Designing of double cross catenary screen as sunlight catcher and diffuser.

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ABSTRACT
Considering density of housing in residential area of large cities in Japan, it is very difficult to secure sufficient daylight and lead daylight to whole space in the house. High side lighting is one of solutions for such situation. And when high side windows are designed with open beam, high side light can be propagated to lower level through open beam. On the other hand, high side light brings highlight area on walls or floors. The highlights area often appears on walls close to eye level. The area may cause glare phenomenon or may lower brightness of surrounding area by contrast effect. And open beam may cause excessive impression of air volume for detached house. This paper reports designing of diffuse screen to solve these problems.

1. INTRODUCTION

Daylighting system should be introduced more actively to houses as a means of reducing energy consumption and ensuring a healthy life. However, current housing conditions make it difficult to secure a sufficient daylight and lead it to every corner of the house. As neighboring buildings may obstruct the way of sunlight, daylighting through side windows facing them is difficult. High side daylighting will solve this problem of light paths, making it possible to lead daylight to the inner parts of rooms. High side daylighting is also known to uniformalize the illuminance distribution on the horizontal plane (Kahn, 1975). Meanwhile, direct sunlight coming in through high side windows creates an extremely bright field (a field that reflects direct sunlight: hereafter referred to as "highlight"), resulting in glare phenomenon or appearance of relatively lower brightness of surrounding area by contrast effect. In this study, light-diffusing fabric will be placed as a screen in a house where sufficient direct sunlight is let in through high side windows, in order to lead a certain amount of daylight to each corner of the inside of the house, while maintaining the atmosphere created by the fluctuation of daylight.

2. CONCEPT OF A SYSTEM TO DIFFUSE DAYLIGHT THAT COMES IN THROUGH HIGH SIDE WINDOWS

The Kimbell Art Museum designed by Louis I. Kahn is known as an outstanding example of buildings that effectively use daylight as a natural source of light. In order to lead direct sunlight uniformly to ceiling surfaces, this museum is equipped with the light reflectors and ceiling surfaces that have mathematically determined cycloid curves. While highly reputed for its daylighting system, the Kimbell Art Museum also lets in direct sunlight through side windows. This system makes the silhouettes of trees in the courtyard appear and disappear on the screens, depending on the intensity of direct sunlight. An exquisite balance is created by the combination of the ceiling surfaces on which stable reflected light is incident and the screens that present incessantly changing pictures. Khan himself refers to the beauty of daylight and its ability to produce an atmosphere that varies with seasons and time (NILIM, 2005). In order to make the most of the esthetic advantage of daylight, this study aims to create a luminous environment which lets in and leads sufficient daylight to all corners of the building as uniformly as possible, while ensuring an atmosphere that changes beautifully with seasons and time.

With high side daylighting, depending on the direction of direct sunlight and solar altitude, a highlighted parallel projection image of the window (Fig 1) appears on the wall surface, resulting in glare and making the areas around the highlighted part look darker. Meanwhile, if the light through the high side window is to reach the inner parts of downstairs rooms, there needs to be a open beam. But the open beam, when placed in a space as small as a regular house, often causes a sense of excessive volume space. The problem of a highlight can ideally be solved by making the open beam space surrounded by high side windows a translucent void (Fig 2). But this approach is impracticable. Even if we succeed in creating such a translucent void, this approach will make it impossible for one to enjoy the atmosphere that changes with the movement of the sun. To overcome these difficulties, we placed a multi-layered screen made of a textile material with a high light-diffusing property to create a pseudo translucent void, enabling one to enjoy the changes of positions and shapes of the highlight that appears on the screen. This system is placed to realize following three objectives.

- Catch the sunlight and move highlight area from peripheral walls to the position close to open beam to lead more reflected high side light to lower level.
- Reduce peak luminance of highlight area.
- Relieve excess impression of air volume through open beam.

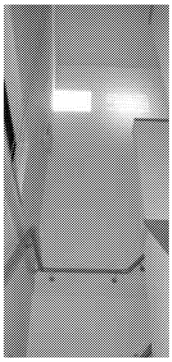

Figure 1: An area high-lighted by high side light.

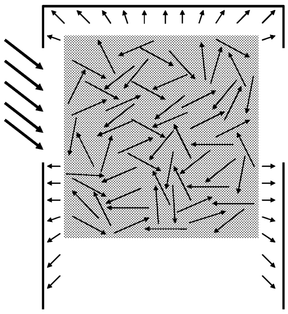

Figure 2: An image of a translucent void.

