The Impact of Daylighting- Guiding Systems on Indoor Natural Light Penetration: Simulation Analysis for Light-Shelves

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ABSTRACT: Daylighting-guiding systems and control strategies are considered as an important step in providing daylit indoor spaces as well as energy–efficient building environments. The application of daylighting-guiding systems is only one significant constituent of a daylighting strategy. These systems could be categorized by many characteristics; therefore the designer must be aware when choosing a system according to the circumstances of the space. However, a poor selection of systems could spoil the performance of a building with good daylight potential. This research paper concentrates on the role and properties of daylighting systems especially the sidelighting-guiding ones, taking into consideration their influence on daylighting performance within indoor spaces. It is also corroborated by a simulation analysis on one type of daylighting-guiding systems: Light shelf through studying its impact and influence on natural light penetration.

Keywords: daylighting, energy conservation, daylighting –guiding systems, light shelf, anidolic system

1. INTRODUCTION

In any project, daylighting is considered a beneficial design concept for many reasons: Human health, comfort and satisfaction, energy conservation, view...etc. In order to accomplish these benefits appropriate fenestration and daylighting systems and control strategies could be used to modulate natural light admittance and at the same time realize the occupants' lighting quality and quantity, i.e. energy-efficient building environments. A satisfactory balance between desirable and unwanted effects within an indoor space constitutes the real challenge when selecting and designing the appropriate daylighting system at the earliest stages of the design process of a building. The first part of this research paper explains the main concept and characteristics of daylighting systems especially the sidelighting-guiding ones. This is followed by the second part which concentrates on one type of daylighting- guiding systems: Light-shelf. This system will be described and evaluated from the point of view of its impact and influence on natural light penetration within the indoor space.

2. DAYLIGHTING SYSTEMS CONCEPT AND CHARACTERISTICS

The main concept of daylighting systems is to obtain redirection daylit effects within indoor spaces. Therefore, the openings of the building envelope need to be equipped with additional or integrated elements. These elements could be either located on the outside or the inside part of the windows or even incorporated with them .The resulting combination of the windows and these equipped elements is called “Daylighting Systems”. Frequently daylighting systems are associated with qualifiers advanced or innovative technologies mainly to denote recent developments [1].

2.1 Classification of Daylighting Systems

Daylighting Systems have different characteristics related to major performance parameters. These parameters include visual performance and comfort, building energy use and systems integration. The primary energy related design objectives of a daylighting system are to provide “usable daylight” for a particular climate or building type and for a significant part of the year [2].There are many categories of daylighting systems that could accomplish these major performance parameters, however this research paper will concentrate on sidelighting-guiding systems which could be classified according to their geometric characteristics into two types:

a. <u>Integrated window elements</u>: These are elements that could be located adjacent to windows or integrated into their glass panel. They are usually made of a repetitive planner arrangement of tiny optical devices (e.g. miniature mirrored louvers, prismatic elements, prismatic films, laser cut panels...etc.) positioned on a parallel plane a few millimetres behind a single glass, or between two panes of multiple glazing unit (Fig.1), (Fig.2) [1]. On the other hand, these elements could be made of no-optical treatment: Fixed or operable blinds and louvers that according to their tilted angle may reflect daylight and sunlight into an indoor space and act at the same time as shading devices. [3]

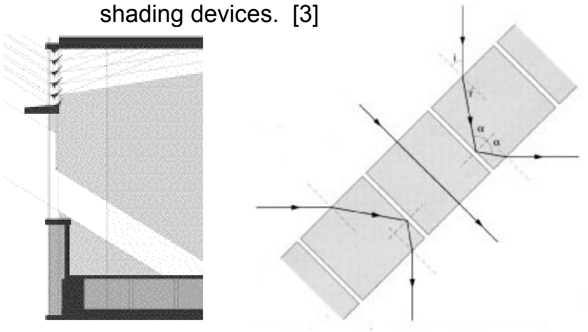

Figure 1: (Left) Specular louvers installed into in the upper part of the window.[4] (Right) Reflection by total internal reflection in laser-cut panel that usually installed inside double glazing units [1].

