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A Critical Analysis of Sunlight Patches in Patient Rooms via Simulation

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Abstract: Recent research on patient recovery has indicated significant improvement in the conditions of patients treated in sunny rooms compared to those treated in shaded rooms. In this study, the amount of sunlight received in patient rooms with different orientations and opening positions was observed. Desktop Radiance 1.02 software was used to simulate the conditions in a typical double patient room. The area and location of sunlight patches on room surfaces were considered as analog indicators for the investigation. Seven orientations and three positions of standard window openings were studied on an hourly basis in different combinations at solstices and equinoxes from sunrise to sunset. Data were statistically analyzed for advantageous combinations of orientation and opening positions. Results indicated that rooms with right- and left-shifted openings receive direct sunlight more than rooms with centered openings, and these have sunlight mostly on walls, while those with centered openings have it mostly on floors. The study revealed that opening positions rather than orientation is crucial to the design of patient rooms regarding the penetration of sunlight. Orientation is effective only when the room surfaces are studied individually. The study enabled sun patches to be visualized in relation to patient beds, which is a significant determinant that can affect the location of the bed, and so patient in the room. The paper concludes with four proposals of an informal choice from these combinations that both admits sunlight and protects the patient from glare and excessive heat gain.

Keywords: Health, Hospitals, Lighting, Orientation, Patient rooms, Sunlight

Introduction

The admission of sunlight into a building is generally regarded as an amenity, especially in temperate and cold climates. From the beginning of the 20th century, many studies have been conducted to understand people's need for sunlight in buildings and to obtain evidence of its physiological and psychological effects, in order to come up with proposals for its penetration in inhabited buildings (Hopkinson, Petherbridge & Longmore, 1966). According to Walsh (1961) and Hopkinson *et al.*, (1966), the most convincing argument for the provision of adequate sunlight in buildings is simply the evident desire of their inhabitants to have it. There is also scientific evidence that sunlight has positive effects on people, and its admission into buildings has recently become an issue not only of the mere satisfaction of personal desire, but also one closely related to health (Guzowski, 2000; Hobday, 1999; Lam, 1986; Tanriöver, 2006).

Along with one source (Guzowski, 2000) that (citing Kaiser) describes hospitals as places of healing and (citing Neumann) defines natural light as an environmental factor with the potential to heal; another source (Schweitzer, Gilpin & Frampton, 2004) sees sunlight as an essential tool for the design of healthcare environments. Exposure to sunlight is one of the greatest concerns patients have, especially those whose conditions call for prolonged confinement. Notably, Beauchemin and Hayes (1996) recorded an improvement of roughly 16% in the recovery times of patients treated for depression under bright and sunny conditions in patient rooms compared to a control group treated indifferently. Another study, noted by Hobday (2006), showed that sunlight in hospital patient rooms affects both the pain level patients feel and the amount of analgesic medication they need to cope with it. Post-surgical patients who had greater sun exposure experienced less stress and pain, both immediately after surgery and on discharge from the hospital. This group of patients needed 22% less analgesic medication each hour to control pain during their stay in hospital. Schweitzer, Gilpin, and Frampton (2004) recorded a significant increase in the rate of neonatal jaundice, from 0.5%-17%, in a study conducted in the obstetric ward of a tropical hospital, when the amount of sunlight entering into the ward was decreased by the installation of exterior shading devices.

Issues to be addressed when dealing with the admission of sunlight into patient rooms require great care, especially when patients are bedridden and have little control over their environment (Guzowski, 2000). Although sunlight is essential for many reasons, it may not be healthy and desirable everywhere, all the time. Therefore, its admission must be consciously planned and controlled by architectural decisions (Walsh, 1961). In the literature, the relationship between sunlight and architecture is limited. Kim and Kim (2003) noted that sunlight received in the interior of a building could serve a useful purpose as an additional source of natural illumination. Leslie (2003), who reviewed the literature on daylighting and the design of buildings that use sunlight, underscored good daylighting techniques. Configuring buildings properly, elongating buildings along an east-west axis, locating critical visual tasks near the building's perimeter, bringing the light in high, admitting daylight from more than one side of a space, controlling direct sunlight, using light-colored interior surfaces, and locating workstations and computer screens perpendicular to windows, were some of these techniques. Another mini-scale model (1:20) revealed that when a suitable altitude and azimuth is maintained, in regards to the vertical shading device and the sun position, not only is shading achieved, but the area of the daylight zone can also be substantially increased (Cheng, Chen, Chou & Chan, 2007). Furthermore, the potential for energy savings on lighting using an "ideal window area" concept when there is effective daylight integration with the artificial lighting system was studied by using rooms of ten different dimensions and five different room ratios; the potential for energy savings was assessed for each room using a method based on daylight factors (Ghisi & Tinker, 2005).

Although there is limited research about the relationship between direct sunlight and architectural design in order to control the admission of sunlight into spaces, the relationship between the intransigent matters — such as room orientation, position and size of windows, room dimensions and room surface characteristics — and transient ones, such as time of year and time of day, must be considered. In this paper, the amount of sunlight received by patient rooms with different orientations and opening positions was observed, because the presence of sunlight was proven to affect well-being and is therefore desirable in spaces.

In Turkey, the aspects noted above are rarely considered, not just for healthcare facilities, but also for buildings at large. Neither the building bylaws currently in effect for the Greater City of Ankara (Ankara Büyükşehir Belediye İmar Daire Başkalığı, 2004), nor the Turkish Building Standards (Türk Standartları Enstitüsü, 2002) provide standards or rules regarding the admission or exclusion of sunlight in buildings. In view of the conditions in Turkey, this study focuses on the controlled admission of sunlight in healthcare facilities, especially in patient rooms. The amount (area) and the location of sunlight patches on room surfaces were defined as prime concerns, as they are the analog indicators of sunlight entering into the room and the sources of reflected light that thereby can affect the overall illumination levels. Based on this outlook, the specific objectives of the study were to define the difference in the areas and locations of sunlight patches between the patient rooms:

- With different opening positions (left-shifted openings, OPleft; centered openings, OPcentered; and right-shifted openings, OPright) (see Figures 2 and 3/a).
- With different orientations, of similar OP (Figure 3/b).
- With similar orientations, of different OP (Figure 3/c).

