Carrying Daylight Without Glare To Rear Interior Spaces

Dr. Doaa Ismail Ismail Attia
Lecturer of Interior Design and Furniture, Faculty of Applied Arts, Benha University

Abstract :
The subject of this paper is adopting an active, and cheap interior design process that uses the sun, our natural free resource to flux through window to obtain a successful and effective method which allows penetration of the natural light with reduced glare to the rear interior spaces. This helps in serving health and comfort of occupant, increase productivity and decrease both electric energy consumption and electromagnetic pollution. The quantitpy and quality of sun-rays fluxing through the window is characterized by variability according to orientation and seasons which in turn leads to variability in the profile angle of sun-rays (the angle between the sun-ray and the vertical axis). The process considered in this paper depends on two steps: first step, is reflecting and collecting the fluxing sun-rays through window towards a concave wall-ceiling area (the concave area covering the intersection line of the ceiling and the window wall) by using a window reflector panes system. Second step, is transporting the sun-rays from the concave wall-ceiling area to the rear interior space by successive reflections of sun-rays through interior ceiling tubes beside each other lie inside the hollow space between upper and lower double surfaces ceiling. Each ceiling tube is covered internally by specular reflective material and consists of three successive essential parts: the **collector**, which is the first part in the ceiling tube, part of the concave wall-ceiling area, that reflects sun–rays to the **transporter**, the middle part of the ceiling tube, that transports sunrays by successive reflection to a concave shape **distributor**, the last part in the ceiling tube which reflects sun rays downwards to the rear space. The process is based on two new ideas: the first idea, is applying a mathematical relationships between the pane inclination angle (the angle between the reflector pane and the horizontal axis) and the sun profile angle. This relationship is used to obtain the optimum concave wall-ceiling area(collector), the optimum length between any two successive window panes and the optimum number of panes used to cover the window area, to provide the maximum quantity of daylight to the rear interior space. The second idea is an interior design management for the ceiling shape which play an essential role for placing ceiling tubes and for facilitating the reflection of daylight inside the ceiling light tubes. The method consists of three stages: First stage is the interior manipulation for designing the shape of the ceiling. Second stage is reflecting daylight from window to concave wall-ceiling collector. Third stage ,is reflecting daylight from concave wall-ceiling collector to the rear interior space.

Keywords:
illumination, glare, daylight, collector, transporter, distributor, inclination angle, profile angle, incidence angle, reflective angle .

1-Introduction

Day lighting within interior space is the controlled admission of natural direct sunlight and diffuse skylight. Day lighting is a fundamental passive design element that can be employed as both: a primary mean of ambient light and as an energy efficiency strategy within interior space. Benefits of daylight within interior space, if utilized correctly include :increased occupant satisfaction and comfort, increased psychological and physiological health benefits, increased productivity, and reduce both electric energy consumption and electromagnetic pollution and glare(2,3). Different previous architecture strategies as light shelves(8) ,light pipes and light tubes (2,5) were used to capture natural daylight from outside to illuminate the inside of the building without glare. These strategies developed new technological tools to carry day light to rear and /or deep interior space of the building. The main principal in those tools was to collect the sunlight and reflect it through the horizontal and /or vertical reflective tubes placed exteriorly.

There exists almost no research studies based on using interior tools such as the ceiling or wall shape to carry daylight without glare to rear interior space.

The purpose of this paper is to explore and discuss the role of interior ceiling shape to provide simple and cheap interior design procedure, using the daylight fluxing through the window to bring daylight without glare to the rear interior space far from the window.

This study is based on using the window reflector pane system for bringing daylight and reflector pane system for bringing daylight and reflecting it to ceiling direction depending on mathematical relation ships between the sun profile angle and the pane inclination angle then reflecting it to rear interior space by using the shape of interior ceiling.

Daylight interior design process is typically preferred in areas that are most heavily occupied for extended periods during day time such as large gathering areas e.g.: library rooms, areas in clubs and restaurants, computer rooms, school rooms,….etc.

Statement of the Problem:

illuminating the rear interior spaces with electric light during daytime causes, the following negative results:

- Increase in electric energy consumption and electromagnetic pollution.
- bad impacts on: health, comfort and production for occupiers the spaces.

