DAYLIGHTING SIMULATION OF JAPANESE ARCHITECTURE USING ALL SKY MODEL

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ABSTRACT

There are two purposes for this paper, one is that the calculation method, which took sunlight into consideration using All Sky Model, is shown, and another is executing simulations by this method. The simulations are able to verify the daylighting technique of Japanese traditional architecture. Skylight and sunlight intensity are calculated using All Sky Model. The algorithm of daylight calculation uses the virtual cube, which divided into many grid cells. This cube is placed on a sample point and the illumination at the sample point from each patch is calculated. Calculation of interreflection is executed based on this result of the illuminance. The daylighting simulation of a room was executed by this calculation method. As a result, this simulation confirms us the method often used in traditional Japanese architecture, which is using reflected daylight from garden as indoor illumination.

INTRODUCTION

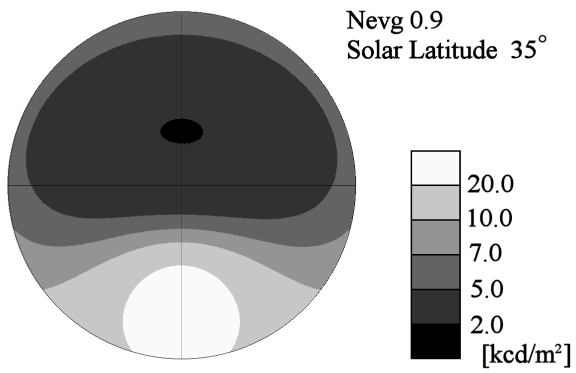
As sky luminance distribution model, All Sky Model was adopted and simulation algorithm was shown. The model, which simplified Japanese architecture with a square garden, was used for the simulation, and the indoor illuminance distribution is calculated. It is not the purpose for this paper to compare the result of this paper with the result of other simulation tools.

In traditional Japanese architecture, reflection light from the outside is used in many cases as the daylighting technique. When using such a technique, the color of gardens usually consists of a bright color. Simulation is executed in order to clarify the effect of such a daylighting technique.

SKYLIGHT

All Sky Model

In order to executing daylighting calculation, suitable skylight



Firue1 Sky luminance distribution

distribution model is required. There are important sky luminance distribution models, such as the CIE Standard Clear Sky, the CIE Standard Overcast Sky and the Intermediate Sky. And there are [1], [2] and etc. in calculation which used the model of CIE. Those models are developed for obtaining skylight distribution of specific sky condition, and we have to change a model according to the weather. Moreover, since only skylight distribution is obtained using these models, we should notice that the sunlight intensity at that time is unknown.

Thus All Sky Model of Ikawa et al.[3][4] developed as a model showing the sky luminance distribution in all sky conditions is used. Regression analysis of the observational data of zenith luminance distribution makes a function of normalized global illuminance, which is represented relative luminance to zenith luminance. In this model, the product of a relative luminance distribution and zenith luminance obtains sky luminance distribution. If horizontal skylight illuminance is calculated from All Sky Model, sunlight intensity is able to calculable from the definition formula of All Sky Model.

In All Sky Model, sky condition is specified by Nevg (normalized global illuminance). Value of Nevg indicates clear sky (Nevg 1.0-0.9), near clear sky (Nevg 0.9-0.75),

