by shadows, the cooling load decreases. Moreover, the long wave

radiation from the outside surfaces of the building decreases by reduction of the form factor to the sky.

In a single house, in order to examine the ideas for realizing good living environment by the low energy and low environmental impacts, the study on the energy consumed in the building including the effects of arrangement of adjoining buildings or trees is necessary. However, dynamic shading systems including trees are still difficult to model. Therefore they may complicated procedure to implement the shadow calculation into the general simulation. So, they are often ignored in simulation for design at the practical stage. Asawa and Hoyano (2004) are proposed a model which computes total skin temperature of residential external surfaces after reproducing complicated form of trees by 3D-CAD . From such a viewpoint, the effect of trees on the room temperature and heat load of the building was verified using the simulation program *EESLISM* (Higuchi, Udagawa, Sato and Kimura 2001, 2007) which can take into consideration the thermal effects of trees and adjoining buildings.

BASIC ALGORITHM FOR THE EXTERNAL ENVIRONMENT

Basic algorithm

For the effect of outside environment on a room, convective heat transfer of the outside surface, short wave radiation, long wave radiation, natural ventilation and cross air flows are considered.

A generalized simulation program of room thermal environment and air conditioning load, *EESLISM*, can consider the short wave radiation and the long wave radiation in connection with the shading effects of the solar radiation and obstacles for the long wave sky radiation.

The calculation of shadows is necessary in order to find a direct solar radiation in outside surfaces. In addition, the form factors are necessary in order to find a reflected solar radiation in outside surfaces. The form factors are also necessary to find the long wave radiation between the outside surfaces and the surrounding as well as the sky. The calculation method of shadows and the form factors developed by the authors is shown below.

- The algorithm of shadows

In calculation of a shadow, there are two ways. First method is to find the figure of the shadow on outside surfaces directly, and another method is to divide the outside surface (an outer wall, a window, a roof) into a small grid and to judge the existence of the direct solar radiation across the grid. In this research, since the calculation of the overlapping obstacle and coordinate conversion are complicated, the method of dividing into a small grid was adopted.

- The algorithm of form factors

In calculation of form factors from the outside surface to the sky, trees, eaves and the building outside of the own, there are two ways. First method is to use a formula, and the another method is to use *the Monte Carlo method*. *The Monte Carlo method* is the calculation technique which is often used to obtain approximate solution using random numbers. In this research, *the Monte Carlo method* was adopted for flexibility in case of overlapping two or more obstacles. Basically, a form factor defined from a central point of each outside surface of the house to outside objects is calculated using the vectors of emitted radiation generated by random numbers.

- A setup of the surface temperature of external obstacles (an adjoining building, trees, etc.) and the ground

Generally, it is assumed that the surface temperatures of trees and the ground are equal to outside air temperature. However, the ground temperature may be higher than the outside air temperature on sunny days. Therefore, the surface temperature of trees was assumed to be that of the outside temperature, and the surface temperature of the ground was assumed to be a sol-air temperature.

Key EESLISM features

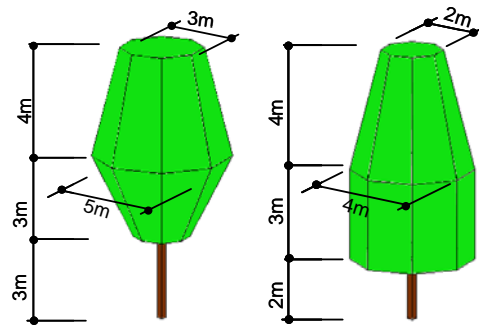
- 1) The shadow of the outside surface can take into consideration the shadow by external obstacles (an adjoining building, trees, etc.), attachment obstacles (eaves, a balcony, etc.), and the building itself.
- 2) Not only shadows onto windows but also shadows onto walls and roofs can be calculated.
- 3) There is no restriction in arrangement of external obstacles. For example, the external obstacle may float or lean.
- 4) Reduction of the reflected solar radiation of the ground due to shadows can be taken into consideration.
- 5) Long wave radiation exchange is considered.