Objectives:

- Bringing daylight without glare to the rear parts of the interior space during daytime by adopting an easy and cheap interior design process to replace artificial electric light.
- Achieving the benefits of health and comfort for occupant, increasing productivity, and decreasing energy consumption and electromagnetic pollution .

2-Methodology:

The quantity and quality of sun-rays fluxing through window is characterized by variability according to orientation and seasons as a result of variability in the profile angle of sun-rays (fig 2b). (fig1 a,b)(3,6) For example, south direction sunlight is strong and ideal ,with large profile angle in winter because the sun is low so sun-rays are deeply extend from window to interior, while in the summer sun-rays are shortly extended inside window because sun is high and has small profile angle (4). This paper considered an interior design process to shows how to manage this variability to obtain an optimal value of bringing daylight for the interior parts in the space which are rear from window. The process will take place through the following steps:

1-Redirecting daylight rays from window to a reflective concave wall-ceiling collector by using window reflective panes system. This system is adjusted according to a mathematical relationships between the inclination angle of the panes and the profile angle of sun –rays to obtain optimum concave wall-ceiling collector, optimum length between any two successive window panes and number of panes which are used to cover the window area. These optimum choices has the purpose to achieve the maximum quantity of daylight arriving the rear interior space.

2- Redirecting daylight rays from collector to transporter then to distributor by successive reflections of daylight through ceiling tubes which lies interior the hollow space between double reflective surface ceiling.

3- Redirecting daylight by reflection from distributor down to the rear interior space.

For this daylight interior design process, the interior designer must know each of the occupant's activities comfort criteria ,the importance of using daylight for this activities as well as the frequency and the time duration each day that the occupant occupies this part of the interior space.

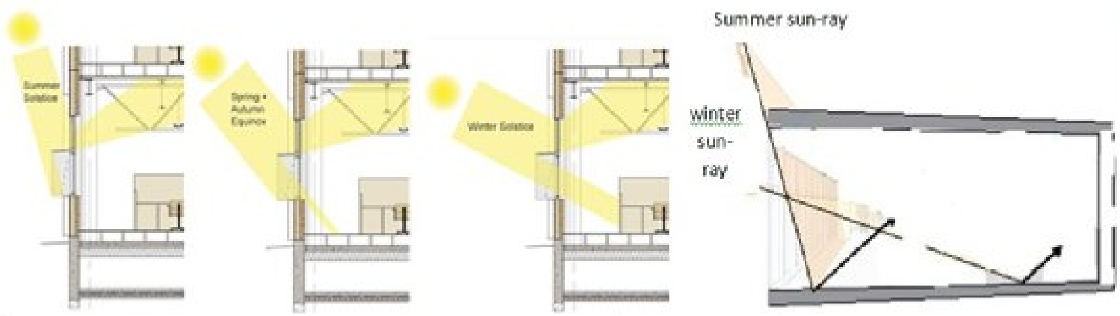
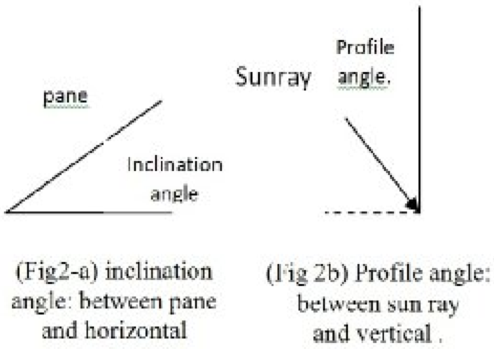


Figure 1 a,b Entrance of sunrays throuh interior space depends on sun elevation which occures of differs according to season variation (3,6)



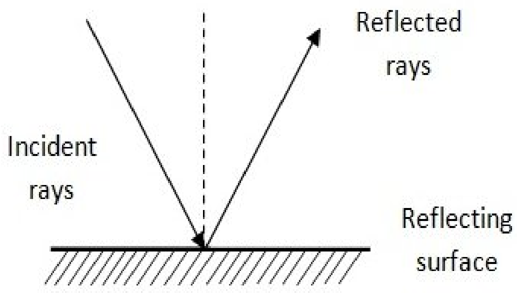


Figure 3a A sample of specular reflections on a planes surface; incidence ray angle= reflected ray angle (7)