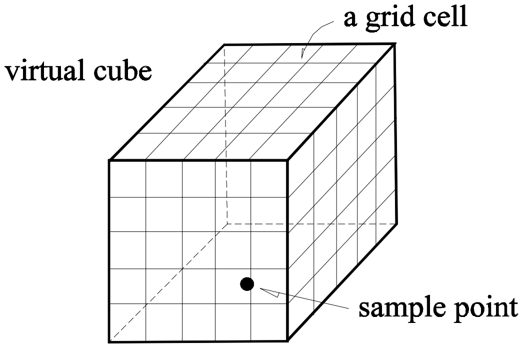


Figure2 Virtual cube

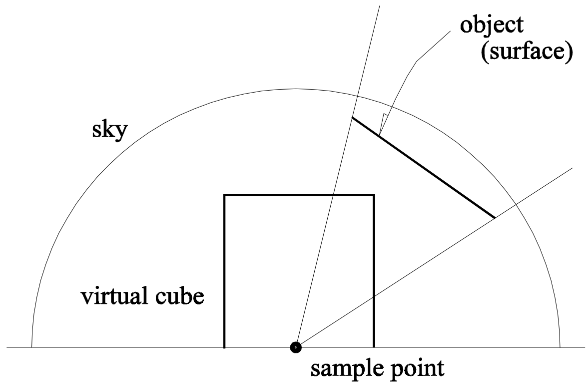


Figure3 Projection of an object on virtual cube

intermediate sky (Nevg 0.75-0.4), near overcast sky (Nevg 0.4-0.25) and overcast sky (Nevg 0.25-0). The sky luminance distribution map (Nevg 0.9 and solar altitude 35) of clear sky is shown in Figure1. The brightest part indicates more than 20 [kcd/m^2] and the darkest part indicates below 2 [kcd/m^2].

Skylight illuminance calculation

Virtual cube: Daylighting calculation is executed using a small cube called virtual cube, placed on the sample point. The center of bottom face of the cube is placed on a sample point. The situation is shown in Figure2. Each face of the cube except the bottom is divided into small grid cells. Skylight illuminance from every grid cell is calculated, and skylight illuminance as result is obtained by totaling those skylight illuminances of grid cells. Although a cube is used in this paper for skylight illuminance calculation, it is possible to use various rectangular solid as a hemicube is used in the radiosity method[5]. Three rectangular solids are examined and the comparison of them is shown below.

Three rectangular solids have different heights (0.5, 1, 1.5) and same bottom size (1x1). Each face of the rectangular solid except the bottom is divided into small grid cells. The number of division of each rectangular solid is chosen so that it may become the grid cell of the as same number as possible. Height 0.5 of rectangular solid has 50700 grid cells altogether, and each grid cell size is 1/130 x 1/130. Height 1 has 50000 grid cells, and each grid cell size is 1/100 x 1/100. Height 1.5 has 49392 grid cells, and each grid cell size is 1/84 x 1/84. Each configuration factors of a face and a grid cell is calculated.

Height	Configuration factor	Upper face (1.0 x 1.0)	Side face (1.0 x Height)
0.5	face	0.5541264240	0.1114683940
	grid cell average	0.0000327885	0.0000131915
	maximum	0.0000753159	0.0000244633
	minimum	0.0000085450	0.0000001471
1.0	face	0.2394564705	0.1901358824
	grid cell average	0.0000239456	0.0000190136
	maximum	0.0000318267	0.0000413331
	minimum	0.0000143367	0.0000003247
1.5	face	0.1233175894	0.2191706026
	grid cell average	0.0000174770	0.0000124246
	maximum	0.0000200481	0.0000585748
	minimum	0.0000135379	0.0000005499

Table1 Comparison of the Configuration factor

Table1 shows configuration factors of the upper face and the side face, and average, maximum, minimum of grid cell configuration factors. Comparing those configuration factors, we adopt height 1.0 (cube), which has smallest differences.