Figure 3: Target space.

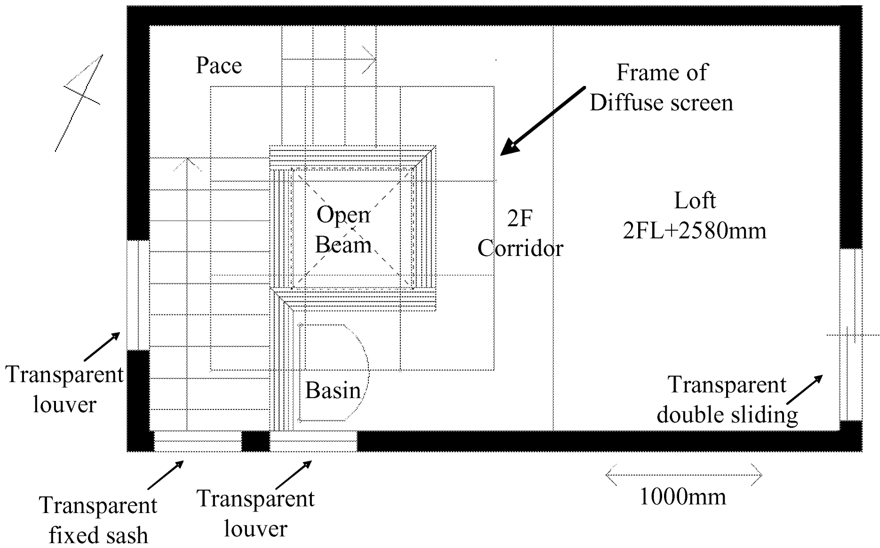

Figure 4: Top view of the second-floor space around the open beam and the position of the diffuse screen.

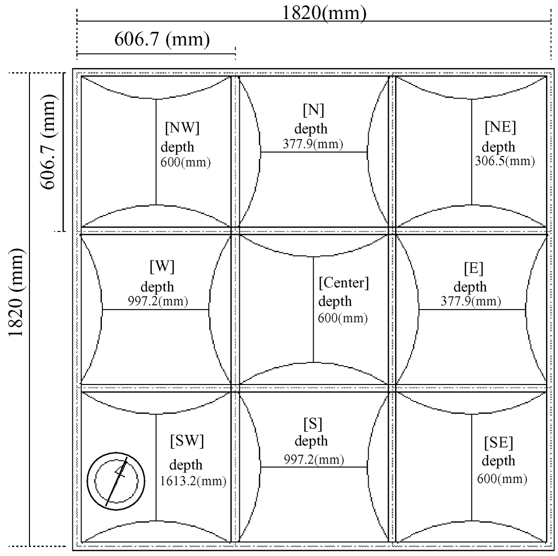

Figure 5: Dimensions of the light-diffusing screen and the depth of each fabric.

3. DESIGNING OF DOUBLE CROSS CATENARY DIFFUSE SCREEN

Based on the approach discussed in the previous paragraph, we designed a system to diffuse direct sunlight that comes in through high side windows. Figure 3 shows an actual space in which this system was placed. This space is part of an individual's house built in Class I Low-rise Housing Area in Suma-ku, Kobe City, Japan. On the east and west of the house are houses of similar size to this. Because each of these next-door houses is only 100 cm away from the house, it is hard to let in sufficient daylight through the windows placed on the east and west. To address the lack of daylighting, high side windows were placed on the eastern, southern and western walls around the upper part of the open beam (See Fig 4). We suspended a square frame in the upper part of the open beam, divided the frame into nine square sections (3×3 = 9 sections), and hung a fabric screen from each section to diffuse light (See Fig 5). The fabric screen was hung alternately in east-west and north-south directions to deal with light flows in various directions.

We chose the catenary curve as the shape of the light-diffusing fabric because it is simple enough to manufacture and inexpensive enough to produce, and it ensures diffusion of direct sunlight in a multilayered manner. When determining the height of each fabric to be hung, we took into the following points into consideration.