SIMULATION MODEL

Tree arrangement and housing model

The effects of external obstacles for short and long wave radiations were examined using the developed

program, *EESLISM*. In summer, the shady planting can expect reduction of the reflected solar radiation



Akaside(*Carpinus laxiflora*) *Sudajii* (*Castanopsis*)
deciduous broad-leaved tree evergreen broad-leaved tree

Figure 1 Tree model

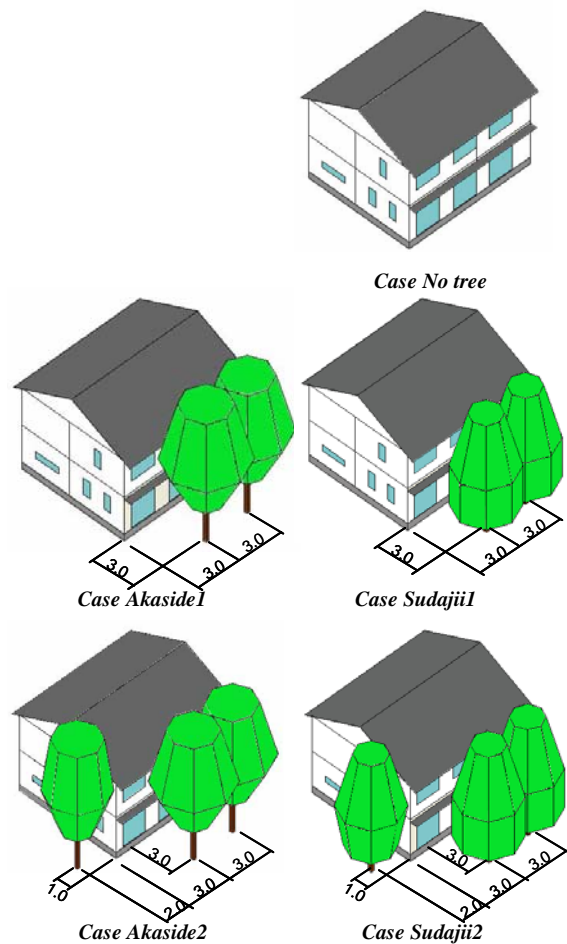


Figure 2 Tree Arrangement

Table 1 Calculation Cases

	Case	Arrangement
1	No tree	Trees are not arranged
2	Akaside1	Two trees arranged in the southern yard
3	Akaside2	Two trees arranged in the southern yard and one trees arranged in the west yard
4	Sudajii1	Two trees arranged in the southern yard

5	Sudajii2	Two trees arranged in the southern yard and one trees arranged in the west yard
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from the front garden by planting trees, and reduction of the incident solar radiation of the afternoon sun by western planting.

In winter on the other hand, heating load increases by reduction of the direct solar radiation by the shadow of trees. Therefore, to suppress the increase in the heating load by using a deciduous broad-leaved tree is desired.

Therefore, in this research, as shown in Table 1 and Fig. 2, it was considered as the following three patterns.

- Two trees arranged in the southern yard.
- Two trees arranged in the southern yard and one tree arranged in the west yard.
- Trees are not arranged.

The effects were examined with two patterns of a deciduous broad-leaved tree, *Akaside*(scientific name:*Carpinus laxiflora*) and an evergreen broad-leaved tree, *Sudajii*(scientific name:*Castanopsis*) as shown in Fig. 1. The model building used for the simulation is a 135 m² 2-story residential house as shown in Fig. 3.

Calculation conditions

Table 2 shows the fallen-leaves schedule of *Akaside* and *Sudajii*. A fallen-leaves schedule is decided by various factors, such as a kind of trees and a growth location and so on. Therefore, it is difficult to decide a fallen-leaves schedule for different types of trees. In this research, it is assumed as shown in Table 2. A leaf area density changes from 0.0 to 0.5. And the fallen-leaves schedule of *Castanopsis* is 0.5 all the year round. Internal heat generation of the building is based on a family of parents and two children. The air conditioning schedule is taken as intermittent air-conditioning as shown in Fig. 4. The air-conditioning schedule is taken as living room:7:00 to 10:00, 12:00 to 14:00, 16:00 to 23:00, bedroom:21:00 to 23:00, and children's room:20:00 to 23:00. In the heating period in winter, the set point temperature is the operative temperature 20°C, and in the cooling period in summer, the room temperature was 26°C and the humidity was 60%. The walls, roofs, floors and windows are shown in Fig. 5. The thermal insulation used for walls, roofs, floors is glass fiber 24K. The window is composed of double layer clear glass (6mm+6mm). The schedule of the curtain is shown in Fig. 4. The location of the house in this simulation is supposed to be Tokyo. The number of divisions of outside surface for calculating the shadow were 10000 devisions in each suraface, and the number of ejection of the random number used for calculation of the form factor were 10000.

