Proposal Daylighting Design Using an Advanced Light Pipe System
Case study: Deep-Plan Design Studio in Mansoura University

مقترح لتصميم الأضاءة الطبيعية بأستخدام نظام الأنابيب الضوئية المتقدمة
لإضاءة صالات الرسم ذات المساقط العميقة بجامعة المنصورة

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ملخص البحث

يعد الحد من استخدام الوقود الحفرى، والانخفاض المصاحب معه فى انبعاثات غازات الاحتباس الحرارى، أمرا حيويا لتحقيق ترشيد استخدام الطاقة باستخدام الإضاءة الطبيعية للإضاءة عوضا عن الإضاءة الصناعية فى المبانى. وقد كما يعد استخدام المساقط العميقة هو الاسلوب الشائع فى تصميم المبانى وذلك لمرونة استخدام المساقط بالاضافة الى الفوائد الاقتصادية المترتبة على زيادة نسبة مساحة هذه المساقط. وبناء عليه، فإن المساحات البعيدة عن النوافذ يصعب إضائتها طبيعيا عن طريق فتحات النوافذ فهي تعتمد اعتمادا كليا فى إضائتها على الإضاءة الصناعية .

ويطرح هذا البحث اقتراحا لإعادة تصميم الاضاءة الطبيعية داخل صالات الرسم المعمارى بجامعة المنصورة بجمهورية مصر العربية، كدراسة حالة عن طريق استخدام نظام الأنابيب الضوئية الافقية المتقدمة لإضاءة مسطحات الفرغات العميقة، وقد تم لعمل ذلك استخدام برامج المحاكاه كالإيكوتكت لتحليل وحساب مستويات شدة الإضاءه داخل فراغات صالات الرسموعمل الحسابات والقياسات اللازمة لذلك .

Summary of Research:

The reduction of fossil fuel consumption and the associated decrease in greenhouse gas emissions are vital to combat global warming and this can be accomplish by energy conservation by use of natural light to provide illumination in buildings. Deep-plans are a common practice in many building design, and large open plans have become the preferred due to the flexibility of the space and economic benefits achieved from maximum plot to gross floor area ratios, Consequently, the deep core areas of these buildings cannot be naturally illuminated by side windows, and depend entirely on electricity lighting for illumination. This paper is a proposal to redesign daylighting in universal design studio space in Mansoura University, Egypt, by using an advanced horizontal light pipe system to enhance natural illumination of deep-plan area, Ecotect simulation program was used to simulate the required design configurations.

Keywords:
Daylighting, daylight systems, light pipe, design studio, deep-plan.

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1. INTRODUCTION

Power Benefits of Daylighting in education buildings are well known. In addition to energy conservation, natural light has positive physiological "regulation of the circadian rhythms" and psychological effects on the occupants of buildings. However natural light in the core of deep plan education buildings is nonexistent

And this is due to thermal and economical reasons and spatial requirements of the workplace, deep-plan buildings have become a common practice in many buildings design. This design "floor plans of >8m depth" results in dark cores since side daylight passively reaches only up to 4m distance from the windows. Consequently, deep plan buildings depending entirely on electrical lighting for illumination[1].

The requirements of daylighting in design studios: the average of lighting levels Should not be less than 1000 lux, that amount of lighting is high compared with other activities to twice the amount of lighting available in the library, three times the amount of lighting in the classroom, and five times the amount of lighting in residential buildings. Also the average of daylight factor must not less than 6%[23].

Previous research has shown that light transport systems "light pipes" represent a possible solution for natural illumination of the core of deep plan buildings by means of piping light from the building envelope to be distributed in the interior space.

2. AIMS OF THE RESEARCH

This research aims to study and analyze the advanced daylight systems for deep-plane education buildings and there's application, to redesign daylighting in universal design studio space in Mansoura University. And to Emphasize the role of renewable energies, (daylighting in particular), and fostering the effective role of architecture in disseminating and developing sustainability buildings.

3. METHODOLOGY

Studying the different daylighting systems, their applications, and the requirements of daylighting in design.

Making a model for the design studio by using simulation tools to analyze the distribution of lighting levels.

Redesign daylighting in designed studio using Light pipe system.

Comparing between the three cases, in terms of lighting levels, energy consumptio.., and total cost over 20 years, and they are:

- Case 0): Daylighting Levels, from the Side windows.
- Case 1): Overall Light Levels, from the Side windows and illuminates.
- Case 2): Daylighting Levels with light pipes.