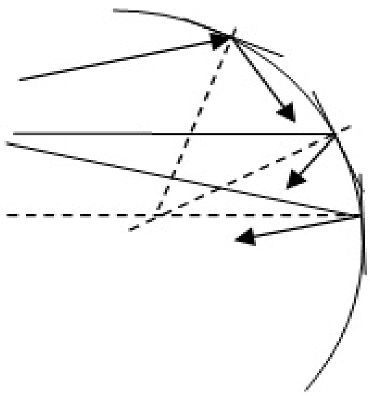


Figure 3b A sample of specular reflections on concaved surface (7)

The procedure is based on three stages:

<u>First stage: Designing the shape of ceiling (fig4)</u>

The ceiling is composed of two thermally insulated upper and lower surfaces A& B ,forming in between a hollow space C. The two surfaces of the ceiling ceilings A& B are covered internally by specular reflective material (fig 3). D is a concave area that covers the intersection line of both the window wall F and the upper ceiling surface. A (fig4,6) From the window side ,the lower surface of the ceiling B is smaller in area than upper surface of A the ceiling, such that the concave area D is uncovered from below, hence D can recieve the sun-rays reflected from the window panes (fig 5). The hollow space C, surface A and surface B are divided into a successive number of ceiling tubes and so each tube is covered from inside by a specular reflective material. Each ceiling tube consists of three successively joined parts : **rays collector** which is part of the concave area D thus having a concave shape& opened from the lower part, then rays **transporter** which is a part of the hollow space between surface A and surface B at last **rays distributor** at the end of the transporter which has a concave shape opened from the lower part. The lower surface B at the rear part of the space has several spots at the sites of the distributors, from which daylight passes downwards to illuminate the place (fig7).

<u>Second stage: Reflecting daylight from Window to wall-ceiling area D:</u>

The window is covered by reflective panes system that utilizes an alignment of insulating glass panes ,each of which is covered by secular reflector material (Fig 5),thus allowing all sun-rays fluxing on panes to be reflected towards the ceiling.

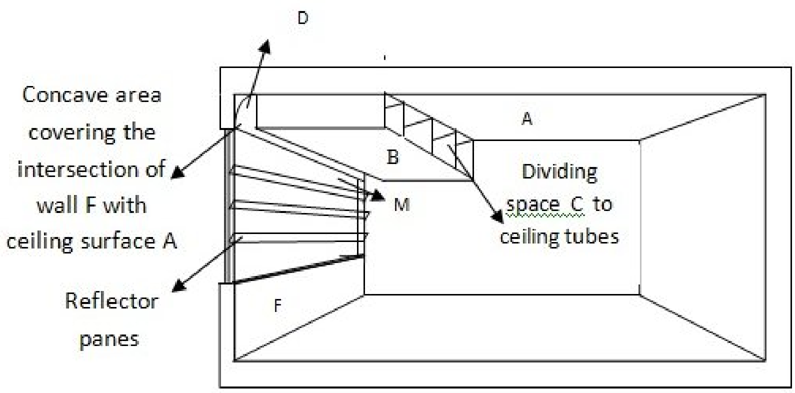


Figure 4 A perspective sector to show the ceiling design

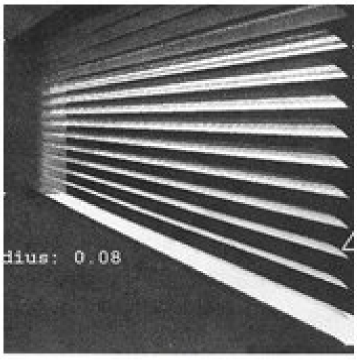
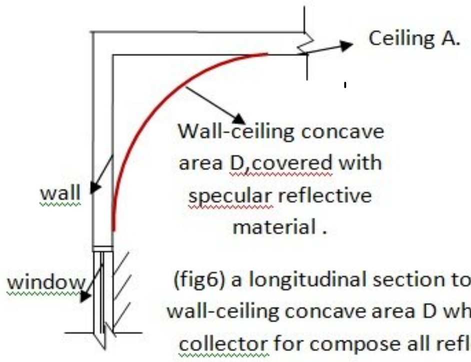
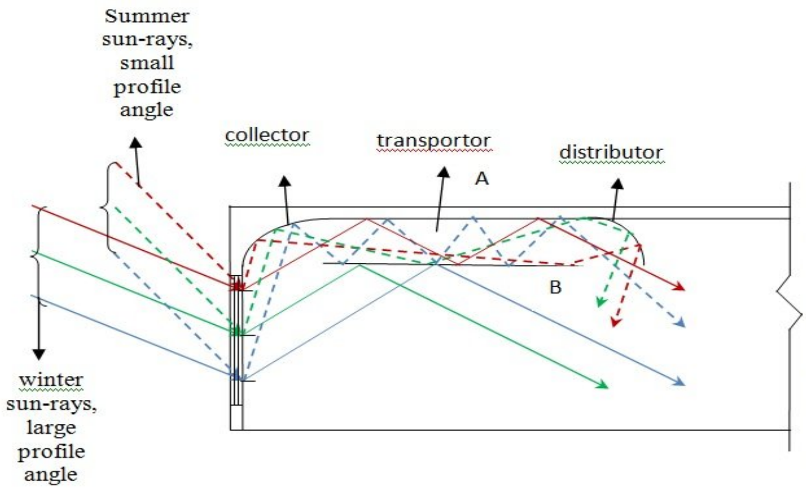