Skylight Calculation: When the sky is partially hidden with objects at a sample point, an object is projected on a virtual cube (Figure3). Executing perspective projection to each cubical side as a screen, no projection area of a screen will turn into sky visible area. The skylight illuminance from each grid cell of this sky area is carried out calculation using sky luminance in the center of a grid cell and configuration factor of a grid cell (Figure4). Totaling all the illuminances of grid cells that exist in this sky area, the illuminance of sample points is obtained. When the normal vector of a sample point changes, after all the vectors from a sample point to each grid cell are

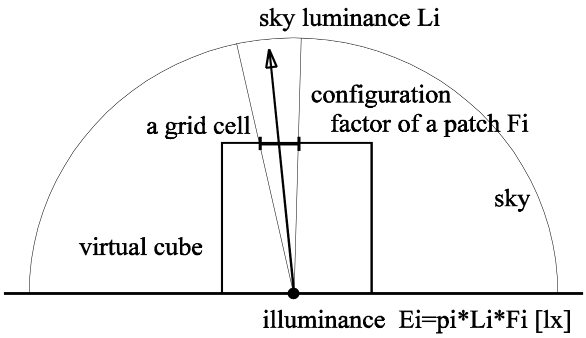


Figure4 Illuminance of a sample point from a grid cell

re-calculated, sky luminance at each grid cell is re-calculated based on All Sky Model.

Calculation of a windowpane: Processing in case skylight penetrates glass and reaches a sample point is shown. As for glass, transmittance changes with the incidence angles of light. Therefore, skylight that passes each grid cell will change in transmittance with positions of a grid cell (Figure5). In order to calculate accurately, it is necessary to calculate transmittance of glass at every grid cell. Transmittance of glass is calculated from the relation between the vector from a sample point to a center of grid cell and the normal vector of a glass surface. In order to enable this calculation, it is necessary to memorize that light which penetrated glass has reached a grid cell. When an object (glass) is projected on a virtual cube side, a grid cell, which an object is projected and is, attaches the mark of being covered with glass.

Daylighting calculation algorithm

The indoor daylighting illuminance calculation consists of tow calculations, which are skylight and sunlight calculations. This daylighting calculation is executed using a virtual cube divided in many small grid cells. The outline of the procedures is as follows:

2) Calculate sunlight intensity based on All Sky Model.

<Preparation procedure>

1) Calculate sky luminance distribution using All Sky Model and calculate horizontal skylight illuminance.

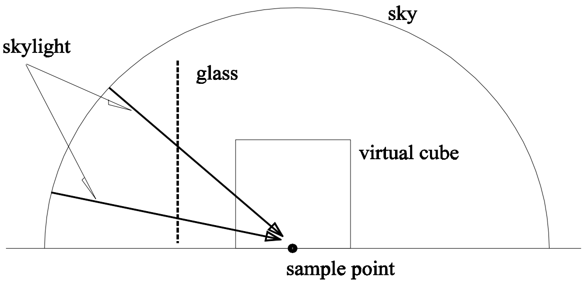


Figure5 transmitting light

3) Generate a virtual cube and divide into small grid cells.
4) Calculate each configuration factor of a grid cell at a sample points using shape factor subroutine[6].
5) Calculate the vector from the center at the bottom of a virtual cube to the center of a grid cell.
6) Divide each object (surface like a floor, a wall and etc.) into patches, and then a center point of patch becomes a sample point. This is preparation for interreflection calculation.

<Simulation procedure>

7) Set up a new center point of patch as a sample point.
8) Place a virtual cube on a sample point.
9) Perspective projection of objects is carried out on a screen, using each face of a virtual cube as a screen.
10) By sky illuminance and configuration factor of each grid cell, the illuminance from each cell on a sample point is calculated.
11) Calculate the sum of the illumination of each grid cell.
12) Shadow test: Sending shadow ray towards sun. If the ray had an intersection with object, an object shadows the sample point.
13) Calculate sunlight illuminance of a sample point.
14) Continuous 7) - 13) until finish the calculations of all sample points.
15) Calculate configuration factors of all patches at each sample point.
16) Solve a liner equation of interreflection, then diffuse illuminance of sample points is obtained.
17) We obtain the illuminance as a result, which is sum of direct illuminance and diffuse illuminance.