These three objectives were studied in a number of steps, from general to specific:

- For the total areas.
- For the areas on walls and floors.
- For the areas on the individual surfaces of a room.

Physical Features of Patient Rooms

The location of the facility housing the patient rooms was Ankara, Turkey (39° 55' north and 32° 50' east). A room intended to accommodate two patient beds with a floor area of 27m^2 was chosen as the basis for the study (Figure 1). This choice was made in accordance with norms suggested by Turkish (Turkish Building Standards, 2002) and American (De Chiara and Callender, 1990) healthcare building standards. Only the basic configuration parameters of the room; dimensions along the x, y, and z-axes; and the size and lateral position of the window opening (at a fixed windowsill height) on the external wall were used in the simulation. Neither the functional organization of the room (entrance hall, bathroom, and bed positions) nor the layout of furnishings was included, as these were considered peripheral to the investigation. The size of window openings was determined in reference to the building bylaws currently in effect for the Greater City of Ankara (Ankara Büyükşehir Belediye İmar Daire Başkalığı, 2004) and was required to be between 1/8 and 1/12 of the overall room area; therefore, they were set as the mean of the two, approximatley at 1/10.

Three different positions of window openings were used for the simulation study. Among others cited in the literature, the classifications of Ching (1996) and Egan and Olgyay (2002) were found to coincide with those most commonly used opening positions for healthcare buildings in Turkey (General

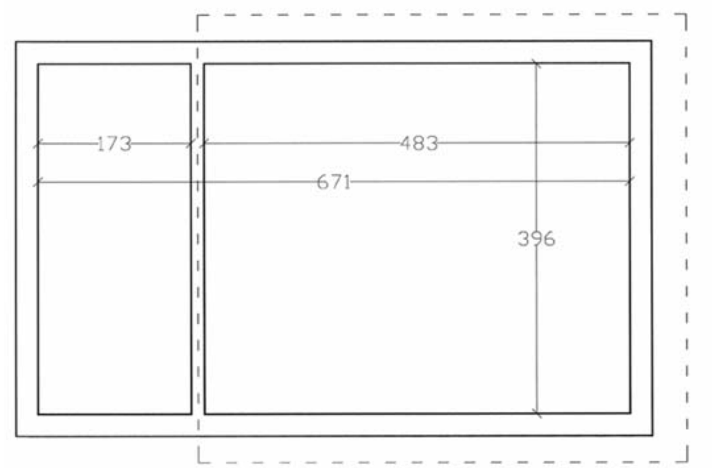

Figure 1: *Dimensions of the patient room (Turkish Building Standards -TS12813, 2002; De Chiara & Callender, 1990).*

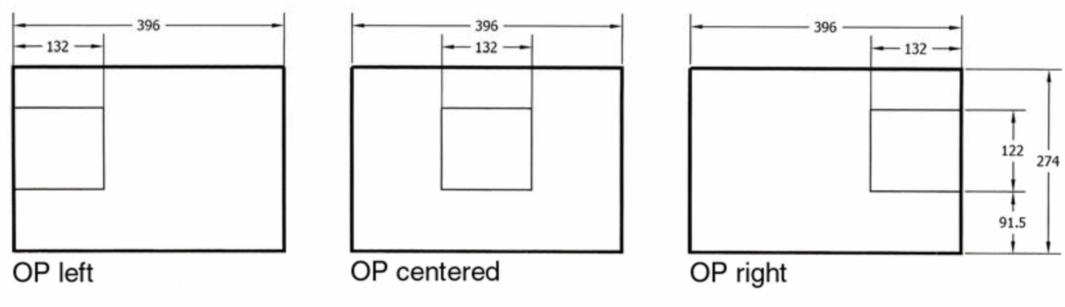

Figure 2: *Interior elevations of patient room exterior walls: OPleft: left-shifted opening; OPcentered: centered opening; OPright: right-shifted opening.*

Directorate of Construction Works, Ministry of development and Settlement, Republic of Turkey, 1997). The composite configuration derived from both sources was renamed as "right-shifted openings", "centered openings," and "left-shifted openings"; all three were considered to be on the middle horizontal axis of exterior walls (Figure 2).

Three rooms with three opening positions — OPleft, OPcentered, and OPright — were assigned to seven orientations, comprising the three cardinal and the four ordinal points of the compass; the latitude in question precluded a northern orientation.

Because only capturing and analyzing the locations and areas of sunlight patches on the surfaces of the rooms and the location of the patient bed were the matter of concern in this stage, neither the color nor the material of the room surfaces was considered. The material with 36.7% reflectance, 0.00% specularity, transmittance and roughness and a manufacturer's code of 1k 127 was specified for the walls and ceiling; another, with 31.50% reflectance, 0.00% specularity, transmittance and roughness, and a manufacturer's code of 7k 712 was specified for the floors; while clear single glazing was specified for the windows, from the material and glazing library of the program, Desktop Radiance 1.02. On the same grounds, the sky condition was chosen as "clear" and the turbidity level in the atmosphere as 2.0.

To permit subsequent referral, room surfaces with potential for receiving direct sunlight were given letter designations of A, B, C, and D to represent the left-hand wall, the right-hand wall, the rear wall, and the floor, respectively, when facing the window opening (Figure 4).

Method

Simulation Process

Patches of sunlight on patient room surfaces and patient beds were produced and recorded by means of Desktop Radiance 1.02 for Windows (2005). Compagnon (2004) states that, Desktop Radiance creates technically the most accurate architectural renders and predictions for illumination levels, because it creates images based on physical parameters rather than on computer graphics.