Table 2 Fallen-leaves schedule

<i>Akaside</i> (deciduous broad-leaved tree)		<i>Sudajii</i> (evergreen broad-leaved tree)	
Period	Leaf area density	Period	Leaf area density
1/1-3/10	0.0	1/1-12/31	0.5
3/11-4/10	0.2		
4/11-4/30	0.4		
5/1-10/31	0.5		
11/1-12/31	0.2		

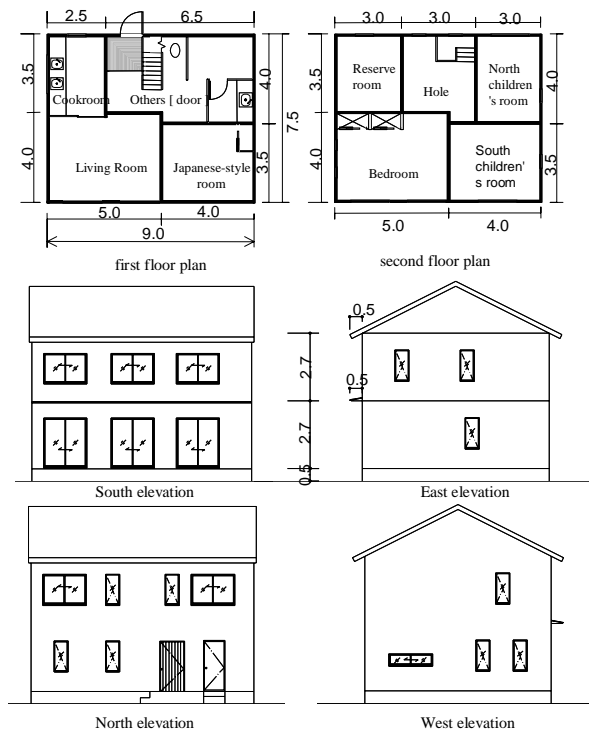
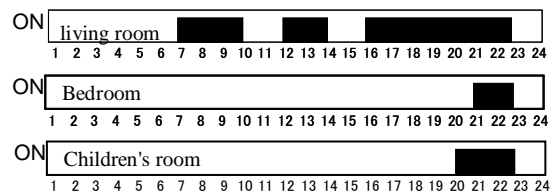
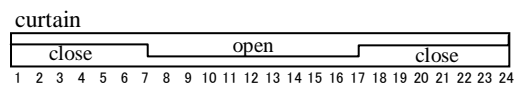


Figure 3 House model1

Air Conditioning



Window



Cooling: Room temperature is 26°C, humidity is 60% .Heating: Operative Temperature is 20°C