SIMULATION TOOLS,

The Author uses the following modeling and simulation programs to form and determine lighting levels and energy consumption:

- AutoCAD (2D-3D)
- ECOTECT

4. BACKGROUND

The Numerous daylight systems have been developed to improve natural illumination in the deep core of buildings. Innovative daylight systems can be generally divided into two groups:

1) Light guiding systems, which redirect natural light "direct and diffuse" to the core

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[1] Garcia Hansen, V., Edmonds, I. and Hyde, R., "The use of Light Pipes for deep-plan Office Buildings. A case study of Ken Yeang's bioclimatic skyscraper proposal for KLCC, Malaysia". In 35th Annual Conference of the Australian and New Zealand Architectural Science Association Victoria University of Wellington, New Zealand, 2002.

[2] Energy Conservation and Planning Agency, "Directory of architecture and energy",Cairo, July 1997

[3] Society of Light and Lighting , "Code of Lighting-Butter Worth - Heinemann-Oxford" , Boston, 2002.

of the building up to 6 to 8 meters, by means of reflection, refraction or deflection "e.g. light shelves, louvers "Fig. 1".

2) light transport systems, which can reach further distances than light guiding systems by means of channeling sunlight "generally the direct component of sunlight" through guides from the building exterior where it is collected, to the interior to be distributed "e.g. light pipes "Fig. 2".

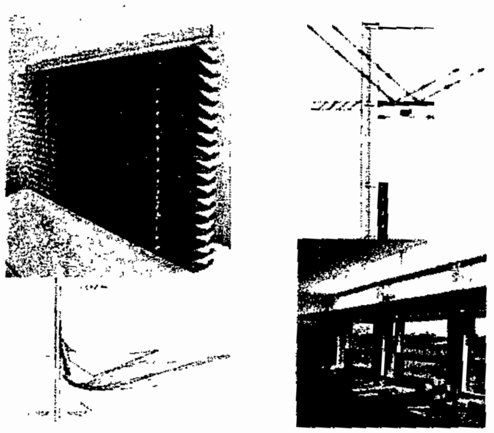

Fig. 1. Examples for light guiding systems.

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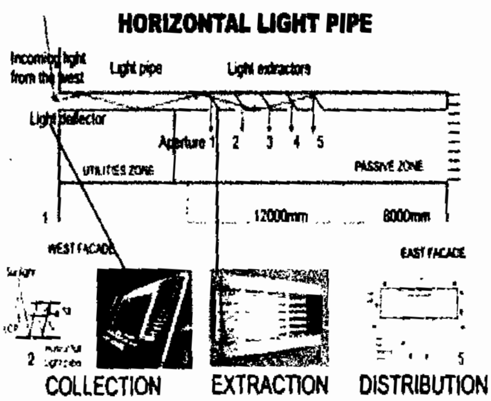

Fig. 2. Example for light transport systems.
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Benefits of light transport systems include:

1) The potential of integrating artificial and natural light into one system.

2) Providing a centralized lighting system in the building that pipes light to distribution devices, there by replacing many electrical fixtures and cabling.

3) Eliminating infrared and ultraviolet radiation from sunlight.

4) Reducing heat in air conditioning areas.

Light transport systems consist of three major components: 1) light collection "a device to capture sunlight", 2) light transport "guiding material", and 3) light distribution "extraction and distribution within the space". The general classification of light transport systems depends on the material used to transport the light. Current light transport technologies include the following "Fig. 3":

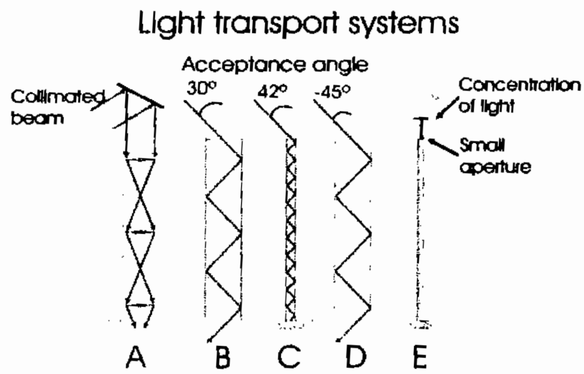

Fig. 3. Different light pipe technologies. A: Lenses, B: Hollow prismatic pipes, C: light rods, D: Mirrored light pipes and E: Fibre optics.
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1- Fiber optics are highly efficient systems that transport light by total internal reflection. They are usually made of silicate glass or plastic. Its use has been constrained to decorative applications and artificial light due to cost. Light needs to be highly concentrated before entering the fiber, as the fiber acceptance aperture is very small. Therefore, when is used for daylighting applications, the optical fiber systems need complicated heliostats to concentrate daylight. The efficiency of the system depends on the length of the fiber and not the width. The attenuation values are from 0.1 dB m^{-1} to 0.6 dB m^{-1}, which means light traverses for 18 to 30 m before loosing half of the intensity. Fibers are only 6mm wide and can be 40m in length[4]. Recent studies are exploring the use of luminescent solar concentrators to absorb the natural light emitted as fluorescent light and then transport the fluorescent light through flexible light guides made from low cost material as a more economical alternative to fiber optics.

