Strategy of Interior Colour and Thermal Storage for Insulated House in Cold Region

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ABSTRACT

Increasing environmental awareness, higher costs for energy use contributed significantly to the expansion of building passive house. On the other hand, the economic crisis spread around the world. Therefore it is very hard for general people to built high performance house with PV system, solar hot water supply system, HEMS and so on. Direct solar gain technique is very simple and inexpensive idea for passive heating. Although, large window for direct solar gain cause huge heat loss, also there is the possibility to escapes solar radiation from large window in some case that the absorption rates of inner surface are low. That is why, we, researcher, architects, customer, needs the method for evaluating the effects of direct solar gain with colour pattern of walls and thermal storage in a room on a thermal environment. In this paper, we propose the method to calculate solar absorption on inside walls by using *Radiance*. The results of detached house in memuro-cho, Hokkaido, indicates that the solar absorptions on the west walls and floors are bigger than other walls because of the position of window. It helps to decide the colour of walls and the position where heat storage install on. Also, we defined the Effectiveness of Direct Solar gain to evaluate how much solar radiation effectively used for passive heating. The relation between the value and the area of black wall indicates that high absorption rate on the floor is effective on direct gain technique. Also, there is the correlation between the solar absorption and the Effectiveness of Direct Solar gain. It saves time and computer resource, the calculation for solar absorption takes much time because of many images for the calculation, by predicting the tendency of solar absorption by using the Effectiveness of Direct Solar gain.

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KEYWORDS
Direct gain, Radiance, Distribution of Solar absorption, Effectiveness of Direct Solar gain

INTRODUCTION

In Hokkaido Island, the techniques for building high performance housing with thick insulation and high air tightness has been developed for several decades to remove cold places, moisture problems from housings. Those successive efforts achieve the high performance housing without cooling and heating system in severe climate recently. To establish those high performance housings, it is important to think about thick insulation, high air tightness and direct solar gain. Because the solar radiation in Hokkaido, especially east area, are not so small. A large south window with high permeability and low U value can get better solar radiation than heat loss through the window. Although, there is the possibility to return the solar radiation which reflect on the inner surface to the outside through the high permeability and large window. Therefore, to design the strategy of direct gain technique, it is necessary to evaluate the effect of absorption rate of walls on the thermal environment.

There are many researches about direct solar gain technique in Japan. Matsuo et. al. suggests summation of the difference of temperature between room temperature and setting temperature, degree hour, as the index of passive solar house (Matsuo and Inoue 1989). Also, some experimental results are introduced (Inoue and Sunaga et. Al. 1996, Ito and Sunaga 1987), Those result indicate that the heat capacity in housing reduce heating energy. Furthermore, there are the results by numerical simulation (Honma 2003, Komano and Sunaga 1991, Hasegawa and Ishikawa et. al. 1982),. However those results are calculated by the solar radiation just enter into the housing. It indicates that the effect of direct solar gain on the thermal environment is bigger than real case, because some of the solar radiation comes back to the outside from window. Furthermore, there are some international researches about passive heating and overheating (D. M. Burch 1984, Jana and Janez 2011, Bojic and Lukic 2000,). However, there is no research for the effect of the distribution of absorption rate on the passive heating and direct gain technique.

In this report, the distributions of absorbed solar radiation with each parameter, absorption rate, were calculated by *Radiance*. After the calculation, we analyze where solar radiation is primarily absorbed, how much solar radiation is absorbed in each case.

RESEARCH METHODS

Software *Radiance* [1)] was used for the analysis. *Radiance* is free software developed by Lawrence Berkeley National Laboratories as part of their research into assessing visible light distribution in illuminated spaces. This software allows the users to obtain an image of spectral radiance values in buildings by specifying the observation point, material, time, date and the condition of the sky. We used the software to obtain how much solar radiation is absorbed on each wall. The procesuret is as follows.

1st Numerical model for the calculation is made by *Google Sketchup* and *Su2Rad.*

2nd Fisheye eye view images from each observation point are made by *Radiance*.
3rd Fish eye image means luminous flux from other walls, therefore incident solar radiation on each point can be calculated to integrate brightness of each pixels in images.
4th Absorbed solar radiation can be calculated to multiply incident solar radiation by absorption rate.