Simulations were conducted for rooms with different orientations and opening positions by taking solar noon as the reference point at hourly intervals, + and – hours, and from sunrise to sunset. Simulation dates were the four principal dates

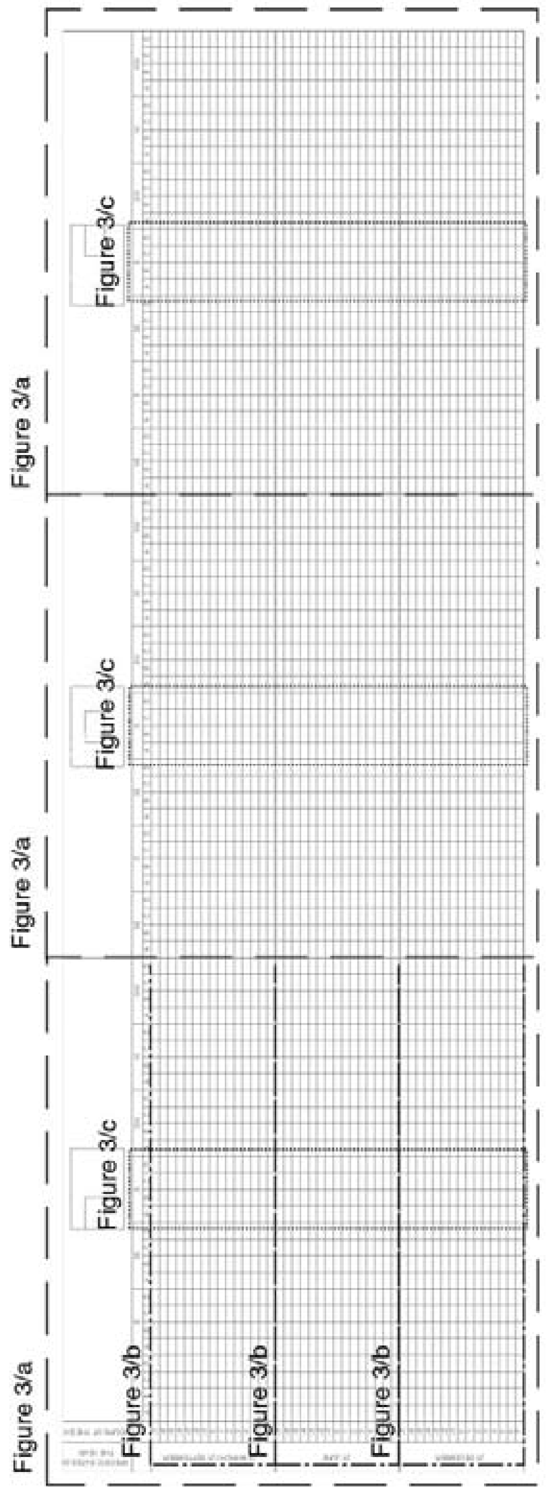

Figure 3: *The areas of sunlight patches were recorded in the table below for 21 rooms for three different opening positions and seven different orientations at four specific dates of a year.*

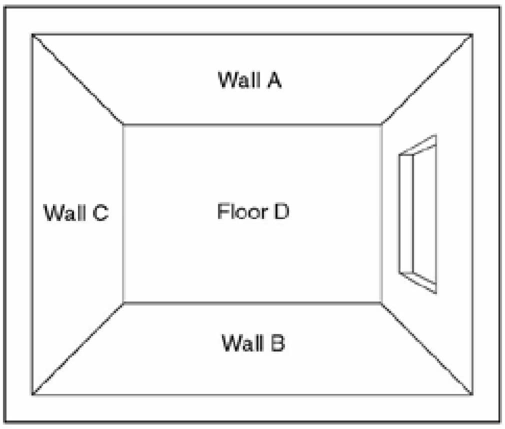

Figure 4: *Wall specifications for patient rooms (plan perspective).*

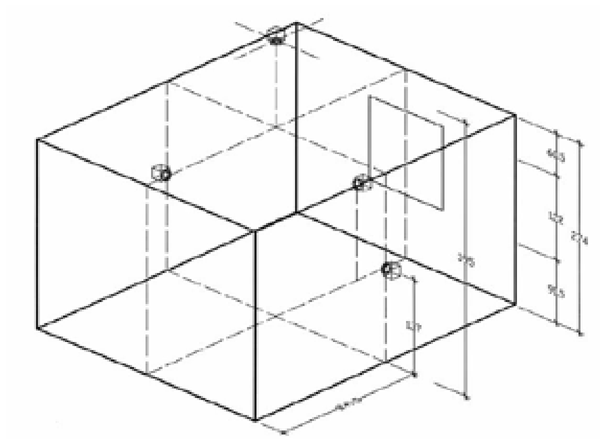

Figure 5: *Camera setup for patient room.*

of the year, namely the two solstices (June 21 and December 21) and two equinoxes (March 21 and September 23) with all in local time, for the latitude and on the dates in question (Sunrise and sunset, 2005) (Figure 3).

Four cameras were placed at specific points in the rooms to follow the path of sunlight patches on these surfaces and patient beds throughout the day. Their positions were chosen to minimize inherent perspective distortion and thereby to improve both the accuracy and the reliability of the area calculations. For walls, cameras were on the geometrical centers of each wall, aiming to capture the patch on the wall across. The optical axes of the cameras were normal to the wall under observation at a height of 1.37m and for the floor, similarly, directly above the geometrical center of the floor, all at a distance of 3.95m from their subject surfaces (Figure 5).

Actual areas were calculated in a number of steps. First, the perspective views produced by Desktop Radiance 1.02 were converted to image files. Not being vector drawings, however, these could not be used directly for calculation purposes. Therefore, these image files were reopened in AutoCAD 2000, brought to scale, and each patch in each perspective view was drawn individually as a polygon. The area of each patch calculated (raw data) was compiled in tables that listed 21 rooms for the three different opening positions and seven different orientations, at four specific dates of a year (Figure 3). One such perspective view - with the patch drawn as a polygon

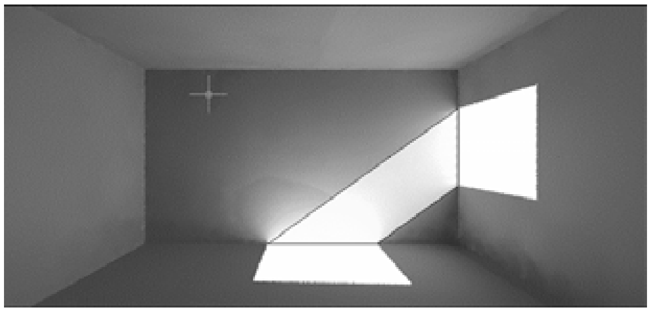

Figure 6: *Perspective given by Desktop Radiance for the sunlight patch on wall A of room OPleft, oriented due west, at 18:00 hours on the summer solstice (June 21).*