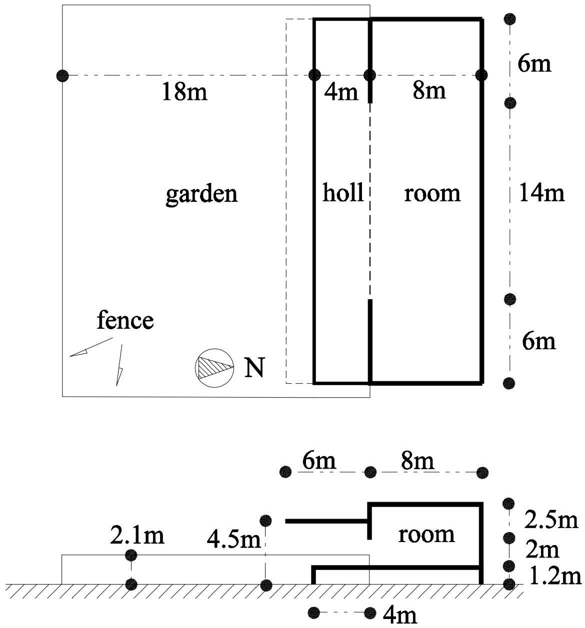


Figure6 Simulation model

Simulation

The purpose of this simulation is investigating the influence that the reflection light from a garden affects indoor illuminance. The simulation program was developed based on the algorithm as we have described, and the simulation was executed.

Figure6 shows the simulation model, which is a simplified model of a room of Japanese traditional architecture with a square garden. Since indoor optical environmental calculation is the purpose, a roof like a part that has almost no influence for the calculation is omitted. The size of the room is 26x8m, and the length opening of 14m is in south side. Moreover, there are deep eave with a length of 6m in south. Each part's reflectance of simulation model is made into a ceiling 0.3, the floor 0.35, the lower part 0.35 of a wall, the upper part 0.6 of a wall, the passage 0.2, the eave 0.2, and the garden 0.2 or 0.5. It is assumed that all surfaces are Lambertian surfaces. The numbers of division of each part for interreflection calculation are floor:27x9, ceiling:27x9 and north wall:27x6, east-and-west wall:9x6, graden:14x10, etc., and are divided into 1263 patches in altogether.

Simulation conditions are place: Kyoto in Japan, date: October

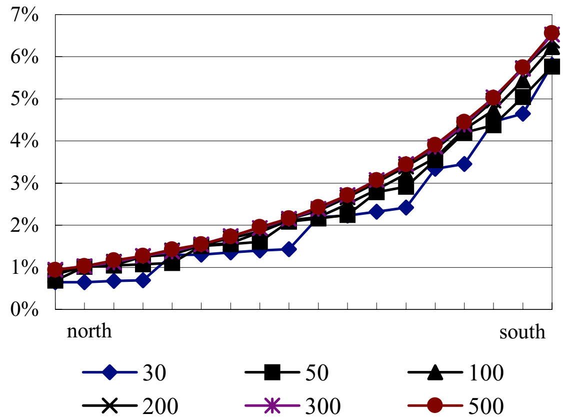


Figure7 Sky factor the middle floor section

15, three different time (9:00, 12:00, 15:00), two sky conditions (clear sky: Nevg=0.9, intermediate sky: Nevg=0.6).

The number of division of a virtual cube faces

Since calculation accuracy changed with the numbers of grid cell division, the comparison is shown. The number of division of one side of virtual cubes is changed to 30-500. Figure7 shows the sky factor on the floor section (south center to north center) of simulation model's room. In simulations number of division is 200 because of figure7's indicating that if the number of division becomes grater than 100 or 200, the sky factor is almost same value.

Simulation result

Table2 shows horizontal skylight illuminance and horizontal sunlight illuminance, which are different two conditions (clear sky and intermediate sky). Figure8 shows sky factor distribution on the floor.