Figure 4 Air conditioning and window schedule

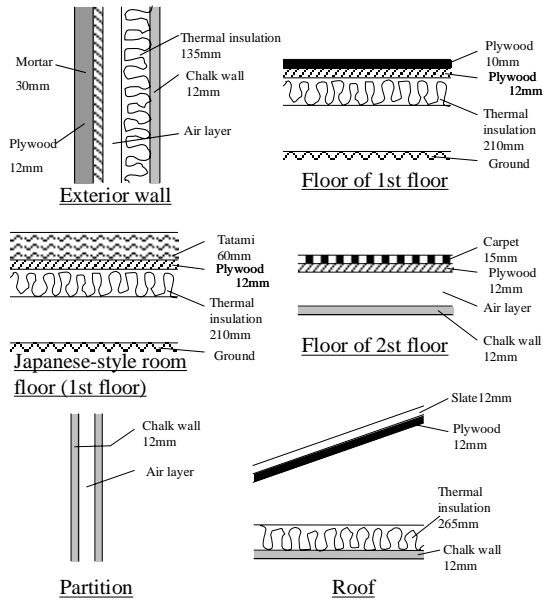


Figure 5 Composition of walls

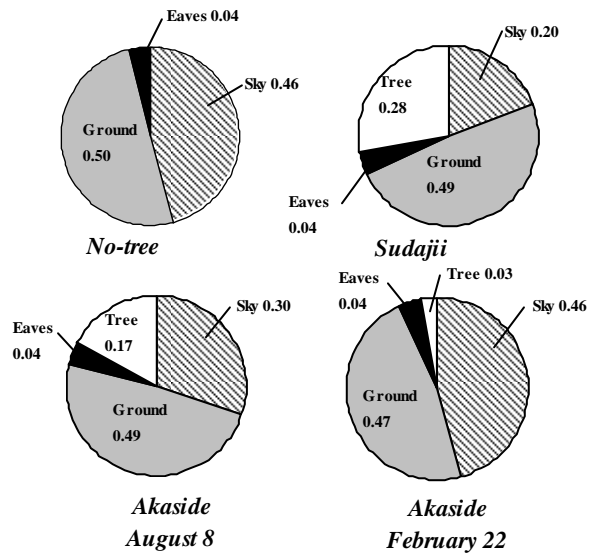


Figure 6 Form factors from south external surface of the living room to outside environment

SIMULATION RESULT

Form factor

Fig. 6 shows form factors from south external surface of the living room to the outside environment.

In case of *Akaside*, since the leaves fell to a schedule as shown in Table 2, the form factors to trees were 0.17 in summer, 0.03 in winter, respectively, and the form factor to the sky was 0.3 in summer, 0.46 in winter, respectively. In the case of *Sudajii*, the form factor to trees were 0.28, and the form factor to the sky was 0.20.

Solar radiation and long wave radiation

Fig. 7 shows shadow ratio of south yard of the living room, and reflected solar radiations from south yard in summer sunny day, August 8. Shadow ratio is defined as a ratio of a shadow area to an outside surface area. The shadow area was 35% at the maximum in both *Akaside* and *Sudajii*. In connection with it, the daily total of reflected solar radiations from the front yard to the living room outer wall for the cases of *Akaside* and *Sudajii* decreased by 28% and 31% against *No-tree*, respectively.

Fig. 8 shows shadow ratio and direct solar radiation on south wall of the living room in summer sunny day, August 8. The shadow is mainly based on eaves. Shadow ratio had little effect by tree arrangement. In the *No-tree* case, daily total direct solar radiation incident on south external surface of the living room was 0.663 [kWh/m²]. Direct solar radiations for the cases of *Akaside1* and *Sudajii1* were 0.483[kWh/m²] and 0.576 [kWh/m²], respectively.

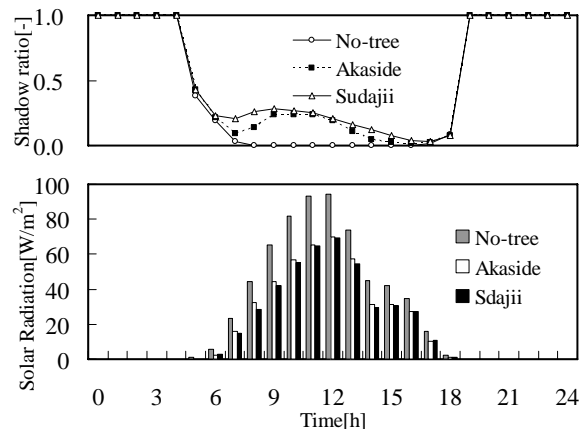


Figure 7 Shadow ratio of south yard of the living room, and reflected solar radiations from south yard in summer sunny day, August 8.

Fig. 9 shows incident total solar radiation on south wall of the living room in summer sunny day, August 8. In the case of *No-tree*, daily total incident solar radiation was 1.96 [kWh/m²]. Incident solar radiations for the cases of *Akaside1* and *Sudajii1* were 1.39 [kWh/m²] and 1.31 [kWh/m²], respectively. Daily total incident solar radiations for the cases of *Akaside1* and *Sudajii1* decreased 29% and 33%, respectively.

Fig. 10 shows shadow ratio and direct solar radiation on south wall of the living room in winter sunny day, February 22. Shadow ratio of the *Akaside1* case was equal to the *No-tree* case in winter since *Akaside1* is a deciduous broad-leaved tree. To the contrary, shadow ratio of the *Sudajii1* case was 60% at the maximum. As a result, daily total direct solar