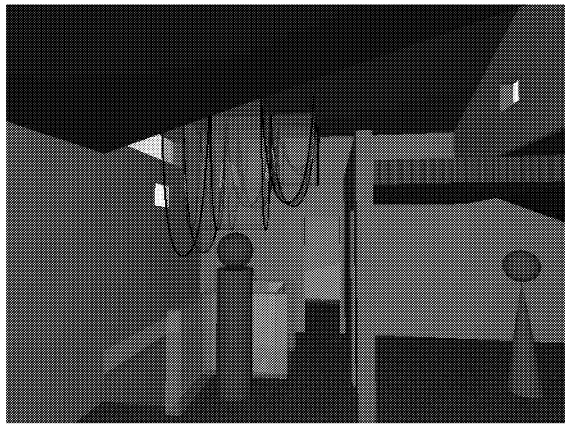

Figure 6: Examination of the lengths of fabrics, considering the position of the sun. (Examination immediately after the sunrise on the summer solstice)

- To reduce a sense of excessive volume space, the fabric should be highest (hung deepest) at the southwestern corner of the open beam where the ceiling is the highest and, from there, the depth of the fabrics should be reduced step by step toward the north along the stairs.
- To make sure that the fabrics hanging from the southeast and south sections of the frame are of the height that does not to affect use of the wash basin on the second floor.
- To make sure that the fabric in the southeast section is of the height that does not to affect movements between the second floor and the loft.
- To make sure that the fabrics in the other sections are of the height that does not affect movements below the screen.
- To make sure that morning sunlight directly shine on the walls without passing through the fabrics so as to give a refreshing, awakening effect to the residents of the house.

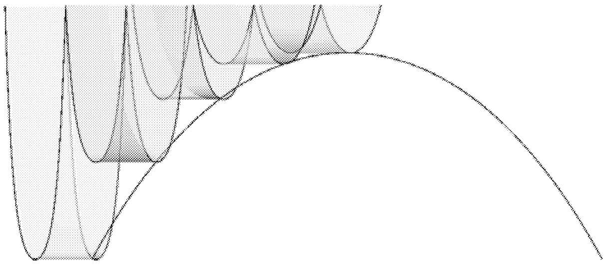

Figure 7: Exam Normal axonometric drawing of the light-diffusing screen projected on the surface (southwest-northeast) 45° to the axis of the light diffusing screen.

Relationships between the light-diffusing screen and direct sunlight were examined by creating CG models of the house and letting direct sunlight of various seasons and hours into these models (See Fig 6).

Based on the above examination, and taking into design into consideration, we worked out five different fabric depth for 1)southwest, 2)south and west, 3)southeast, center and northwest, 4)east and north and 5)northeast, respectively, and gradually reduced the heights from southwest to northeast (See Fig 7. See Fig 5 for the actual dimensions of the screen.) Another point that should be noted is that the lowest points of the nine fabrics constitute a part of a larger catenary (which is created by vertically flipping and translating a catenary curve expressed by equation (1), assuming $a = 1300$). This system is placed around a lighting fixture hanging from the center of the sloping ceiling so that it will also function as a lamp shade at night.

We named this system "Double Cross Catenary Screen" because catenary curves appear in both east-west and north-south directions and, in addition to the nine catenary curves drawn by the nine fabrics, a line made by connecting the lowest points of these nine curves also constitutes a catenary curve.

Fabrics used for the light-diffusing screen were preliminarily fastened to whitewood frames with double-faced adhesive tape. The fabrics were then permanently fixed to the wooden frames by putting aluminum frames over them. The finished screen was fixed to the sloping ceiling with metal fittings and chains.

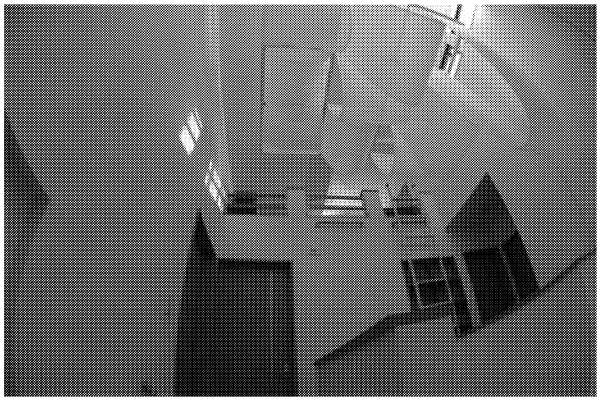

Figure 8: Relationship between the morning sunlight and the diffuse screen.