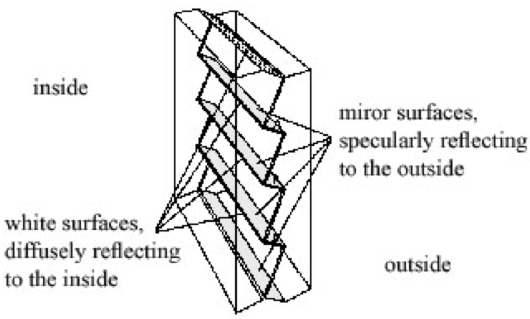

Figure 2: Mirror fixed louvers placed inside a double glazed unit [5].

b. Reflectors and light shelves: These are systems made of reflectors positioned on either the interior or the exterior part of the windows. They often combine the shading and the daylight-redirecting functions which might be improved by adding the property of tilting around the horizontal axis of these reflectors [1]. In the second part of this research paper, light shelves will be described and evaluated in details.

2.2 Strategies of Establishing Daylighting-Guiding Systems

The climatic and site daylighting conditions, as well as the numerous parameters that could affect daylighting performance within indoor spaces, make choosing the appropriate daylighting-guiding systems quite complex. A methodical approach is certainly the best strategy [1]. This procedure consists of several steps that could be summarized into four main ones:

a. Identifying the key elements of decision-making process: The functions and the major objectives of a daylighting-system should be clearly defined in order to identify the key elements of decision- making process. This can be done by answering two primary questions; first, what benefits could be achieved with a daylighting-system? And secondly, which system should be chosen? [2]. For any daylighting-system, three main functions should be fulfilled : collecting the incoming light from the environment, carrying it through the building envelop and, finally, directing it to the interior light rays to interact with the system components in various optical rays (i.e. reflection, refraction, absorption and refraction) [1]. It is also important to achieve the major objectives for applying a daylighting-system, as follows: [2]
   - Redirecting natural light to under-lit zones
   - Improving daylighting for task illumination (recommended illuminance)
   - Improving visual Comfort and glare control
   - Achieving solar shading and thermal control

b. Integration with the architectural building design: In order to apply a daylighting-system the above mentioned objectives should be complied with the daylighting strategies implied in the architectural design of the building. Additionally, it should be integrated with the design of the interior space especially that its surfaces are required to complement the system in order to obtain satisfactory performance.

   Moreover, for all the systems that use the ceiling as a reflector, the space beneath it should be kept free of obstruction however, this necessity may interfere considerably with the desired layout of several building service, such as ventilation ducts, suspended luminaries, acoustics absorbing elements and sprinklers [1].

c. Evaluation of performance of the proposed system: The performance of the proposed system needs to be checked and evaluated. The goal of this evaluation is to validate its dimensioning, positioning and its impact on daylighting performance and energy consumption [1]. Detailed examination for the performance of the proposed system could be determined and analysed through physical scale modelling techniques or specialised simulation programs.

d. Maintenance and installation: Maintenance is of prime importance to ensure that the performance of the daylighting-system does not deteriorate significantly. All systems inevitably collect dust and dirt that need to be removed periodically. Moreover, with movable systems, mechanical failure could always be expected [1]. Therefore, to protect the efficiency of the system and to ensure its maintenance, means of accessing its critical parts, as well as, periodical checks for its proper operation, should be planned and studied. Installation of the daylighting-system in the building also requires careful attention. All components of the system should be protected on site and carefully installed.

These explained steps of establishing daylighting-systems are coherent and integrated in a certain sequence as shown in (Fig.3).

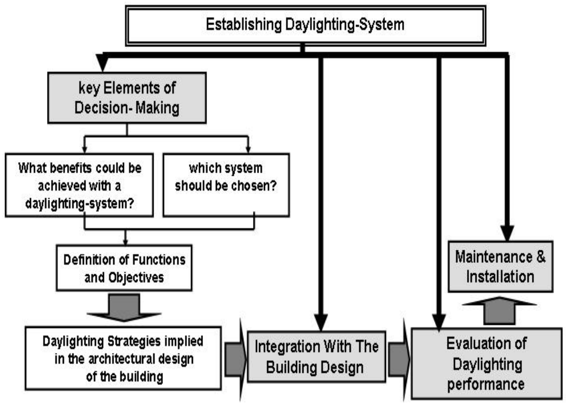

Figure 3: The process of establishing a daylighting-system in a building.