Numerical model

The building to be analyzed is a residential building in Memuro-cho, Hokkaido, Japan. Memuro-cho is located on the center of Hokkaido. The climate in winter is very severe, daily minimum temperature is usually under -15 ℃.

Six different models with walls of different reflectance of short wavelengths were prepared with the models named Cases 1-6 respectively. Bird's eye view images for Cases 1-6 with the ceiling removed are presented in Figure 1. Table 1 shows a relationship between the building and the reflectance of the wall.

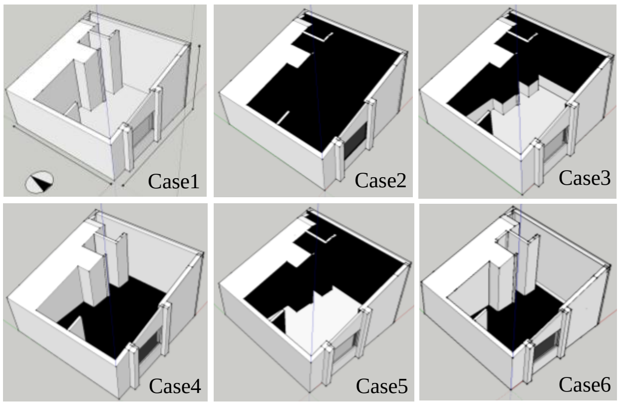


Figure 1. *Bird's Eye View of Case 1 through Case 6*

Table 1. *Wall Reflectance*

	Floor	Paneling	Upper wall	Ceiling
Case1	0.8	0.8	0.8	0.8
Case2	0.2	0.2	0.2	0.2
Case3	0.8	0.8	0.2	0.2
Case4	0.2	0.2	0.8	0.8
Case5	0.8	0.2	0.2	0.8
Case6	0.2	0.8	0.8	0.8

The ceiling and floor were segmented by 50cm-pitch grid lines, while the east, west, south and north walls were segmented by 30cm-pitch grid lines. The observation points were situated at the intersections of the grid lines facing the inside of the room, with a total of 924 observation points created for this study.

Date and Time for calculation

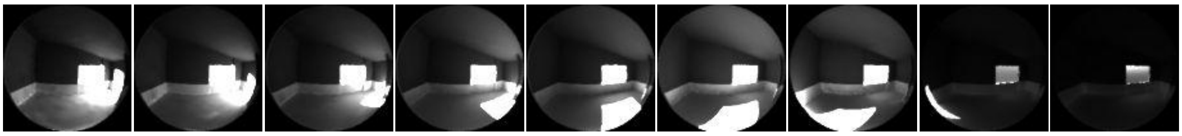
January 15th was selected as the date for calculation. Nine different times of the day between 8 AM and 4 PM were selected. After obtaining direct solar radiation and sky radiation from expanded AMeDAS data, the condition of the sky was defined using *gensky* [3)], an internal function of *Radiance*.

Method for calculation

Images for calculation can be obtained as a fisheye view (orthographic projection). Figure 3 presents example images of Case 3 from 8 AM to 4 PM, shown left to right, with the viewpoint near the center of the north wall. At 10 o'clock, the west side is lit brightly because the sun is shining from the east side, and the wall section that is lit is seen to move as the time elapses. It can be observed that the floor and paneling are white, while wall sections above the paneling are black, and the one can see the way in which the transmitted sunlight is diffused. Figure 4 presents images for Case 6 with a viewpoint near the center of the east wall. The image depicts the short-wavelength radiation coming into the observation point, and by adding up the radiation amount of all the pixels in the image by equation (1), the radiation coming into the observation point from all the wall faces can be calculated. The amount of solar radiation absorbed at the viewpoint, *I*, can be calculated by multiplying the radiance of the wall by the summation of the radiation.

$$I = a_w \frac{\pi}{N} \sum_{i=1}^{N} p_i \qquad (1)$$

Where a_w is the absorption rate of wall, N is the number of pixel in an image, and p_i is the pixel value, *Radiance* hdr image has the information of short-wavelength radiation [W/m^{2}sr]. Usually, *Radiance* user makes photo realistic image by converting it.