Figure9, 11, and 13 show illuminance distribution of clear sky on the floor of the room, when garden's reflectance is 0.5. Front side of a figure is north, the depth direction is south and right-hand side is west. Figure10, 12, and 14 shows the illuminance of clear sky on the floor section (south center to north center). "skylight" means direct illuminance of skylight. "r=0.2" and "r=0.5" mean reflectance of garden and this illuminance value is the sum of diffuse and direct illuminance. Figure15-20 are cases of intermediate sky, similarly as

Nevg	Date 10/15	Horizontal global illuminance	Horizontal skylight illuminance	Horizontal sunlight illuminance
0.9	9 am 12 am 15 am	50205 [lx] 74440 [lx] 39341 [lx]	19012 [lx] 26204 [lx] 16021 [lx]	31193 [lx] 48236 [lx] 23320 [lx]
0.6	9 am 12 am 1 am	33471 [lx] 49627 [lx] 26227 [lx]	26375 [lx] 38003 [lx] 21290 [lx]	7096 [lx] 11624 [lx] 4937 [lx]

Table2 Daylight illuminance based on All Sky Model

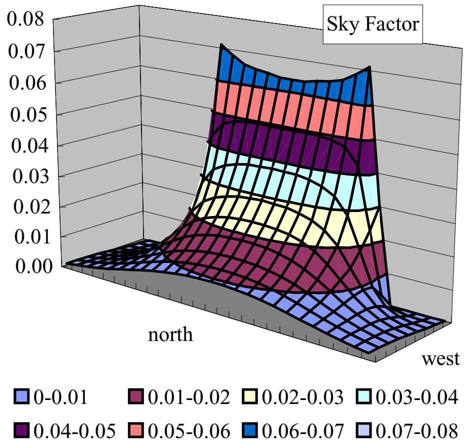


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Figure8 Sky factor distribution of the floor

Figure9-14.

In the case of this simulation, the room doesn't get sunlight because of deep eave. Therefore, sunlight affects indoor illuminance only in interreflection. Figure9, 11, and 13 indicate that the indoor illuminance distribution is changing according to a solar position.

When these figures of the case at clear and intermediate sky are compared and the reflectance of the garden differs, it turns out that the brightness of the room differs. In "r= 0.5", from the case of the reflectance "r= 0.2" of the garden, the floor is bright by any case. In Figure12 (clear sky, 12:00) of "r= 0.5", the floor has become bright about a maximum of 580 [lx] from the case of the reflectance "r= 0.2" of the garden. In Figure18 (intermediate sky, 12:00) of "r= 0.5", the floor has become bright about a maximum of 330 [lx] from the case of the reflectance "r= 0.2" of the garden.

Comparing these results, we are able to get the difference of room illuminance cause of the difference of garden's reflectance. This difference comes from interreflection phenomenon. This simulation confirms validity of the technique often used in Japanese architecture, which is using reflected skylight form garden as room illumination. The indoor illuminance simulation by daylight is able to confirm the lighting technique, because we are able to execute accurate calculation using All Sky Model.

CONCLUSIONS

We showed daylighting calculation algorithm, and developed the simulation program. In this program, sky luminance and sunlight intensity are calculated from All Sky Model. Using sky luminance distribution, illuminance calculation is able to be executed, and it also has interreflection calculation function.

The simulation was executed about the traditional Japanese architecture with a garden. The reflectance of a garden was changed, the simulation was executed and the illuminance distribution on indoor floor showed the result. When reflectance of the garden was 0.5, floor illuminance became brighter then 0.2. This result indicates that we are able to use the reflection light from the garden as indoor lighting. The lighting method using in traditional Japanese architecture was confirmed by simulation.