Figure 5 Window reflective panes system



(fig6) a longitudinal section to show wall-ceiling concave area D which is a collector for compose all reflected window sun-rays.



Fig(7) Longitudinal section giving comparison between the direction of the reflected sun-rays for small and large profile angles using horizontal window-panes (inclination angle=0).

The window horizontal reflective panes reflect sun-rays towards the concave area D for small profile angle (summer season), while for large profile angle (winter season), the panes reflect sun-rays towards ceiling, but not necessary on D. (fig7)

In what follows ,we solve the challenge which guarantee that ,in all seasons ,sun-rays fluxing from outside on window panes are always reflected on the concave area D, which compose all the collectors of the ceiling tubes. In the following, let ϕ be the sun-ray profile angle, while ɵ be the inclination angle of the window reflective pane. Let q be the point of intersection of the first reflective pane from above with the vertical axis of the window. Let n be the point of intersection of the extension ceiling surface B with the vertical axis of the points n and m are the two end points of vertical curve D window. M is the fixed vertical distance between points q and point n. E and T are, respectively, the vertical and horizontal length of the opening of the ceiling tube collector. S is the width of the reflective pane, while L is the distance between any two successive panes. N is the number of panes covered window area. p is the point of intersection of the reflected sun ray from point q to Collector D .Angle (ϕ-2 ɵ) is the angle between vertical and reflective sun-ray pq .Variable t is the horizontal distance from point p to the vertical side of angle (ϕ-2 ɵ) & variable e is the vertical distance for point p to extension of ceiling surface B, and so variables (t,e) satisfy the relation $0 \le t,e \le T,E$. To guarantee that the reflected sun-ray pq directed towards D (fig 8 a,b) angle ɵ must satisfies the following:

1) $0 \le ɵ \le ϕ/2$: since (ϕ-2 ɵ) ≥0 and ɵ =[ϕ-(tan^{-1}(t/(M+e))]/2 : since tan(ϕ-2 ɵ) = t/ (M+e)