3. LIGHT SHELVES: DESCRIPTION AND EVALUATION THROUGH SIMULATION ANALYSIS

In this part of the research paper, light shelves - as a part of daylighting-systems classifications - will be first described in details regarding their configurations and components. Secondly, they will be evaluated - using a specialized computer simulation - and fulfilled to analyse the effect of the different parameters of light shelves characteristics on natural light penetration within an indoor space.

3.1 Light - Shelves Description

Light shelves are considered as a classic daylighting-system, they have been used since the time of the Egyptian pharaohs to control sunlight in buildings and to reduce glare from the sky while admitting sky light and reflected sunlight. The main advantages of light shelves that they permit natural light to penetrate deep into a building, to improve illuminance distribution and to reduce glare. Light shelves affect the architectural and structural design of a building; therefore they should be integrated at the early stages of the design phase.

a. Light shelf location in a window system: It is usually positioned above eye level. The light shelf is typically positioned to avoid glare and maintain view outside; its location will be dedicated by the indoor space configuration, ceiling height and the user eye level [2].(Fig.4)

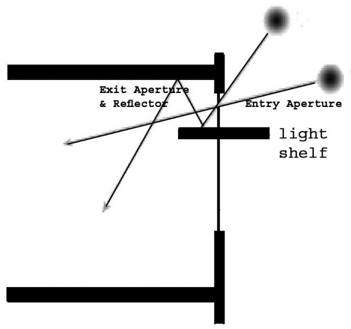

Figure 4: Light shelf location in a window system [6].

b. Light shelf configurations: The configurations of a light shelf could be classified into three main categories. First, its extended position that could be internally or externally or a combination of both. Each position could change the performance characteristics considerably. [3].Second category is the tilted angle of the light shelf that could also provide interesting solutions according to the seasonal sun rays and the surrounding obstructions. The tilted light shelf could collect the incoming light from the unobstructed part of the sky and redirect it within indoor spaces. Finally, the third category is the shape of the light shelf that is usually horizontal, however, to achieve the ideal objective of redirecting all incoming rays further within the indoor space, an 'anidolic" reflector with a curved shape could be used. The "anidolic" system is considered as an innovative light shelf that could provide slightly higher daylight factors at the back of the space than the horizontal one, (Fig. 5) [1].

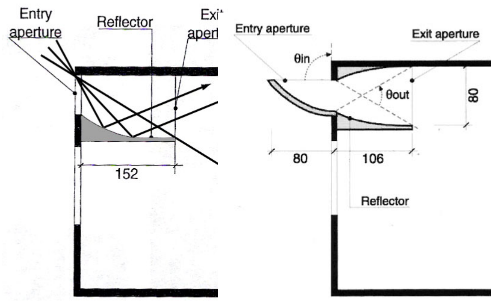

Figure 5: (Left) An "Anidolic" internal light shelf. (Right) "Anidolic" Zenithal system: It consists of an externally curved reflector that concentrates all incoming light (90º) onto a vertical opening. The light rays are then shaped into a beam of well-defined angular spread (60º) using two curved reflectors mounted face to face. [1]

c. Light shelf components: Light shelf consists of three integrated components according to the aperture: the entry aperture, the reflector and the exit aperture. These components, together, operate the whole system of the light shelf and affect its performance. Light shelf position, tilted angle and shape form the entry aperture that could be divided into two parts: The upper and the lower part of the light shelf. These two parts include the glass transmittance of the aperture and the reflectivity of the shelf's upper and lower surfaces. It is possible to vary the transmittance of the glass in the two parts; the clerestory part often uses clear glass in order to optimize the depth of natural light penetration. Regarding the reflectivity of light shelf's surface - which represents the first part of the reflector light shelf's component - a highly reflective surface, could be used on the top of it to reflect and redirect natural light towards the ceiling (the second part of the reflector and the exit aperture) then deep into the space [3]. The whole system of light shelf's configurations , components and operation is shown in (Fig. 6)