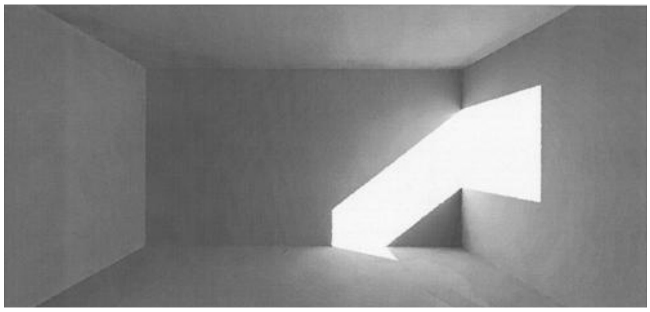

Figure 6a: *The areas of sunlight patches on surfaces.*

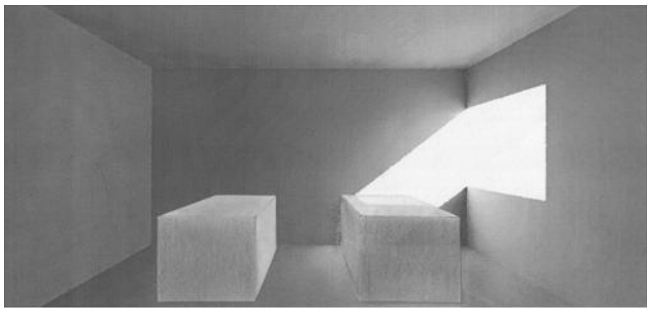

Figure 6b: *The areas of sunlight patches on patient beds.*

in AutoCAD - for room T1 at 18.00 hours, when faced west on the summer solstice, is given in Figure 6 as illustration. Finally, since both programs ran under the imperial system of units, all data compiled were converted into metric. Moreover, the patient bed was included in some of the room simulations to visualize the sunlight patches falling on to the patient (Figures 6a/6b).

The raw data tables were then graphically illustrated by the perspective views to reveal both the areas and the paths of sunlight patches appearing on different surfaces of rooms with different opening positions and orientations, by referring to different hours of the day, at four specific dates of the year (Figure 7).

Data Analysis

The variable, *areas of sunlight patches*, was assigned to a number of "treatments" consistent with the basic factors defined for the investigation, and one-way analyses of variance (ANOVA) were then conducted as $H_o: \tau_i = 0$ at $\alpha = 0.05$. The student's t-test, as $H_o: \mu_1 = \mu_2$, was used where tabulation gave

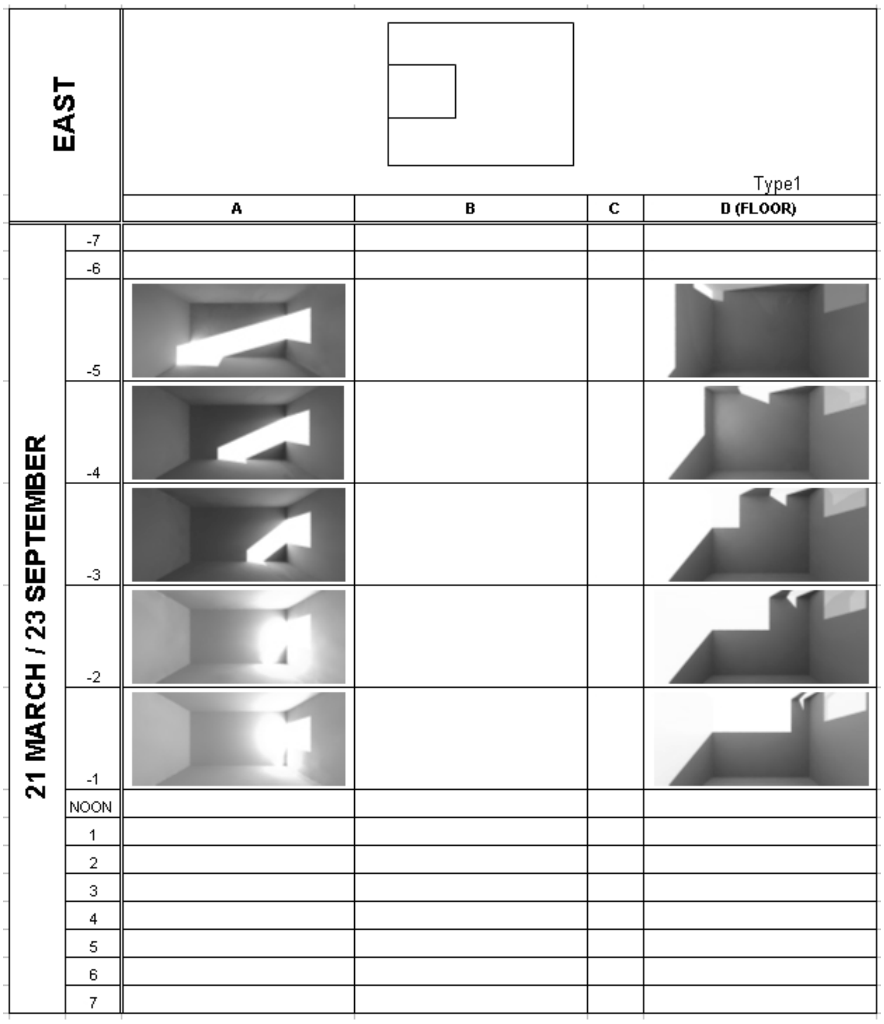

Figure 7: *The areas of sunlight patches on the different surfaces of a room.*

only two treatments. The treatments listed below were analyzed in SPSS 13, from which the significance is determined, based on P-value outputs. These comprised ANOVA on the variable, the areas of sunlight patches:

- On all surfaces (A+B+C+D),
  - by opening position (OP) (App.1/a);
  - at each orientation, by OP (App.1/b);
  - of each OP, by orientation (App.1/c);
  - at four specific dates of the year, by OP;
- On wall surfaces (A+B+C) and floors (D),
  - by OP;
  - at each orientation, by OP;
- On wall surfaces (A+B+C),
  - by OP;
  - at each orientation, by OP;
  - of each OP, by orientation;
- On floor surfaces (D),
  - by OP;
  - at each orientation, by OP;
  - of each OP, by orientation;
- On wall A, wall B, wall C, and D (floor), separately,
  - by OP;
  - of each OP, by orientation;
  - at four specific dates of the year, by OP.