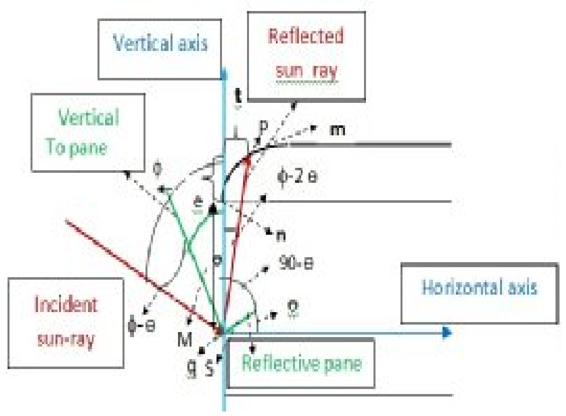


Figure 8a

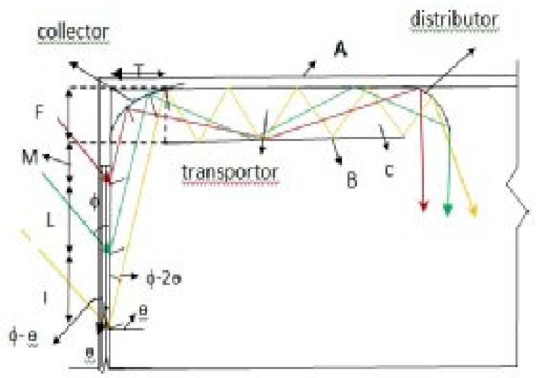


Figure 8b

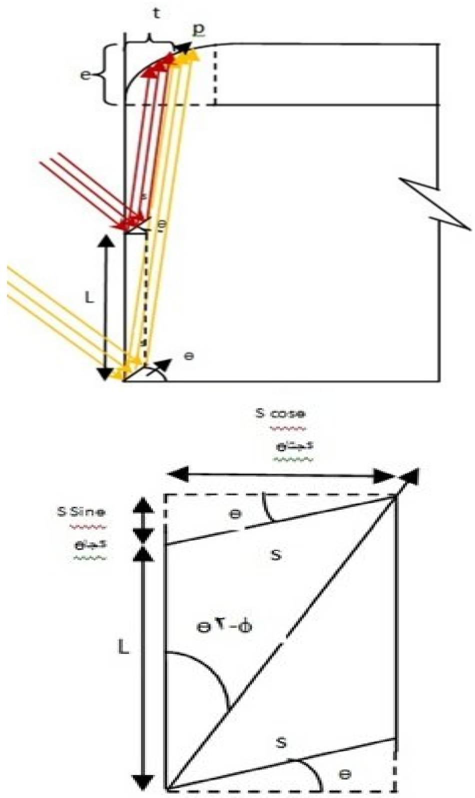
Figure 8a,b Logitudinal section show how to prove the mathematical relation (1) between the profile angle of sunray and the inclination angle of relective pane to guarantee that the refletive sun –ray pq from windows pane directed towards collector D.

2) To guarantee that for any two successive panes the upper pane does not prevent reflected sun-rays from lower pane to reach collector D, the distance L must satisfy the relation L= [S cosɵ /(tan(ϕ-2ɵ))-S sinɵ] since tan (ϕ-2ɵ) =S cosɵ / (L+S sinɵ) (fig8c,d). Any other different value for L does not cause any error in the method but only prevent some of sun-rays to arrive D by reflecting them down to floor and so decrease the quantity of daylight illuminating the rear interior space.

Third stage: Reflecting sun-rays from the wall-ceiling area D to rear interior space :

The third stage begins from the collector of the ceiling tube (part of D) which reflects sun-rays to the transporter, where they travel by successive reflections along internal lower and upper reflective surfaces to settle the concave distributor ,which in turn reflects the sun-rays downwards to illuminate the rear interior space (fig 8b).

There are loss of sun- rays during successive reflections through the transporter which is due to the absorption of the reflective material results .To avoid that, we reduce for each sun-ray the number of successive reflections inside the transportor, that mean increasing the length of each successive sun-ray reflection. This implies that point p must lie on the most concave part of the collector which is the middle part a b for the concave area D. This can be done by decreasing the angle (ϕ-2ɵ) and so increasing the inclination angle ɵ (fig9 a,b,c). Hence, the optimum value for the inclination angle ɵ= [ϕ-tan^{-1}(t/(M+e))]/2,is that for points p≡(e,t) lying on the middle part ab of the collector where $0<t_a<t<t_b<T$, $0<e_a<e<e_b<E$. for this optimum choice for angle ɵ and also interval a b, downloading of sun-rays through the distributor to the interior rear space is compact (fig 9 a,b) since sun rays are reflected from the corresponding curve c d which is also in the middle of the concave curve . Ex: choosing the concave collector curve to be a quarter of a circle with center c and radius r, the central part ab where a≡(t_a,e_a)& b≡(t_b,e_b)(fig10c) where t_b=r-rcos 67.5,e_b=r sin67.5& also t_a=r-r cos22.5 and e_a=rsin22.5



(fig8c,d) Two longitudinal sections to show how to calculate the distance L between any two successive panes to guarantee the arrival of all sun-rays to D.