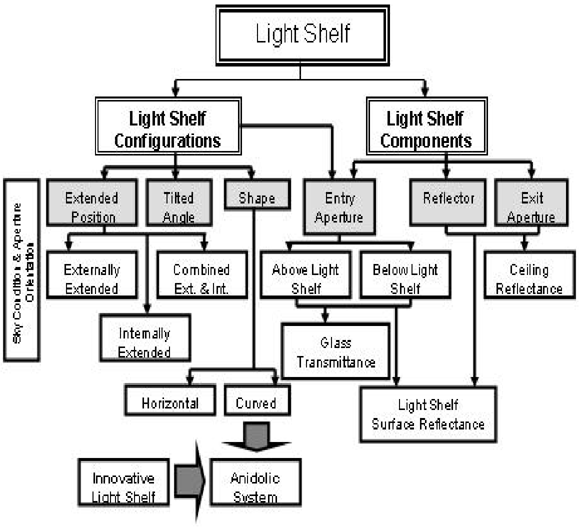

Figure 6: The integrated parameters of light shelf's configurations and components.

3.2 Light - Shelves Evaluation through Simulation Analysis

The simulation analysis of the light shelf consists of a group of experiments which concentrate on the effect of the light shelf configurations and the internal surfaces reflectivity on natural light penetration within the indoor space. A specialized computer program is used in this simulation analysis [7]. The experiments could be considered as a comparative analytical study between different parameters in order to reach some accurate results.

A base case or "reference case' has to be defined to be able to compare the performance of the alternate designs to it. It is worth noticing that there are an infinite number of assumptions for each parameter of the base case that could lead to an infinite number of simulation results. Therefore, some of these design assumptions have been chosen as follows, (Fig. 7):

- Latitude: 30° N - Longitude : 31° E
- Sky condition : Clear sky with sunshine
- Indoor space dimensions: 4.80m * 8.40m - Height :4.00m
- Internal surfaces reflectance :
  - Walls : 60%
  - Ceiling : 85%
  - Floor: 20%
- The lower part of the light shelf :
  - Glass Transmittance: 50%
  - Surface Reflectance of light shelf : 60%
- The upper part of the light shelf :
  - Glass Transmittance: 85%
  - Surface Reflectance of light shelf : 97% (Galvanized Metal)
- Window dimensions : 3.60 * 2.95 m
- Window orientation : North (To prevent the effect of direct sunlight : Diffused light)
- Working plane height : 0.85m
- Measurements grid: 1.2 m spacing in both directions.
- Date and time : 21 June - 12:00 Noon
  (12 Noon is the time of maximum illuminance at North orientation)

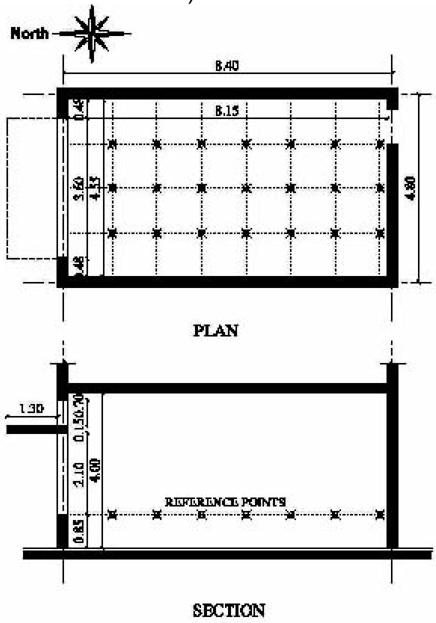

Figure 7: The design assumptions of the base case

The simulation analysis consists of four suggested experiments. In each one, only one parameter of the base case is changed and all the others remain constant. The comparative analytical study between the base case and the changed parameter of the light shelf is focussed on the grid line at the mid-width of the window.

a. <u>Extended Position</u>: In this experiment, the parameter of extended position is changed. Two positions are added to the base case, one is internally extended while the other one is a combination of both (Half externally and half internally extended), (Fig 8).