Results

The compiled raw data was analyzed from general to specific to determine whether any significant relationships existed between the amount of direct sunlight received by rooms, regarding opening positions and room orientations, or not. One aspect to be explicitly noted is that the areas and locations of sunlight patches on room surfaces were reciprocally identical in mirror symmetry on the cardinal and ordinal points of the compass for rooms that were:

- OPcentered facing east and west, southeast and southwest, northeast and northwest.
- OPleft and OPright facing south.
- OPleft facing east and OPright facing west.
- OPleft facing west and OPright facing east.
- OPleft facing southeast and OPright facing southwest.
- OPleft facing southwest and OPright facing southeast.
- OPleft facing northeast and OPright facing northwest.
- OPleft facing northwest and OPright facing northeast.

First, the total areas of the sunlight patches were analyzed by opening positions, which indicated a statistically significant difference between OPleft, OPcentered, and OPright. OPcentered appeared to be different from the other two, as shown in the *scattered plot graph* of Figure 8. Then, the areas in the rooms with different orientations of similar

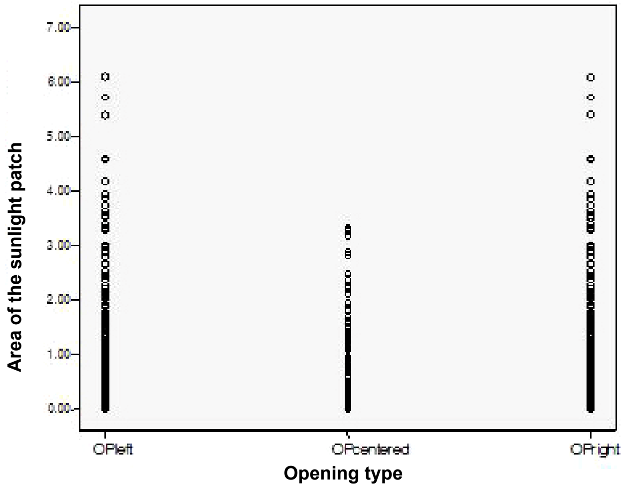

Figure 8: *The areas of sunlight patches on the total surfaces, by opening position.*

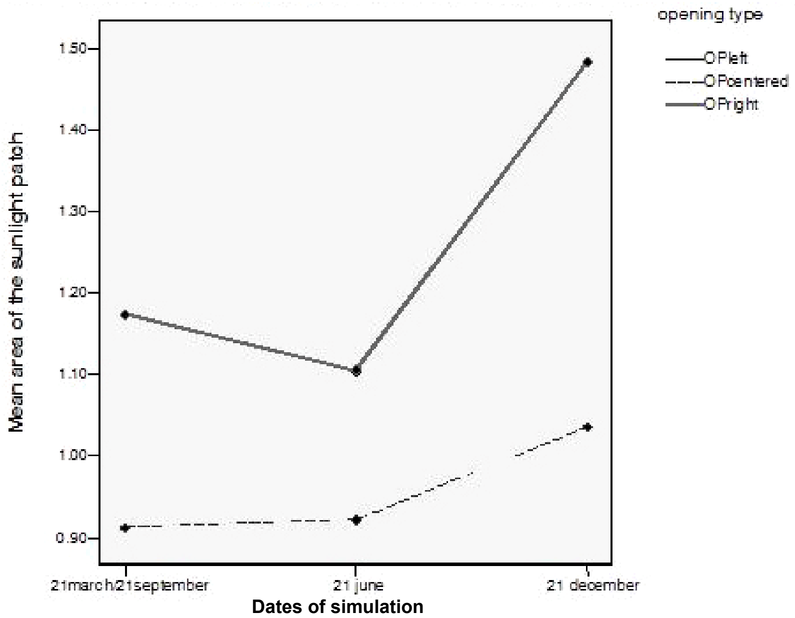

Figure 9: *The areas of sunlight patches on the total surfaces of rooms at four specific dates of a year, by opening position.*

opening positions and the ones with the same orientation of different opening positions were analyzed; no statistically significant difference appeared. When the four specific dates were considered, the total areas of sunlight patches in a room appeared to be significantly different from each other on December 21 and June 21, as shown in the *line graph* of Figure 9. Because OPleft and OPright are reverse symmetric, and the sun's path in the sky is symmetric, the graph lines showing areas of sunlight patches in rooms with OPleft and OPright overlap in the graph above.

The concern at the next level was differentiating between the areas of sunlight patches on walls and floors, because sunlight patches on wall surfaces are mentioned in the literature as sources of both reflected light and glare. The first three *t-tests* indicated a statistically significant difference between the areas of sunlight patches on walls and floors for each opening position, as shown in the *line graph* of Figure 10.

The difference between the areas of sunlight patches on walls and floors of all opening positions at four specific dates of the year was shown in Figure 11, as a *line graph*. The graph lines showing areas of sunlight patches in rooms with OPleft and OPright overlap in the graph below, as in Figure 9. It also indicates that the difference between walls and floors is largest on June 21 for OPleft and OPright. However, it is the opposite for rooms with OPcentered on June 21, when the difference between the walls and floors is the smallest.