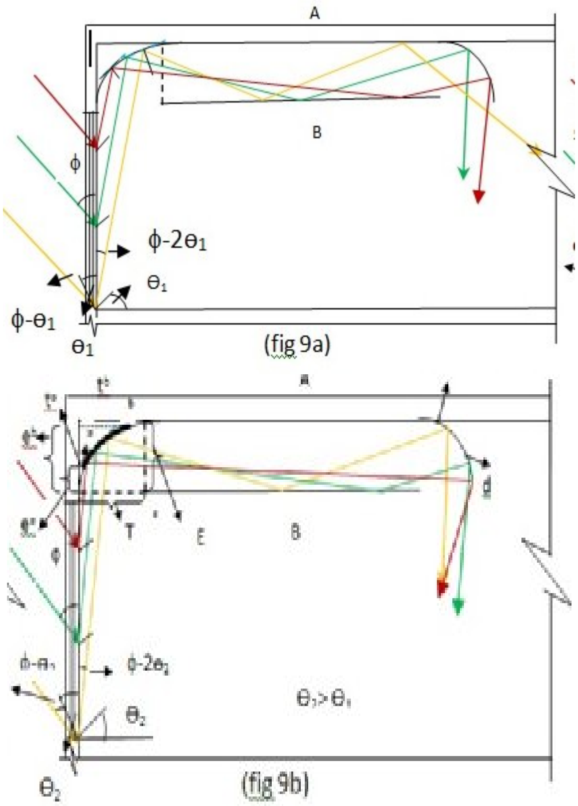


Figure 9 a,b Longitudinal section showing that the choice for the curve ab on collector leads to reflected sun rays length inside transporter, then curve cd on distributer.

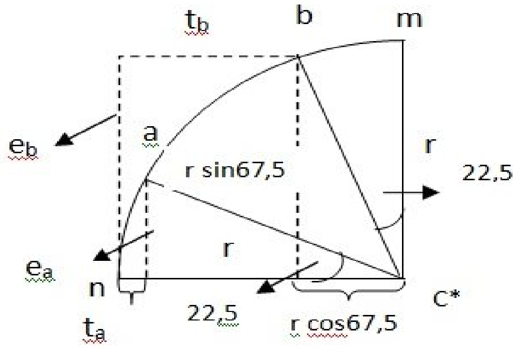
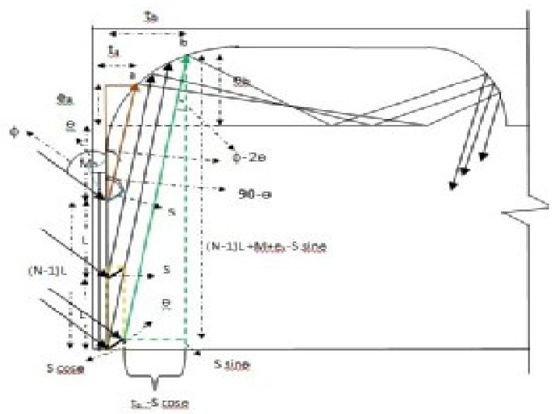


Figure 9c Longitudinal section to show how to determine the curve ab in case D is quarter of a circle with center c* and radius r

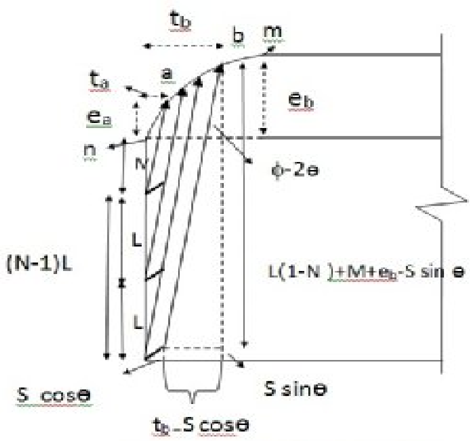
3) Using the values for ɵ,L point a, b we can evaluate the optimum value for N: $N=[1+M(t_b-t_a)-S(M+e_a)\cos\theta - t_a(e_b-\sin\theta)+e_a t_b]$

Since $\tan(\phi-2\theta)=(t_b-S\cos\theta)/((N-1)L+M+e_b-S\sin\theta)=t_a/(M+e_a)$ (from green triangle and orange triangle)(fig10a,b)

Note;[positive number]= the integer part for this number.



(fig 10 a)



(fig 10 b)

(fig 10 a,b)a longitudinal section to show how to evaluate value of N.