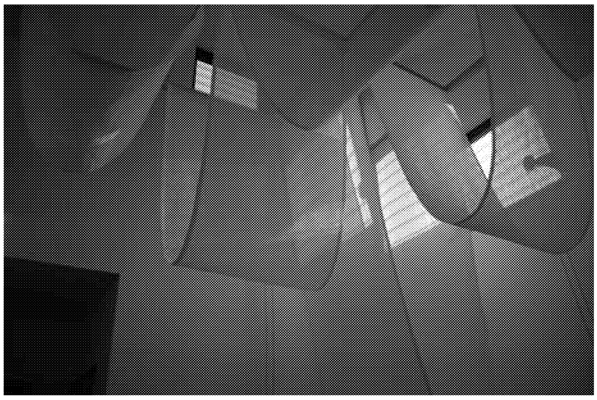

Figure 9: Evening sunlight passing through the diffuse screen.

4. LUMINOUS ENVIRONMENT CREATED BY THE DOUBLE CROSS CATENARY SCREEN

As the result of open beam and diffuse screen, the upper part of the staircase is very bright, and light flows out over its surroundings.

Figure 8 shows a relationship between morning sunlight and the diffuse screen. Figure 9 shows how light from the setting sun passes through the diffuse screen. In most of the seasons, morning sunlight does not pass through the diffuse screen but directly illuminates the walls and produces a highlight. Evening sunlight, on the contrary, comes in through the high side window on the west, if left unblocked, will illuminate the wall below the loft. However, as it is designed to pass through the diffuse screen, evening sunlight will change its direction in the upper part of the open beam and get diffused. This will erase the highlight on the wall below the loft. Instead, a highlight will appear above the screen, but this highlight comprises only diffusely transmitted components, which will result in lower luminance value. In the daytime, light coming in from the west will pass through the fabric in the southwestern corner and becomes incident around the landing, or direct sunlight from the south passes through the fabrics and become directly incident on the wall of the open beam. In this way, the atmosphere of the luminous environment created by this system varies by seasons and hours. Figure 10 shows how the diffuse screen functions as a lamp shade at night.

5. RESULTS OF ACTUAL MEASUREMENT OF LUMINOUS ENVIRONMENT

In the previous section, we described procedures for creating the proposed luminous environment. In order to study the luminous environment in a more detailed, quantitative manner, we performed measurement, under the clear and sunny weather in the afternoon of April 14, 2007, and examined how the presence and absence of the diffuse screen would affect the luminous environment. Items of measurement include, in cases both with and without the screen, luminance values on the wall surface immediately below the window on the west, illuminance and luminance values on the vertical surface of the highlight below the loft, and luminance distribution around the screen. Luminance values of the highlight and its background were measured only in cases where the screen was present. Table 1 shows measurement results. As the table indicate, luminance value on the west wall surface that is most affected by the screen is about three times higher when the screen is present than when it is not. Also, the screen contributed to lowering the luminance value of the highlight to below 10%. Figure 11 shows parts where the luminance value is more than twice as high when the diffuse screen is present than when it is not. From this image, it was confirmed that diffused light had reached most part of the

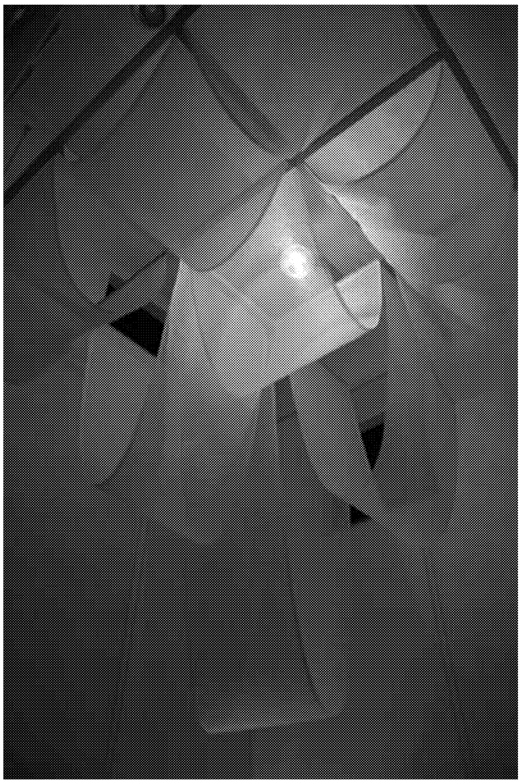

Figure 10: The diffuse screen functioning as a huge lamp shade.