Subsequent analyses dealt with the areas of sunlight patches on walls only. When considered together (as A+B+C surfaces) by opening positions, analysis indicated a significant difference among three positions, in which rooms with OPcentered appeared distinct from the other two. Such a difference did not

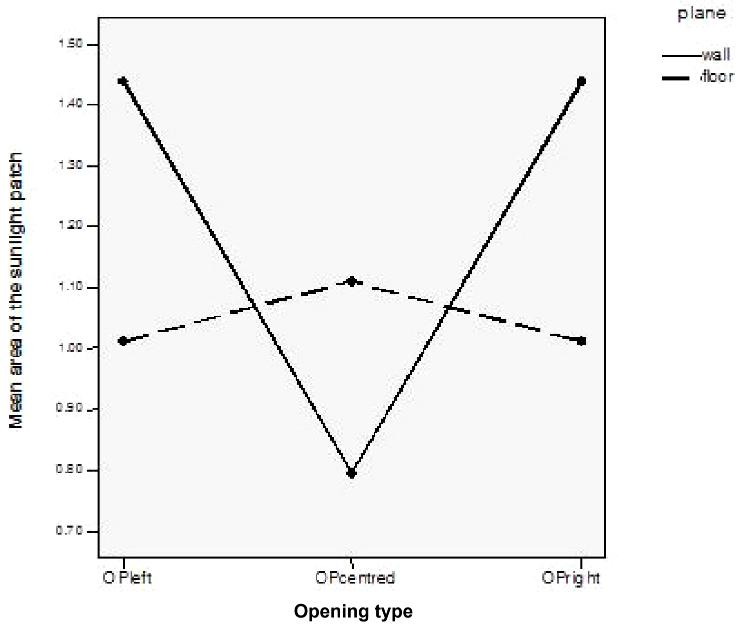

***Figure 10:** The difference between the total areas of sunlight patches on walls and floors, by opening position.*

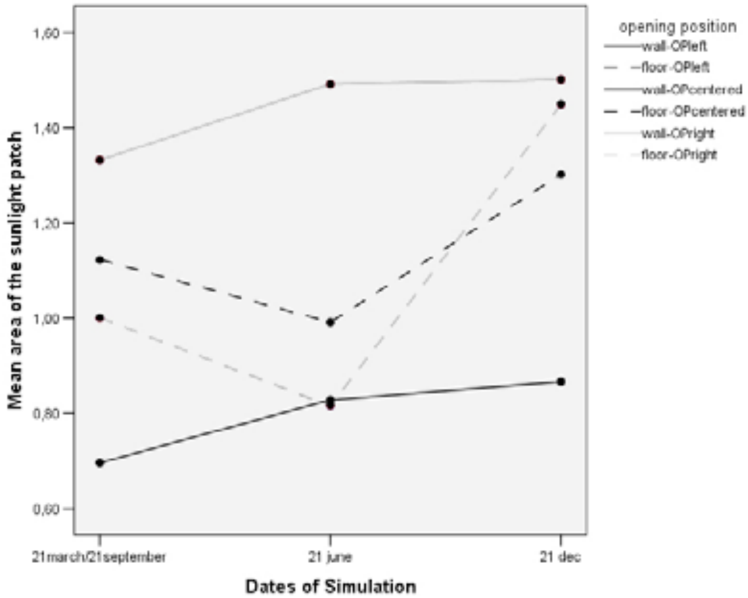

***Figure 11:** The difference between the areas of sunlight patches on walls and floors, by each opening position, at four specific dates of the year.*

appear, however, either for the rooms with different orientation of similar opening position or for the ones with the same orientation of different opening position.

Further analyses of sunlight patches on floor surfaces alone were done along the same lines cited for walls above. Results indicated a lack of significance among the total areas of sunlight patches on floors for each opening position. Furthermore, the analysis done for the rooms with different orientation of similar opening position and the ones with the same orientation of different opening position indicated a similar lack of significance in these respects.

In the next stage, the areas of sunlight patches on each surface (A, B, C, and D) were the major concern. They were evaluated by opening position, in which wall A in rooms with OPleft was significantly different from wall B and floor (D); and wall B in rooms with OPright was significantly different from wall A and floor (D), as shown in the *line graph* of Figure 12.

When these surfaces were analyzed for each orientation, west- and southwest-oriented rooms with OPleft (Figure 13) and east- and southeast-oriented rooms with OPright appeared to be significantly different from the others (Figure 14). In the rooms with same orientation but different opening positions, no significant difference appeared between individual surfaces of rooms with OPcentered. However, wall A in west-oriented OPleft was significantly different from the other surfaces, and

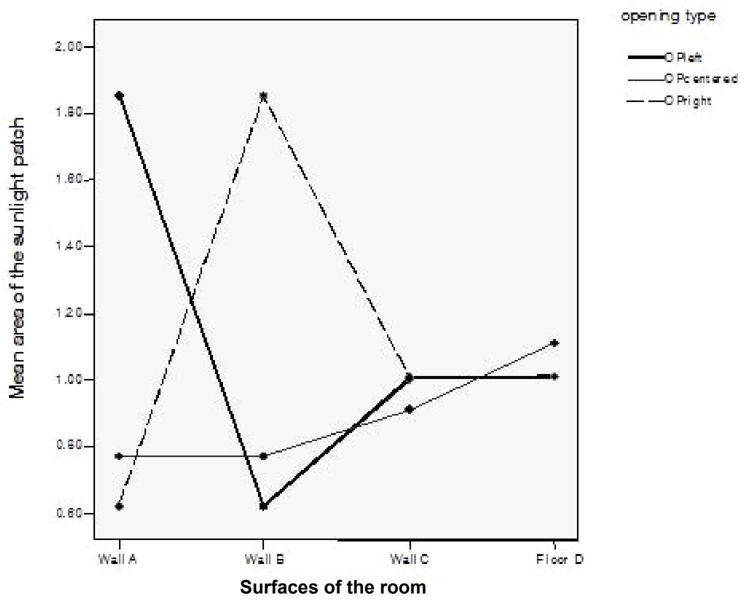

Figure 12: *Wall A in rooms with OPleft and wall B in rooms with OPright were significantly different than the rest of the surfaces for each opening position.*