Steps to follow for the application of the method:

The performance of this method implies using an optical unit to measure the daily change in the profile angle ϕ,and a computer to evaluate the corresponding values for θ, L and N. The points $a \equiv (t_a,e_a)$ and $b\equiv(t_b,e_b)$, also the distance M and S are fixed chosen values independent of the change in ϕ. The following are the automatic steps performed daily independent of the occupant of space.

a) measure angle ϕ by using an optical unit,

b) calculate angle θ from the relation $\theta=\{\phi-\tan^{-1}(t_a/(M+e_a))\}$.

c) evaluate L from relation $L=[(S \cos\theta/\tan(\phi-2\theta))-S \sin\theta]$.

d) evaluate N from: $N= [1+M (t_b -t_a)-S (M+ e_a) \cos \theta - t_a (e_b-\sin\theta)+e_a t_b]$.

some factors positivety affect daylight arriving to rear interior space:

1-The direction of the window and the direction of the sun profile angle. For example, sunlight coming from south direction is strong and idea. Also the noon of month December and june give the maximum luminous intensity of the year.

2-The larger the area of the window, the larger is the quantity of sun-rays reflected on the collector, the larger is amount of daylight reflected from the distributor.

3-The optimal choice of the collector area, the optimal number of panes N and the optimal distance between any panes two successive panes L, put the maximum amount of sunrays directed to collector and so for distributor .

4- covering walles and ceiling areas with reflective material (Ex. white glossary paint) increase luminous intensity distribution in the rear interior space.

5- The area directly under the distributor has the strongest intensity, while it decreases gradually by being far from distributor.

Interior design elements improve the performance of the Process:

Interior surface finishing

The design elements, color, shape, texture and light complete each other in finishing the interior surfaces (walls ,floor ,ceiling) which might be opposite, around or adjacent to the daylight distributors .Indeed design elements can serve a crucial role in receiving and reflecting daylight that travels into the space thus reducing glare & balancing the brightness in the space ,as well as reflecting light deeper into space to give visual comfort.(4)

Furniture placement:

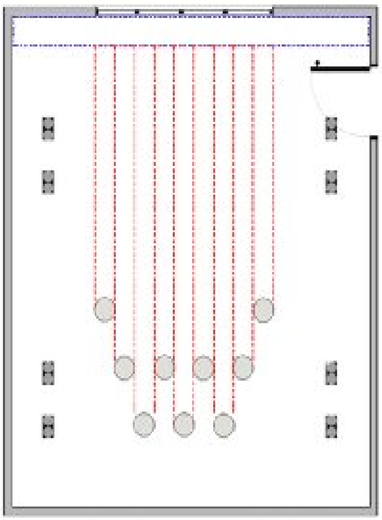
The activity of the space occupier and the quantity of illumination required must be known in advance to place furniture according to activities comfort requirement;

For activities that need daylight with almost no glare, such as an office with fixed visual tasks, furniture is placed in areas under the ceiling distributers. For activities that doesn't need too much daylight (restaurants, patient's room) the furniture is not necessary placed under the distributors.

3- Example for the Daylight Interior procedure:

A meeting room with large area only one south –placed window, where daylight be fluxthrough it for a longtime. The room is functionally divided into two parts : the first part, is a common area near the window illuminated by direct window daylight coming from the uncovered lower part of the window. The second part, is the rear part of the room far from the window which includes a meeting table ,and is illuminated by the reflected window daylight without glare as described in this paper.(fig11a,b)

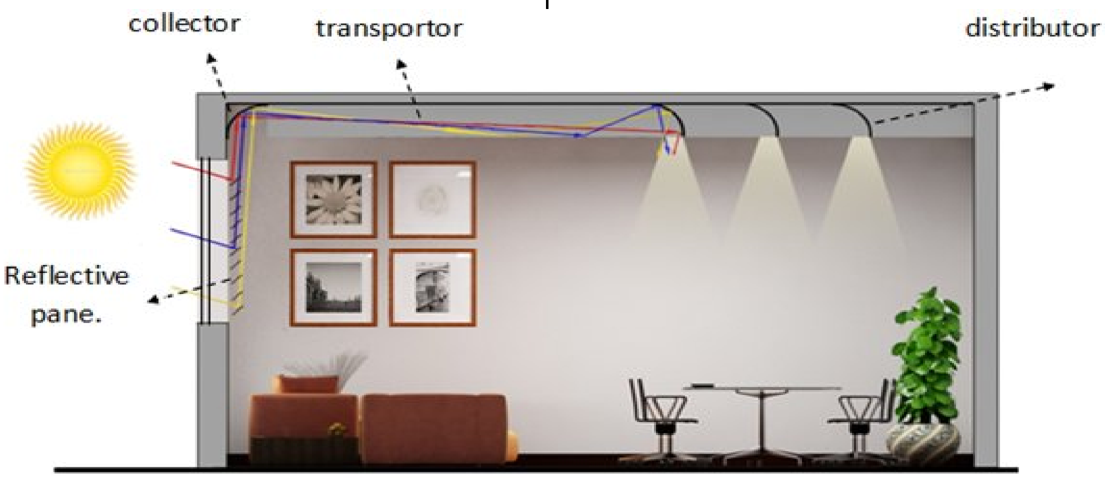
(fig 11a) horizontal plane shows the distributiors of 8 light tubes to illuminate the rear area of meeting room.