8 AM	9 AM	10 AM	11 AM	12 AM	1 PM	2 PM	3 PM	4 PM

Figure 3. *Diagram from the north side (Case 3: Black ceiling, black walls above the paneling, white floor and white paneling)*

8 AM	9 AM	10 AM	11 AM	12 AM	1 PM	2 PM	3 PM	4 PM

Figure 4. *Diagram from the east side (Case 6: White ceiling and walls, black floor)*

RESULTS and DISCUSSION

Figure 5 is the distribution of solar radiation absorbed on the floor surface, with the floor orientation shown in Case 1. The value used at each location is the sum of absorbed values from 8 through 16 o'clock as calculated by equation (1). From this diagram, we can get information about an area where solar absorption maximum on throughout the day. The values were generally lower for Cases 1, 3 and 5 which had white floors, and generally higher for Cases 2, 4 and 6 which had black floors. While the absorption of the sunlight in Case 4 happened mostly near the center of the floor, in Case 6, more absorption was seen near the west wall. The only difference between Cases 4 and 6 was the color of the paneling (black for Case 4 and white for Case 6), therefore it is assumed that the difference in the absorption rate of the paneling accounts for such a difference.

Effectiveness of Direct Solar gain

Effectiveness of Direct Solar gain, μ, is defined in equation (2). This indicates how much solar radiation that entered the room will absorb after being reflected by the walls multiple times. The higher this value indicates that the larger the amount of solar radiation absorbed in the room.

$$\mu = \frac{I_{in} - I_{out}}{I_{in}} \tag{2}$$

I_{in} in equation (2) is the solar radiation that initially entered the room through the window, while I_{out} is the solar radiation that finally escaped from the room. Figure 7 shows the schematics of I_{in} and I_{out}. Since I_a and I_b are solar radiation values calculated from the images. They are nearly equal to I_{in} and I_{out} respectively. Therefore, μ can be calculated by equation (3)

$$\mu = \frac{I_a - I_b}{I_a} \tag{3}$$

Effectiveness of Direct Solar gain is different with g-value. The g-value is one of the criteria to select windows. This shows the ratio in which the solar radiation incident on a glass surface transmits into the room. The higher this value, the more solar radiation, short wave radiation, and heat, long wave radiation is taken into the room. Effectiveness of Direct Solar gain defined here is an indication of how much solar radiation that entered into the room gets absorbed on the wall surfaces, and is dependent on the absorption rate of the walls. In the cold region, it is important to enlarge window area for maximize the effect of direct solar gain technique. Although the direct gain is ineffective in the case that reflectance of inside wall is high, Effectiveness of Direct Solar gain is low, it indicates that the solar radiation entered into the room return to the outside because of high reflectance.

Figure 8 shows the μ value obtained for Cases 1-6. The μ value is smaller for Case 1 compared to other case. This is assumed to be because for Case 1, all the faces were white and have higher reflectance and, therefore, a large amount of radiation escaped from the room. For Case 2, it can be seen that μ is close to 1 and a large amount of solar radiation was absorbed in the room due to its black walls. Since Case 4 (black floor and paneling) shows a higher μ value than Case 3 (black walls above paneling and black ceiling), it is assumed that more solar radiation can be absorbed by using a black floor, rather than keeping the floor white and trying to absorb the reflecting solar radiation through the walls. Figure 9 shows the relationship between the average of Effectiveness of Direct Solar gain μ_{ave} and the area of black surface inside the room. μ_{ave} is a μ value averaged throughout the day (8 AM to 4 PM). It can be seen that in Case 4 and Case 6, the μ_{ave} value is larger than relative value to the black surface area. This indicates that solar radiation effectively utilizes to increase indoor temperature in Case 4 and 6. Also, it is effective for raising μ_{ave} to increase the absorption rate close to the floor. Figure 10 shows the relationship between μ_{ave} and the average solar absorption for the entire wall surfaces. The average solar absorption for all wall surfaces is calculated by adding up the solar radiation absorbed by all the viewpoints from 8 AM to 4 PM, and then dividing it by the number of observation points. Case 1 (low wall absorption rate) shows low μ_{ave} and low average solar radiation absorption for all walls. Case 2 (high wall absorption rate) shows high μ_{ave} and high average solar radiation absorption for all walls. Figure 10 is a diagram created to predict solar radiation absorbed in the room, using μ_{ave}. To calculate solar absorption needs much time and computer resource because many images require to calculate it. We can save time and computer resource for calculating solar absorption for all cases by using μ_{ave} .