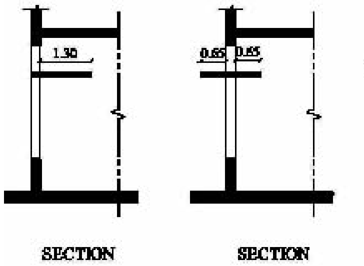

Figure 8: Two extended positions for the light shelf

- Simulation results: From the comparative analytical study between the three positions of the light shelf, the penetration of natural light - at the farthest end of the space - has improved in the case of externally extended (base case) and the combined one: the illuminance has increased by an amount of 30% than the case of internally extended position. Same results were noticed on the perpendicular grid line located at a distance of 2.4m from the opposite wall, (Fig 9).

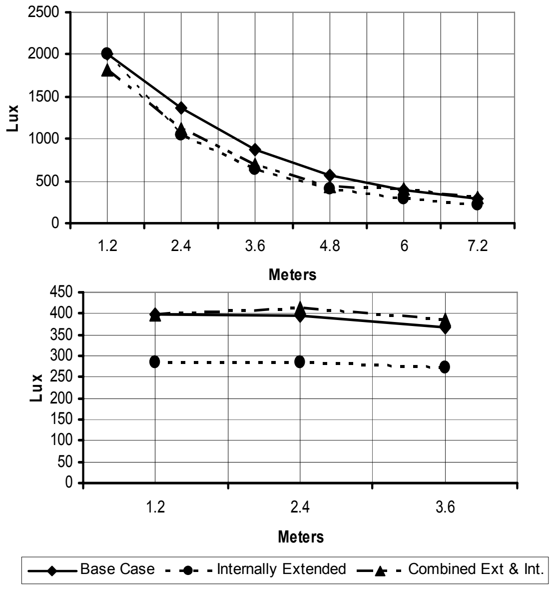

Figure 9: The internal illuminance distribution in the case of the two studied grid lines

b. <u>Tilted angle</u>**:** In this experiment, the parameter of the tilted angle of the light shelf is changed. Two tilted angles are chosen for simulation, the first one is a tilted angle of 30º CCW (downward) with an angle of obstruction equal to 25 º; the second one is 30º CW (upward) with an angle of obstruction equal to 50 º, (Fig.10).

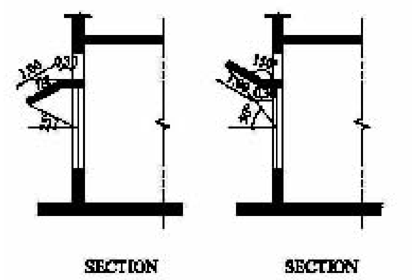

Figure 10: The two chosen tilted angles for the simulation analysis of the light shelf and their relations with the angle of obstruction

- Simulation results: The illuminance has increased by an amount of 18% when the tilted angle of the light shelf is changed from 30º CCW (downward) to 30º CW (upward) at the farthest end of the space. On the other hand, the illuminance has slightly increased by an amount of 10% when comparing the horizontal position of the base case with the two tilted angles. However, there is a remarkable increase in the illuminance of the closed area to the window by an amount of 18% when comparing the base case with the 30º CW (upward) tilted angle (Fig.11).

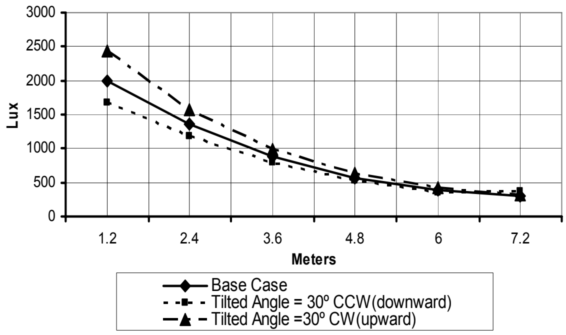

Figure 11: The internal illuminance distribution in the case of the horizontal light shelf and the tilted ones.

c. <u>The shape:</u> In this experiment, the parameter of the shape of the light shelf is changed. The curved shape is compared with the horizontal one of the base case, (Fig.12).