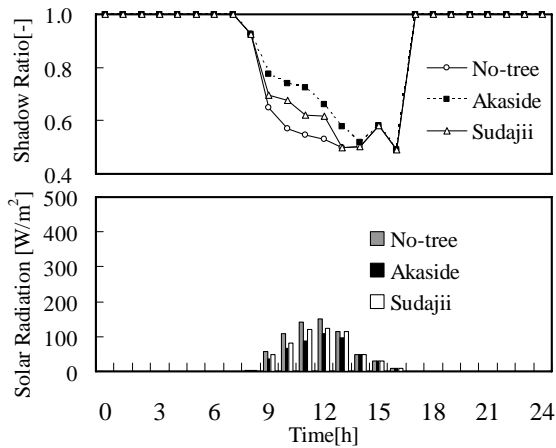


Figure 8 Shadow ratio and direct solar radiation on south wall of the living room in summer sunny day, August 8

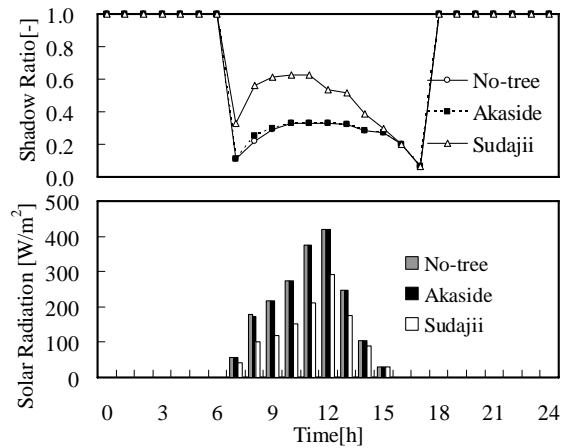


Figure 10 Shadow ratio and direct solar radiation on south wall of the living room in winter sunny day, February 22

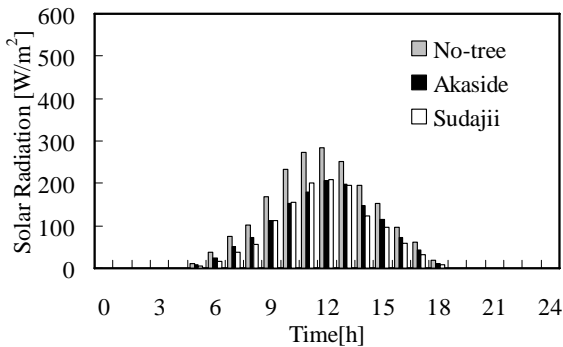


Figure 9 Incident total solar radiation on south wall of the living room in summer sunny day, August 8

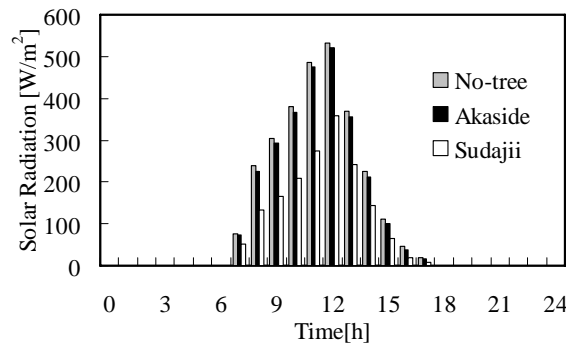


Figure 11 Incident total solar radiation on south wall of the living room in winter sunny day, February 22

radiations for the cases of No-tree and Akaside1 were comparable.

However, daily total direct solar radiation for the Sudajii1 case decreased by 36.4% compared with No-tree.

Fig. 11 shows incident solar radiation on south wall of the living room in winter sunny day, February 22.

Daily total incident solar radiation for the No-tree case was 2.79 [kWh/m²]. Incident solar radiations for the cases of Akaside1 and Sudajii1 were 2.68 [kWh/m²] and 1.67[kWh/m²], respectively. Daily total incident solar radiation for the Sudajii1 case was decreased by 40%.

Fig. 12 shows long wave radiation on south wall of the living room received in August 8. Daily total long wave radiation for the No-tree case was 10.7 [kWh/m²]. Long wave radiations for the cases of Akaside1 and Sudajii1 were 10.5 [kWh/m²] and 10.6 [kWh/m²], respectively. Long wave radiations of Akaside1 and Sudajii1 cases in the daytime decrease when compared to the No-tree case. It is because a shadow is made on the ground and the ground surface temperature falls by the trees.