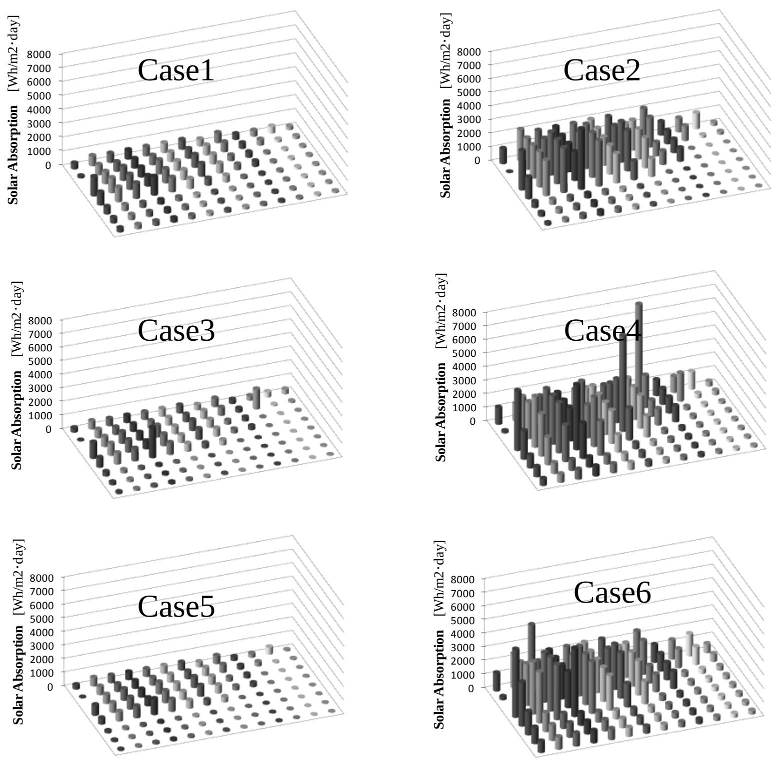


***Figure 5**. Distribution of Cumulative Daily Solar Absorption on the Floor Surface*

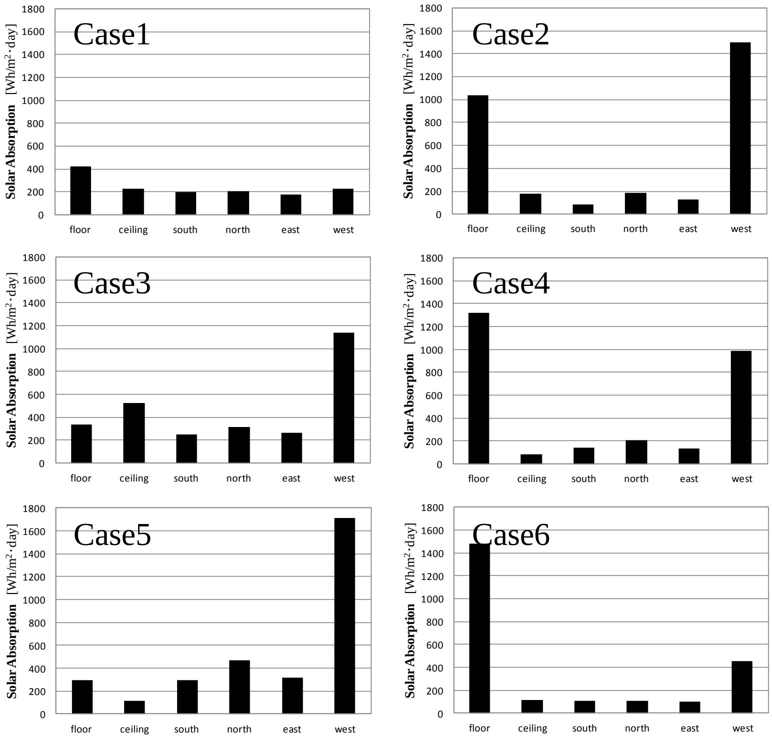


Figure 6 *Cumulative Solar Absorption*

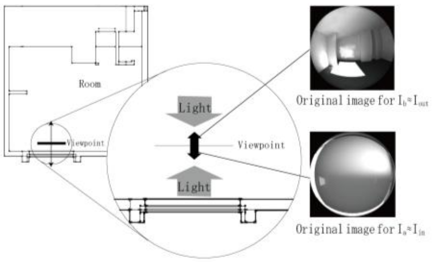
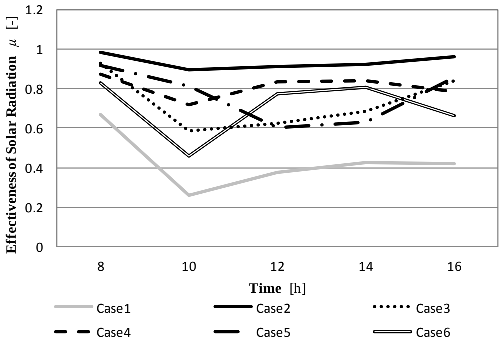


Figure 7*. Schematics of I_{in} and I_{out}*



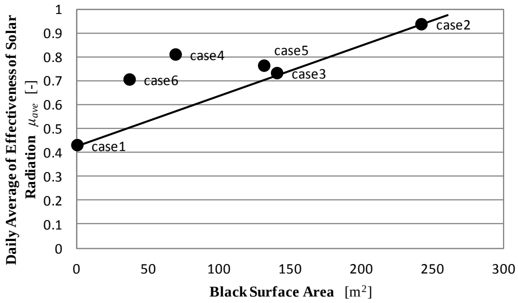