REFERENCE [1] Nishita, Nakamae: "Continuous Tone Representation of Three-Dimensional Objects Illuminated by Sky Light, SIGRAPH86, ACM [2] Preetham,A.J, Shirley,P. and B.E.Smots,B.E.: "A Pratical Analytic Model for Daylight, SIGRAPH99, ACM [3] Igawa, Nakmura and Mastuura: "Sky Luminance Distribution Model for Simulation of Daylit Environment", Sixth Onternational IBPSA Conference, 1999.9 [4] Igawa, Nakmura :"A Sky Luminance Distribution Model to Show All Sky Conditions", Summaries of Technical papers of Annual Meeting AIJ 2000, Environmental Engineering (In Jamanese) [5] Cohen,F and Greenberg,P: "A Radiosity Solution for Complex Environments", SIGRAPH85, and AC M [6] Yamazaki,H :"Shape Factor Calculation and Computer Graphics", The Fourth International Symposium on the use of Computers for Environmental Engineering Related to Buildings, pp.559-564, 1986 [7] Manabe, Yamasaki Kojima: "Study of Computer Graphic Representation of Architecture illuminated by Skylight Luminous Environmental Calculation of a room using All Sky Model", Proceedings of The Twenty-three Symposium on Computer Technology of Information, System and Applications (In Japanese)

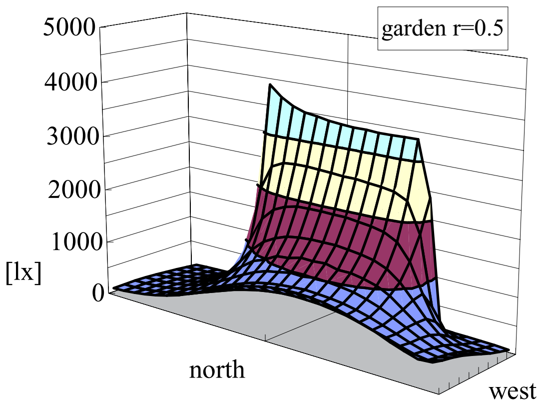

Figure9 Illuminance distribution of the floor
(clear sky, time 9:00)

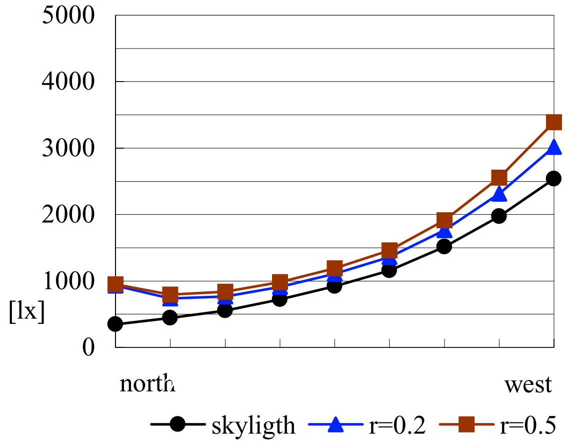

Figure10 Illuminance of the middle floor section
(clear sky, time 9:00)

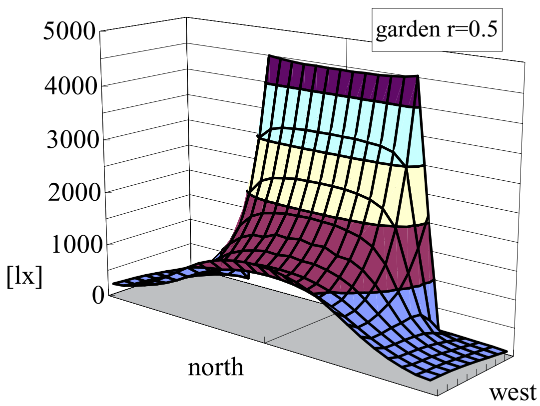

Figure11 Illuminance distribution of the floor
(clear sky, time 12:00)