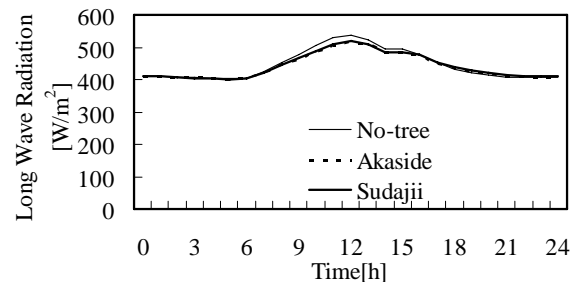


Figure 12 Long wave radiation on south wall of the living room received in August 8

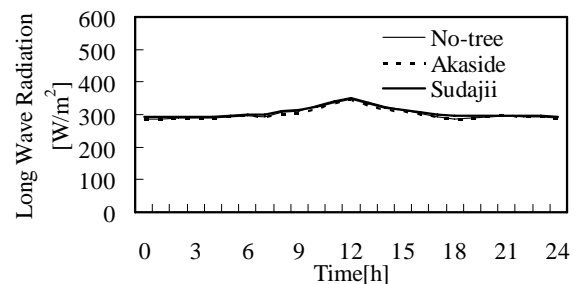


Figure 13 Long wave radiation on south wall of the living room received in February 22

Fig. 13 shows long wave radiation on south wall of the living room received in February 22. Daily total long wave radiation for the *No-tree* case was 7.28 [kWh/m²].

Long wave radiations for the cases of *Akaside1* and *Sudajii1* were 7.22 [kWh/m²] and 7.35 [kWh/m²], respectively.

Transmitted solar radiation and Heat gain of absorption solar radiation

Fig. 14 shows the daily total heat gain of the living room in summer sunny day, August 8 and the winter sunny day, February 22. Heat gain by absorbed solar radiation shows the overall solar heat transmission from the outside surfaces of walls, windows and roofs to the room.

In summer sunny day, August 8, daily total heat gain of the living room for the *No-tree* case was 17.86 [kWh/m²]. Heat gains for the cases of *Akaside1*, *Akaside2*, *Sudajii1* and *Sudajii2* were 14.08 [kWh/m²], 12.43 [kWh/m²], 13.53 [kWh/m²], 11.06 [kWh/m²], respectively. Heat gain for the *Akaside1* case decreased by 21% rather than the *No-tree* case. Heat gains for the cases of *Akaside2*, *Sudajii1* and *Sudajii2* decreased by 30%, 24% and 38%, respectively. Transmitted solar radiation for the *Akaside2* case was almost equal to the *Akaside1* case. To the contrary, heat gain by absorbed solar radiation for the *Akaside2* case decreased by 12 [kWh/m²] rather than the *Akaside1* case. In the living room, since there were only small windows in the west envelope, the effect of the transmitted solar radiation was small. To the contrary, absorbed solar radiation decreased by the shadow for the outer wall.

By planting the trees which interrupt the afternoon sun, daily total heat gains for the cases of *Akaside* and *Sudajii* decreased by 11% and 18%, respectively. If there is a large window in the west envelope, larger effect is expected by planting trees.

In winter sunny day, February 22, daily total heat gain of the living room for the *No-tree* case was 23.17 [kWh/m²]. Heat gains for the cases of *Akaside1*, *Akaside2*, *Sudajii1* and *Sudajii2* were 22.32 [kWh/m²], 22.25 [kWh/m²], 14.32 [kWh/m²] and 13.37 [kWh/m²], respectively. Heat gain for the *Akaside1* case decreased by 3.7% rather than the *No-tree* case. Heat gains for the case of *Akaside2*, *Sudajii1* and *Sudajii2* decreased by 4.0%, 38% and 42%, respectively. Since the leaf area density of *Akaside* in winter was 0.0, the heat gain for the *Akaside* case was almost equal to the *No-tree* case. Heat gains for the cases of *Sudajii1* and *Sudajii2* greatly decreased comparing to *No-tree*.