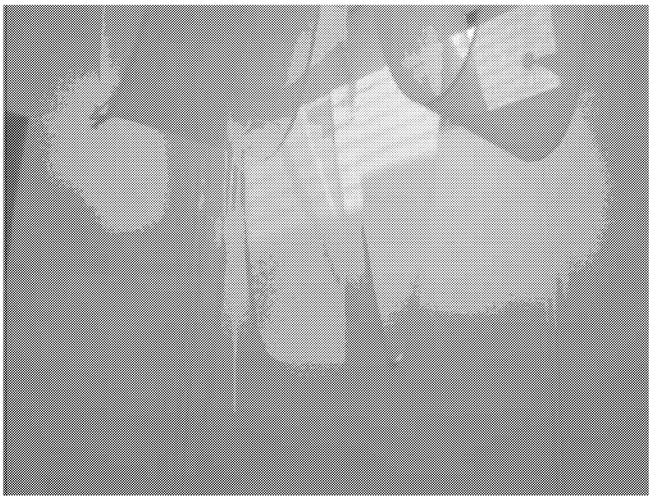

Figure 11: Parts where luminance values are more than twice as high when the screen is present than when it is not.

Table 1: Results of measurement of luminance and illuminance values.

<table>
<tr><td colspan="3">Luminance value on the wall surface immediately below the window on the west (with the screen)</td><td>787.5 (cd/m^2)</td><td rowspan="2">with/without
3.1</td></tr>
<tr><td colspan="3">Luminance value on the wall surface immediately below the window on the west (without the screen)</td><td>254.0 (cd/m^2)</td></tr>
<tr><td colspan="3">Illuminance value on the highlight (with the screen)</td><td>1358.5 (lx)</td><td rowspan="2">with/without
0.098</td></tr>
<tr><td colspan="3">Illuminance value on the highlight (without the screen)</td><td>13810.0 (lx)</td></tr>
<tr><td colspan="3">Luminance value on the highlight (without the screen)</td><td>4260.0 (cd/m^2)</td><td></td></tr>
<tr><td rowspan="8">Diffuse screen</td><td rowspan="4">The 1st transmission</td><td>luminance [a]</td><td>2440.0 (cd/m^2)</td><td rowspan="8">Luminance was measured at an altitude of 1300(mm) where the hallway on the second floor meets the stairs. For both luminance and illuminance, measurement was performed twice each and obtained values were averaged. If values obtained from the first measurement and second measurement differed by more than 10%, measurement was performed again. As Figure 14 shows, a very small amount of direct sunlight passed through the screen even in the case without the screen.</td></tr>
<tr><td>luminance of background [b]</td><td>784.5 (cd/m^2)</td></tr>
<tr><td>luminance resulting from direct sunlight [c] = [a] – [b]</td><td>1655.5 (cd/m^2)</td></tr>
<tr><td>luminous emittance resulting from direct sunlight [d] = [c] x π</td><td>5200.9 (rlx)</td></tr>
<tr><td rowspan="4">The 2nd trans-mission</td><td>luminance [e]</td><td>632.5 (cd/m^2)</td></tr>
<tr><td>luminance of background [f]</td><td>323.5 (cd/m^2)</td></tr>
<tr><td>luminance resulting from direct sunlight [g] = [e] – [f]</td><td>309.0 (cd/m^2)</td></tr>
<tr><td>luminous emittance resulting from direct sunlight [h] = [g] x π</td><td>970.8 (rlx)</td></tr>
</table>

western and southern walls.

6. CONCLUSION

This paper discussed the design and effects of the double cross catenary screen that makes use of direct sunlight coming in through high side windows. The diffuse screen is designed to meet condition of exist detached house in densely built residential area considering the way of sunlight, the shape of detached house and the use of the detached house. The designed screen was simulated by CG. Finally, designed screen was installed to the house. And we made clear that the screen realize required objectives through measurement survey (luminance and illuminance.)

In the years to come, we plan to study the seasonal changes of the screen's effects through actual measurement and simulations.

ACKNOWLEDGMENTS

In the process of manufacturing and placing the double cross catenary diffuse screen, we enjoyed generous cooperation from Mori Wooden Fittings (Sumiyoshi-ku, Osaka, Japan) which manufactured wooden and aluminum frames, from Casa Deco Tarumi Tamon Shop (Tarumi-ku, Kobe, Japan) which selected the right textile material and sewed of the screen, and from Yamahisa Co., Ltd. which placed the screen to the sloping ceiling. We would like to take this opportunity to express our deep appreciation to them.

The double cross catenary diffuse screen was designed by Environmental Graphics Science Lab., Osaka City University, with the cooperation of Yamahisa Co., Ltd. The house in which this system was placed was designed by Yamahisa Co., Ltd., with the cooperation of Environmental Graphics Science Lab., Osaka City University.

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