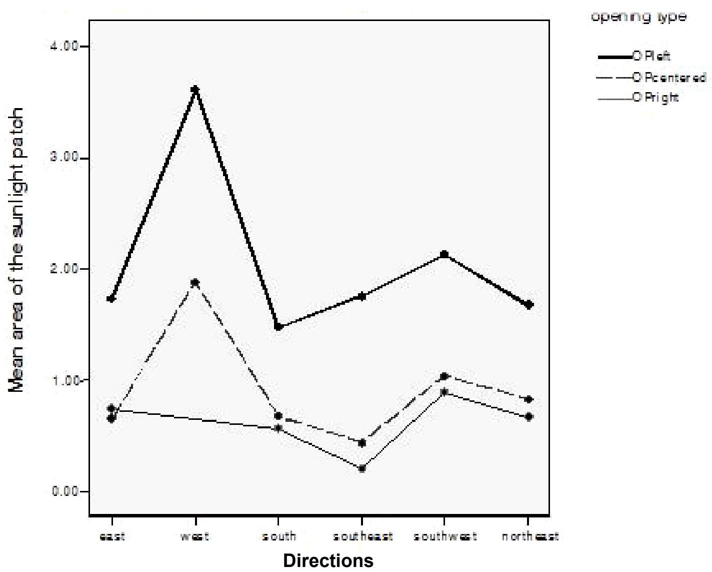

Figure 13: *West- and southwest-oriented rooms with OPleft were significantly different than the other rooms when the areas of sunlight patches on the total surfaces analyzed at each orientation by opening position.*

walls A and B in southwest-oriented OPleft were significantly different from each other (Figure 15). Similarly, wall B in east-oriented OPright was significantly different from the other surfaces, and walls A and B in southeast-oriented OPright were significantly different from each other (Figure 16).

Conclusion

As a general finding, OPcentered rooms appear to receive less direct sunlight—irrespective of orientation—than both OPleft and OPright rooms, in terms of overall areas of sunlight patches. This was attributed to the positions of openings adjacent to walls A and B in OPleft and OPright rooms. When the effect of orientation was tested, differences between the total areas of sunlight patches in different types of room disappeared. The symmetrical path traced by the sun on the N-S axis in the sky, although differently oriented, equalizes the amount of direct sunlight received by rooms on a given day.

Meanwhile, only south-oriented OPcentered rooms showed some difference with respect to these reciprocal pairs. They received more hours of direct sunlight compared to the rooms facing other directions. However, the areas of sunlight patches were smaller, due to the higher solar altitude angles at noon, and the difference remained too marginal to be of significance.

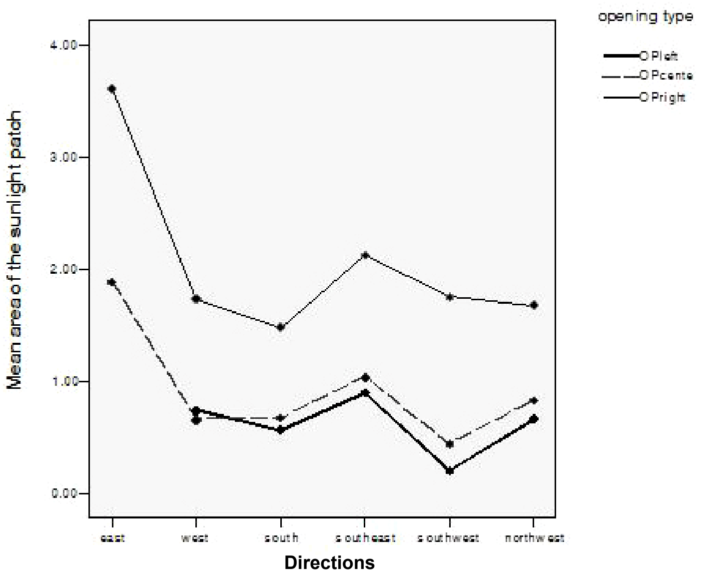

Figure 14: *East- and southeast-oriented rooms with OPright were significantly different than the other rooms when the areas of sunlight patches on the total surfaces analyzed at each orientation by opening position*

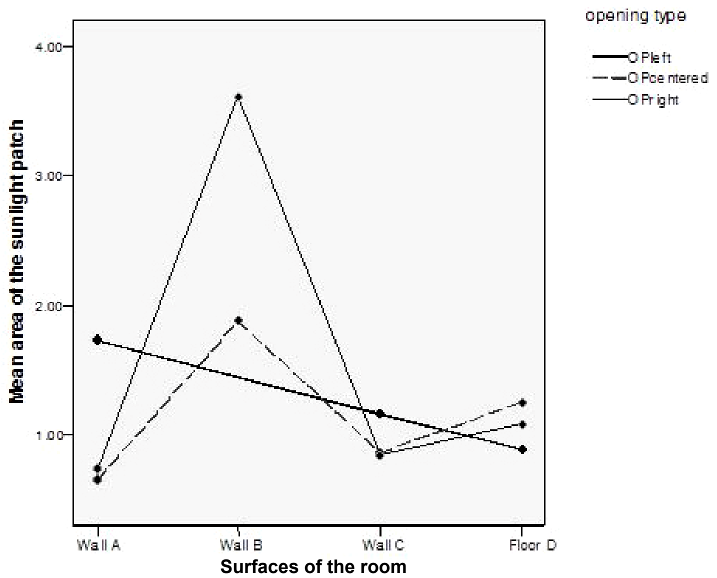

Figure 15: *Wall B in east-oriented OPright was significantly different from the other surfaces.*

Moving from general to specific, results revealed that walls and floors received different amounts of direct sunlight for all types. Especially OPleft and OPright rooms received direct sunlight on walls more than floors, which increased the general illumination level and created the need to control excessive penetration. This also meant that the patient beds located against the two major walls receive plenty of direct sunlight, which could cause visual and physical discomfort, if the admission of sunlight is not controlled. OPcentered rooms, however, have sunlight mostly on floor surfaces; therefore, they would be advantageous, if there is no possibility of taking precautions regarding the penetration of sunlight, the layout, or the surface characteristics of the rooms. In these rooms, sunlight patches are likely to fall mostly on floors and the patient bed, but because the walls do not receive direct light as much as they did with OPleft and OPright, the patient bed head is mostly free from direct sunlight as well as from glare. Beyond the risk of glare, the illumination levels would be higher in rooms OPleft and OPright than OPcentered, because sunlight patches on vertical surfaces act as sources of light, enabling numerous reflections on the four walls of the room.