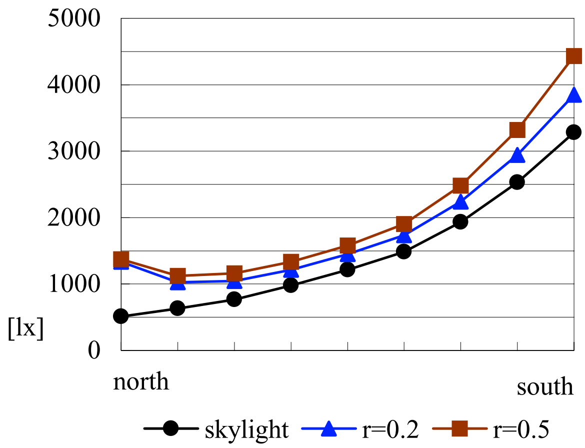

Figure12 Illuminance of the middle floor section
(clear sky, time 12:00)

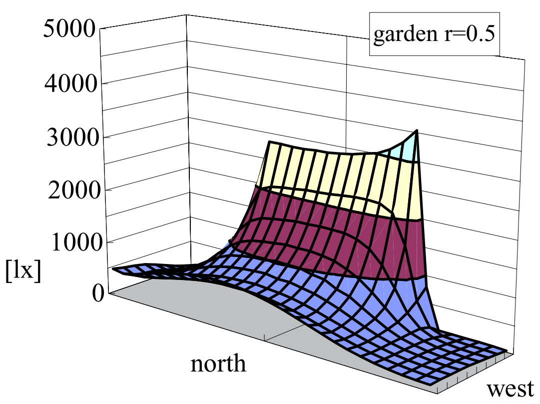

Figure13 Illuminance distribution of the floor
(clear sky, time 15:00)

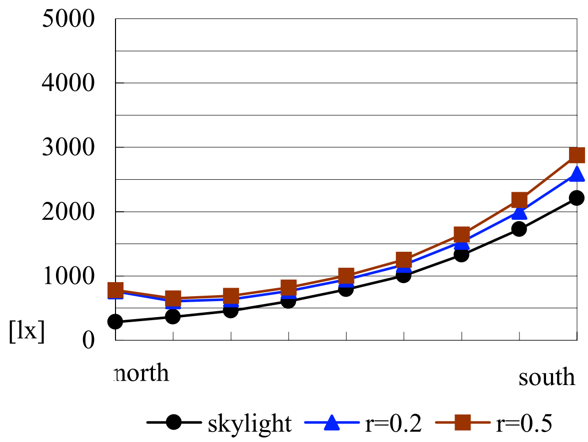

Figure14 Illuminance of the middle floor section
(clear sky, time 15:00)

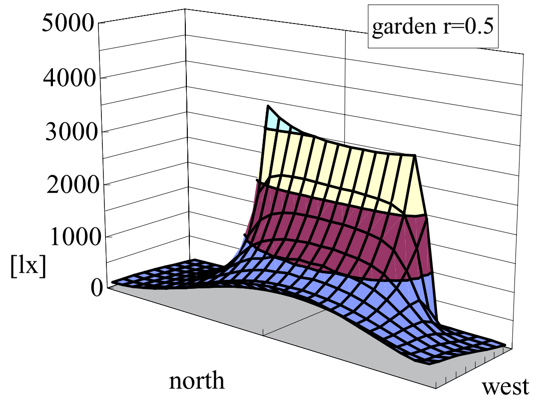

Figure15 Illuminance distribution of the floor
(intermediate sky, time 9:00)

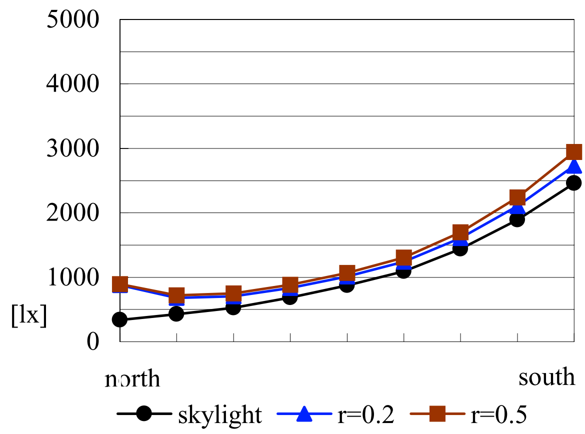

Figure16 Illuminance of the middle floor section
(intermediate sky, time 9:00)