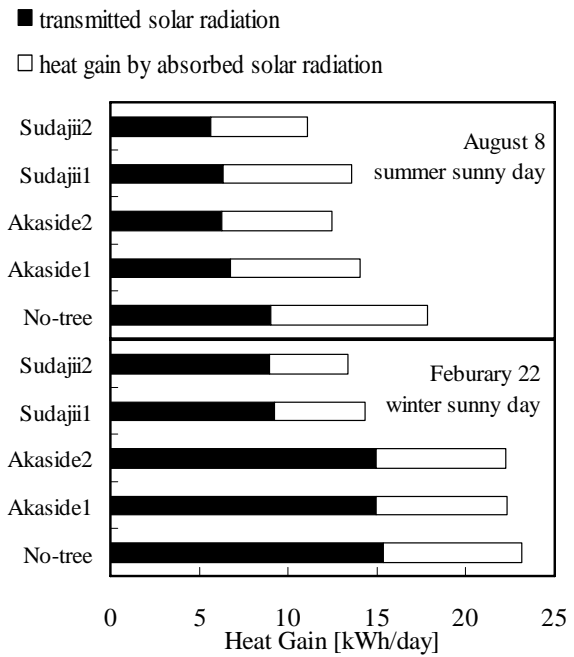


Figure 14 Daily total heat gain of the living room in summer and winter

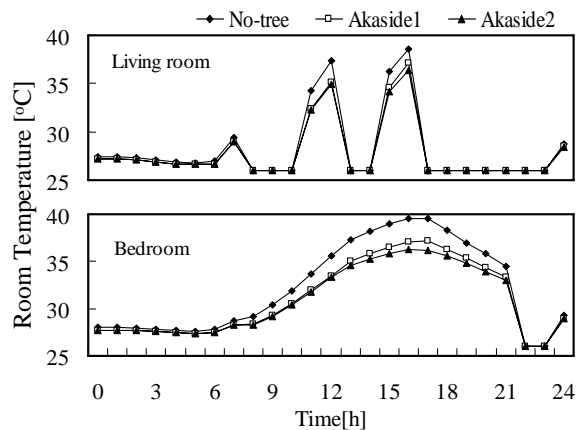


Figure 15 Room temperature of the living room and Bedroom in August 8

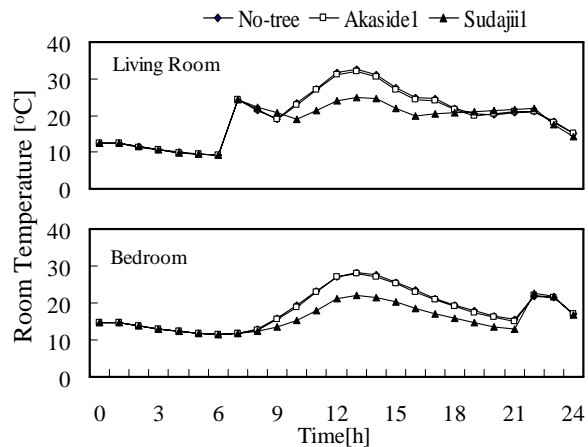


Figure 16 Room temperature of the living room and Bedroom in February 22

Room temperature

Fig. 15 shows the room temperatures of the living room and bedroom in August 8 in the *No-tree* case, *Akaside1* case and *Akaside2* case.

In case of the *No-tree*, the highest room temperature of the living room was 38.6°C.

The room temperatures of the living room for the cases of *Akaside1* and *Akaside2* were 37.1°C and 36.4°C, respectively. In case of the *No-tree*, the highest room temperature of the bedroom was 39.5°C at 17:00. The room temperatures of the bedroom for the cases of *Akaside1* and *Akaside2* were 37.2°C and 36.2°C, respectively.

Both room temperatures of the living room and bedroom in the *Akaside2* case were 1°C lower than the *Akaside1* case.

Fig. 16 shows the room temperatures of the living room and bedroom in February 22 in the *No-tree* case, *Akaside1* case and *Sudajii1* case.

In case of the *No-tree*, the highest room temperature of the living room was 32.5°C. The room temperatures of the living room for the cases of *Akaside1* and *Sudajii1* were 31.9°C and 25.0°C, respectively. In case of the *No-tree*, the highest room temperature of the bedroom was 28.2°C. The room temperature of the bedroom for the cases of *Akaside1* and *Sudajii1* were 27.9°C and 22.2°C, respectively.

The room temperature of the living room in the *Sudajii1* case was 7.7°C lower than the *No-tree* case.

Cooling and heating loads

Fig. 17 shows an annual cooling load and heating load. Annual cooling load for the *No-tree* case was 1.38 [MWh/a year]. Annual cooling loads for the cases of *Akaside1*, *Akaside2*, *Sudajii1* and *Sudajii2* were 1.16 [MWh/a year], 1.13 [MWh/a year], 1.13 [MWh/a year] and 1.09 [MWh/a year], respectively. Cooling load for each case decreased by 15%-20% compared with *No-tree* case.

Since the west windows of the living room were small, there was almost no effect for the afternoon sun.