Lastly, the analysis of sunlight patches on the individual surfaces (A/B/C/D) of each room revealed that the walls adjacent to the openings A and B in OPleft and OPright rooms

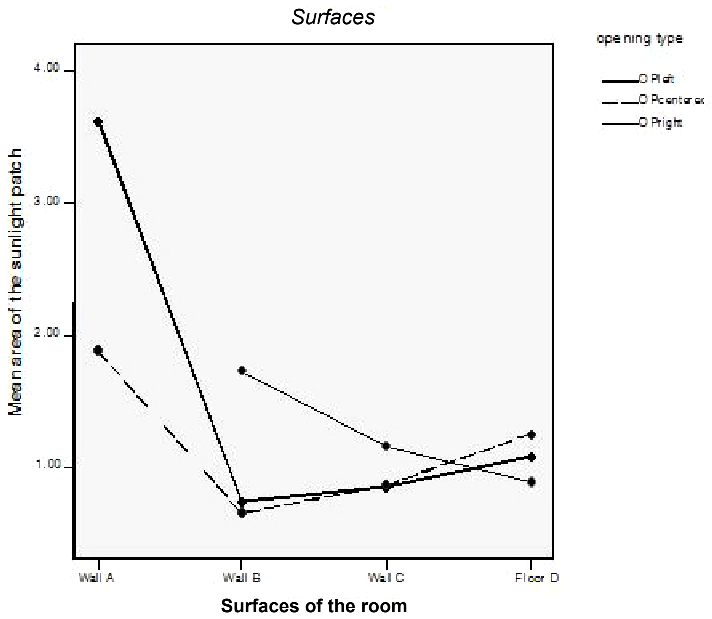

Figure 16: *Wall A in west-oriented OPleft was significantly different from the other surfaces.*

received longer hours of direct sunlight. This was especially so with the openings that are adjacent to one of these two major walls, and positioned with regard to the symmetrical path of the sun in the sky (so long as these major walls "saw" the sun). These walls and the patient beds located against these walls would receive excessive amounts of direct sunlight. For wall A, west-oriented OPleft, and for wall B, east-oriented OPright were significantly different from the others. The shift of the opening increased the areas of patches on walls adjacent to the openings but also prevented opposite walls from receiving direct sunlight. Therefore, the opposite walls would be appropriate for locating patient beds against, if appropriate sun control was not provided. However, providing sun control and locating patient beds against the major walls receiving direct light would be more beneficial, because it gives the opportunity to have sunlight when wanted, and to be in the shade by using shading devices when needed. None of these parameters had a significant effect on wall C, because it received very little direct sunlight.

For four principal dates, the lower solar altitude angles on the winter solstice and higher solar altitude angles on the summer solstice equalized the solstice equalized the amount of direct sunlight falling on wall and floor surfaces in rooms, when the analysis was made with the total areas of patches on all surfaces of a room, in a year. However, when the surfaces were studied individually, on the four specific dates in a year, the difference between the solar altitude angles on December 21 and June 21 affected the areas of sunlight patches on floor surfaces only.

In reference to the results, the position of opening on the exterior wall rather than the orientation of the opening appeared to be the primary concern in the design of patient rooms with regard to sunlight potential. However, orientation is significant when the surfaces are studied individually, especially for the walls adjacent to the openings. Design decisions related to the orientation of patient rooms and to the location and sizes of window openings will definitely affect design decisions related to the layout of the room, the color and texture of the surfaces, and artificial lighting. Therefore, four proposals are made to conclude the study, by presenting an informal choice from the combinations of opening positions and orientation that both admit sunlight and protect the patient from glare and excessive heat gain and by defining the location of the patient bed and related material. Proposals are presented by focusing on orientation forth, because it is usually one of the major constraints of the site. The following is recommended:

- East-oriented rooms to have left-shifted openings (OPleft) with bed heads against wall B and west-oriented rooms to have right-shifted openings (OPright) with bed heads against wall A. Since both walls do not receive direct sunlight at the same time, it is possible to protect the patient from glare, especially if sun control devices are not provided.
- South-oriented rooms to be on the symmetry axis of the sun's path, receive direct sunlight to both major walls. However, wall A in OPright and wall B in OPleft appeared to receive less direct sunlight than the other major wall and walls A and B in OPcentered; thus, it is appropriate for the bed heads to be located against these walls.
- Southeast-oriented rooms to have OPright with bed heads against wall A and southwest-oriented rooms, being in mirror symmetry, to have OPleft with bed heads against wall B. Since both walls do not receive direct sunlight, it is possible to protect the patient from glare, especially if sun control devices are not provided.
- Northeast-oriented rooms to use wall B for all opening positions and northwest-oriented rooms to use wall A for all opening positions to locate bed heads against. However, these rooms receive little direct sunlight; therefore, they are not suitable from an economic or health point of view.

Regardless of opening position (OPleft, OPcentered, or OPright) and orientation, both horizontal and vertical surfaces receiving direct sunlight must be treated specially. The choices of surface material, color, and texture for these surfaces are critical design decisions, because the patient and the overall ambient illumination of the room are affected by these choices.

Although sunlight patches do not qualify as quality delighting in a space, they may decrease the visual performance and thermal comfort if not consciously used and controlled. Therefore, this study aimed to provide a basis for considering and designing with sunlight since it presents a method to master sunlight by tracking the location (path) and area of sunlight patches on the room surfaces.

The results regarding the areas and locations of patches were thought to be significant determinants that can affect the layout of the room (location of the patient bed). In view of the fact that the layout of the patient room is not flexible due to the function and the patients have limited mobility, the location of the patient bed is an important design decision affecting many other issues in the room. For this reason, proposals above were made for the location of the bed in patient rooms with different orientations and opening positions by considering direct glare and glare from reflections.

Although only three basic but commonly used opening positions were tested in this study, results indicate that there are sufficient grounds for further investigation focusing on decisions regarding the design of patient rooms, such as layout (e.g., the location of beds) and choice of surfacing materials, colors, and textures. Moreover, the methodology in this study seems promising enough to be adopted to further and more advanced investigations, not only for healthcare facilities, but also for other types of buildings open to the public-at-large.

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