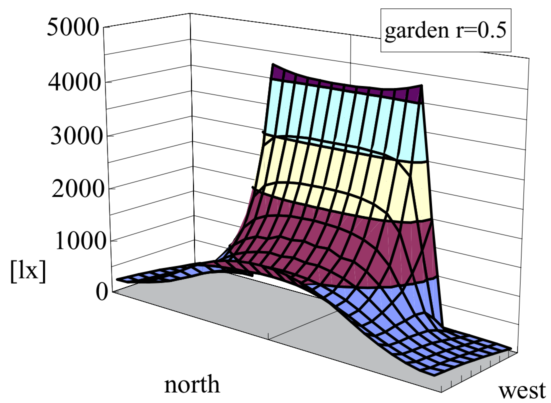

Figure17 Illuminance distribution of the floor
(intermediate sky, time 12:00)

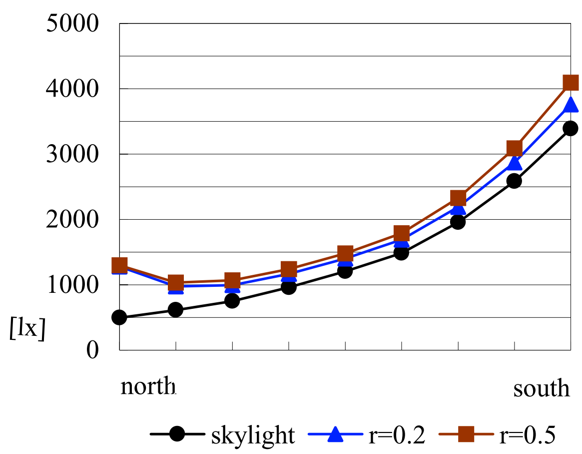

Figure18 Illuminance of the middle floor section
(intermediate sky, time 12:00)

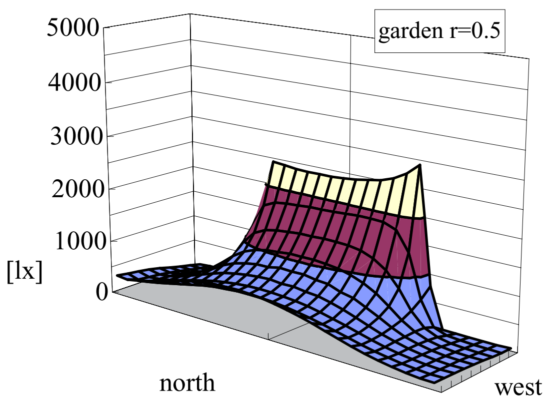

Figure19 illuminance distribution of the floor
(intermediate sky, time 15:00)

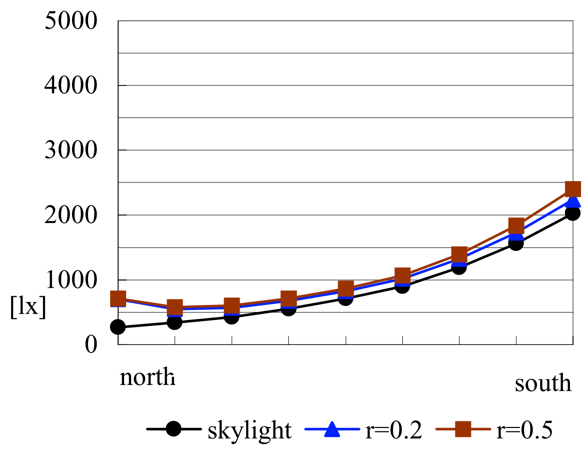

Figure20 Illuminance of the middle floor section
(intermediate sky, time 15:00)