Annual heating load for the *No-tree* case was 1.11 [MWh/a year]. Annual heating loads for the cases of *Akaside1*, *Akaside2*, *Sudajii1* and *Sudajii2* were 1.21 [MWh/a year], 1.21 [MWh/a year], 1.49 [MWh/a year] and 1.52 [MWh/a year], respectively. Heating load for *Akaside* case increased by 8.5% compared with the *No-tree* case. Heating load for *Sudajii* case increased by 26%, since *Sudajii* did not shed leaves.

Fig. 18 shows annual total heat load. Total heat load for the cases of *No-tree*, *Akaside1*, *Akaside2*, *Sudajii1* and *Sudajii2* were 2.49 [MWh/a year], 2.37

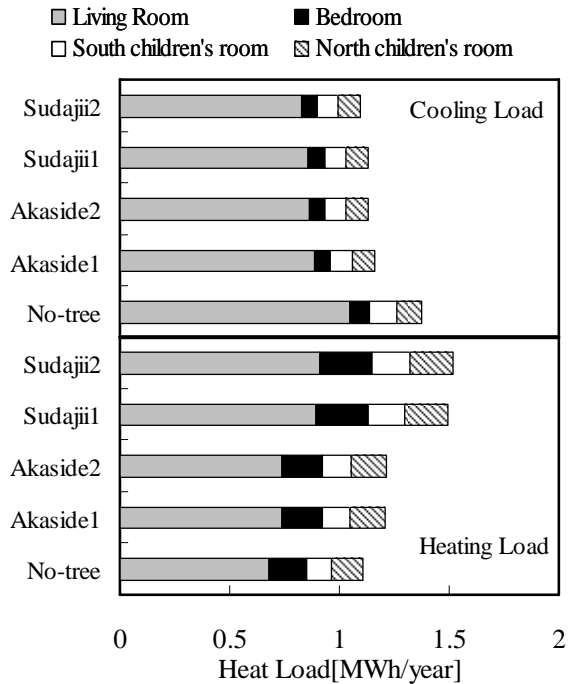


Figure 17 Annual cooling load and heating load

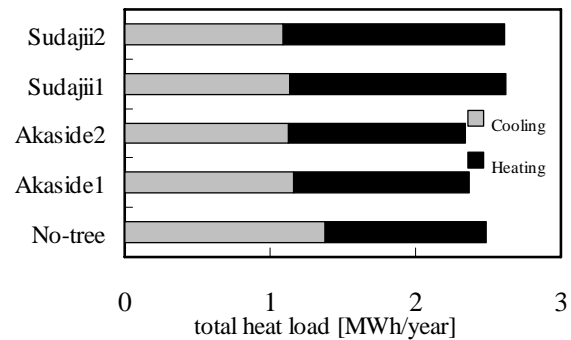


Figure 18 Annual total heat load

[MWh/a year], 2.34 [MWh/a year], 2.62 [MWh/a year] and 2.61 [MWh/a year], respectively. Although heat load for the *Akaside* case decreased by 5% compared with the *No-tree* case, heat load for the *Sudajii* case increased by 5%.

CONCLUSION

The shading effect of trees was examined using the developed program, *EESLISM*.

The simulation was carried out for five cases which consist of two type of trees, two kinds of tree planting arrangement and the base case (*No-tree*).

Cooling load reduced by 15% - 20% against the base case. This result is based on reduction of the reflected solar radiation from the ground, and reduction of the direct solar radiation by the shading effect. The difference in the tree type and the planting arrangement was small for the cooling load.

Since the west windows of the living room were small, there was almost no effect for the afternoon sun. It seems that the shielding effect of planting to the solar radiation is larger when there is a big west window for the living room.

In case of the deciduous broad-leaved tree, *Akaside*, heating load increased by 8.5% compared with *No-tree*. The heating load for the evergreen broad-leaved tree, *Sudajii* increased by 26% compared with *No-tree*. The increase of the heating load in winter can be suppressed by using a deciduous broad-leaved tree.

While annual total heat load for the deciduous broad-leaved tree, *Akaside* decreased by 5% compared with *No-tree*, the evergreen broad-leaved tree, *Sudajii* increased by 5%.

The effects of trees on the heat load were described in this paper using the *EESLISM*. The program can be used to simulate the thermal environment of buildings in city area considering housing arrangement of the surroundings.

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