(fig 11b) horizontal view for both the commen area illuminated by direct daylight and meeting area illuminated with reflected daylight without glare.

(Fig11c,d)is a direct and side view for concave wall-ceiling solar light area D as a result of reflection of sun-rays by window panes system. Two rows of left and right electric spot -light exist for night illumination

(fig 11 e)a picture for the room including the nine unshown ceiling tubes with nine distriputors:2,4,3 lying on three successive different rows.



(Fig11 v): Longitudinal section for only three successive ceiling tubes from total nine with different length from the window. The three distributors extract the reflected daylight without glare towards the meeting table which is far from the window

Conclusion

1. The method is based on a variety of factors, including, climatic conditions, seasonal characteristics and even cultural differences.
2. The method introduces an easy and low cost interior design process essentially based on using a new technological tools

as window reflector panes system, a specially designed ceiling and a number of interior ceiling tubes to carry daylight without glare from the exterior environment to illuminate the rear parts of interior environment during day time.

3. the process takes into consideration during the early stages the window s orientation and the number of ceiling tubes which will be used to achieve the maximum benefits of the process.

Results :

1- The method is an interior design solution that coordinates between the static interior space, the dynamic exterior environment (natural daylight) and human to emphasize the positive effects of using daylight in interior space .

2-The method is an eco-interior design method since it uses eco-interior design element, the sun ,to illuminate the rear interior spaces with minimizing the negative impacts by reducing electric pollution and electric energy consumption ,also maximizing the positive impacts by improving occupant comfort, health, and productivity.

3-The method provides flexibility in the furniture placement to allow the required variability in occupant tolerance and luminous level.

Recommendations :

1-This method implies that the building should be located according to gain maximum daylight by considering the window's orientation , number, size and location, so there must be coordination and cooperation between architectures and interior designers concerning the architectural window's number – size- orientation and placement to ensure that daylight concepts and ideas will be able to be carried through the daylight interior design process .

2- Cooperation between the interior designer and the occupant as regards the occupant's needs, and the required interior level of illumination, is a must ,so that activities comfort requirements may not be wailed.

3-There must be a comparative study between the electric stationary system and this daylight dynamic system, as regards the cost and performance.

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References :

١-Day J ,Theodorson J & VanDen Wymelenberg K., 2012, Understanding controls, behaviors and satisfaction in the daylight perimeter office: A daylight design case study, Journal of Interior Design ,Volume 37,(1), pages 17-34.

٢- Jarana Yudha I K, 2005 The design of daylight transporting systems for deep space Illumination. M.SC. in Architecture State University, Faculty of Virginia Polytechnic Institute.

3- Sorrento L, 2012 A natural balance: Interior design, humans, and sustainability. Journal of Interior Design ,Volume 37(2).

4- Reinhart C F, 2002 Effects of interior design on daylight availability in Open Plan Offices, National Research Council Canada, Institute for Research in Construction, Otawa,Canada.

5- http://en.wikipedia.org /wiki/light-tube.

6- www.wbdg.org/resources/daylighting.php

7- http;//spie.org/documents/publications/00 step%20module 2003.pdf Leno S.Pedrotti .L. : Basic Geometrical optics(fundementals of photonics) C.RD Waco,Texas.

8- www.public.asu.edu/~kroel.

9-,http;//www.trhamzahyeang.com/ features/img/light%20 pipe%20paper.pdf