Figure 8*. Effectiveness of Direct Solar gain* ***Figure 9.*** *The Relationship between Daily Average of Effectiveness of Direct Solar gain and Black Surface Area*

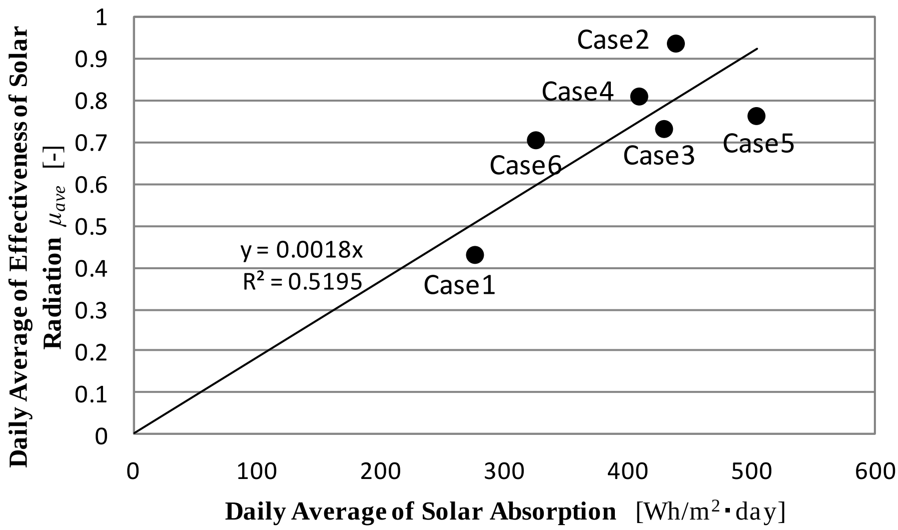


***Figure 10**. The Relationship between Daily Average of Effectiveness of Direct Solar gain and Daily Average of Solar Absorption.*

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