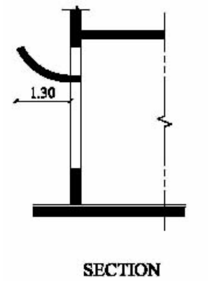

Figure 12: The curved shape of the light shelf

- Simulation results: The illuminance has increased by an amount of 25% close to the window and by 12% at farthest end of the space when the shape of the light shelf is changed from the horizontal shape to the curved one, (Fig. 13).

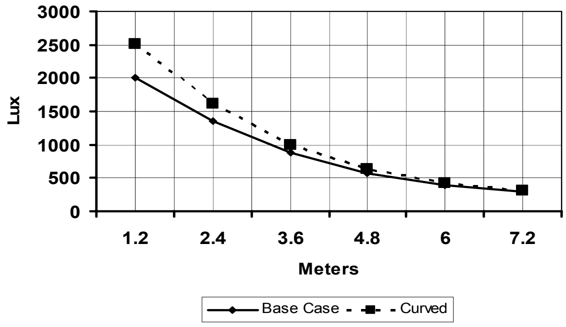

Figure 13: The internal illuminance distribution in the case of the horizontal light shelf and the curved one.

d. <u>The reflectivity of the internal surfaces</u> In this experiment, the parameter of the reflectivity of the internal surfaces of the space is changed. The surfaces experimentally evaluated are the ceiling and the walls. The amount of the reflectivity (ρ) of the ceiling is reduced to 60%, and the reflectivity of the walls is increased to 75%.

- Simulation results: In case of reducing the amount of the ceiling reflectivity from 80% (base case) to 60%, the illuminance has decreased by 10% at the farthest end of the space, (Fig.14). However, the illuminance has increased by 20% at the farthest end of the space and by 32% close to the opposite wall in the case of increasing the amount of wall reflectivity from 60% (base case) to 75% (Fig.15).

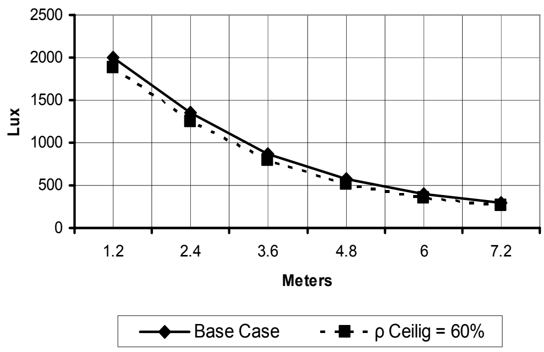

Figure 14: The internal illuminance distribution of the two amounts of ceiling reflectivity.

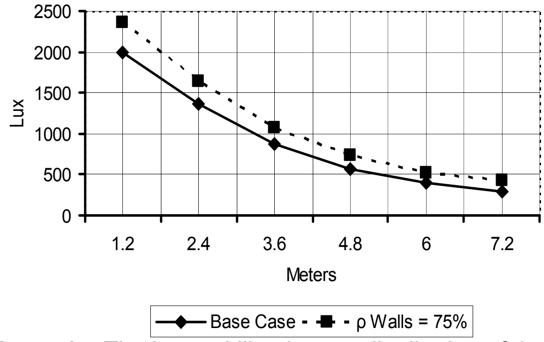

Figure 15: The internal illuminance distribution of the two amounts of walls reflectivity.

As general results, and from the comparative analysis of the simulation study, the natural light penetration could be improved – especially at the farthest end of the space - by some parameters of the light shelf: the externally extended position, the upward tilted angle, the curved shape and the high reflectivity of the internal walls. These results demonstrate that the intrinsic properties of a light shelf could be improved through a careful and knowledgeable design. Other properties may also be varied and simulated to achieve desirable performance of daylighting within the indoor spaces.

4. CONCLUSION

This research paper has shown in the first part of it the properties and characteristics of daylighting - systems which could be considered as an important factor in improving natural light penetration especially in deep indoor spaces. The designer should understand these properties that could help in the decision-making of choosing the appropriate system according to the circumstances of the space. On the other hand, the second part of this research paper, has shown, by the accurate results of the simulation analysis of the performance and efficiency of the light shelf that changing its properties could play an important role in improving natural light penetration within indoor spaces.

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