2- PMMA Transparent guides: polymethyl methacrylate or PMMA are transparent acrylics materials that have been used for its transmittance properties and relatively low cost. Light is transporting by total internal reflection. The guides can be light rods or hollow cylindrical pipes. As a light rod, the system can have an efficiency of 50% for a pipe of an aspect ratio "length: 1200mm to width: 50mm" of 24[5], but it has only been tested for small scale buildings.

3- An arrangement of lenses and mirrors are also used to transport light. Lenses have good transmission characteristics and they are capable of maintaining a concentrated beam of light. This system does not need a guide. The high cost for lens-systems, however, is a problem, in addition to complications in lens mounting due to the precision required in the system. Lenses have a 92% transmittance and the spacing of lenses depends on the lens focal length. Studies have shown efficiency for the system after passing through 13 lenses of 28%[6].

4- Prismatic pipes are hollow structures with transparent acrylic walls containing precise right angles that transport the light by total internal reflection. Currently, the device requires complicated daylight collection systems due to the range of the input angles "~28°/30°" needed for the light to be guided through the pipe. Research has shown efficiencies on the order of 30% for pipes of aspect ratios of 30 when used as a daylight solution[7].

5- Hollow mirrored pipes, which transport the light by multiple specular reflections, are relatively cheaper than other light transport systems and potentially have a wide application in building design. Efficiency depends on: area and geometric form of the pipe, reflectivity of the material "85%, 95%, 98%", and directional properties of the light source. Well-collimated sunlight could produce an efficiency of 50%[8]. Mirrored pipes have been coupled with different light system collections "i.e. anidolic systems, laser cut panels". Anidolic ceilings are devices that integrate compound parabolic collectors with a highly reflective guide to redirect light deeper into a room; they have been designed to improve illumination in buildings occurring in regions with predominately cloudy conditions Previous work has suggested that laser cut panels "LCP" coupled with mirrored pipes could be a simpler, more cost-

[4] Ayers, M. J. and Carter, D. J., "Remote source electric lighting systems: A review". Lighting Res. Technol., pp.1-15, 1995.

[5] Callow, J. M. and Shao, L., "Air-clad optical rod daylighting system. In Tropical Daylight and buildings", Ed, Singapore, N. U. o., Singapore, 2002.

[6] Bennett, D. and Eijadi, D., "Solar optics: Projecting Light into Buildings", AIA Journal, pp.69-74, 1980.

[7] Aizenburg, J. B. , "Principal new hollow light guide system "Heliobus" for daylighting and artificial lighting of Central Zones of Multi Storey Buildings", Right light,pp.4, 2, 239-243,1997.

[8] Ayers, M. J. and Carter, D. J., "Remote source electric lighting systems: A review". Lighting Res. Technol., pp.1-15, 1995.

effective daylight solution for sunny climates. Overall performance of a mirrored light pipe coupled with LCP of an aspect ratio of 30 is 20% [8][9]. This paper explores the benefits and limitations of mirrored light pipes "horizontal and vertical" coupled with laser cut panels as a simple solution for the enhancement of natural illumination of deep plan buildings.

5. APPLICATION OF LIGHT PIPES SYSTEMS

The main reason for deep-plan buildings depending largely on electrical light for illumination is that daylight levels decrease with distance from the window, so that a disproportionate amount of daylight/solar radiation must be introduced into the front of the room to achieve small gains in daylight levels at the back of the room. A greater distance from windows is not the only reason for dark cores in deep-plan buildings.

Other causes for core dependence on artificial light for illumination are:

1) Large differences in illuminance levels between perimeter and central areas due to side lighting, creating problems of bright and dark zones.

2) Large window areas resulting in glare problems, hence the need for blinds and therefore decreasing daylight in interiors.

3)Placement of small offices along the perimeter that block light from side windows to the interior.

In these cases, horizontal light pipes could be used in order to improve natural illumination "Fig. 4". In addition, if facades are not oriented correctly, or are overshadowed by adjacent buildings, vertical light pipes could be used instead, depending on the height of the building "no more than five floors" "Fig. 5".

[9] Edmonds, I. R., Moore, G. I. and Smith, G. B. , "Daylighting enhancement with light pipes coupled to laser-cut light-deflecting panels", Lighting Res. Technol., pp.27, 27-35, 1995.

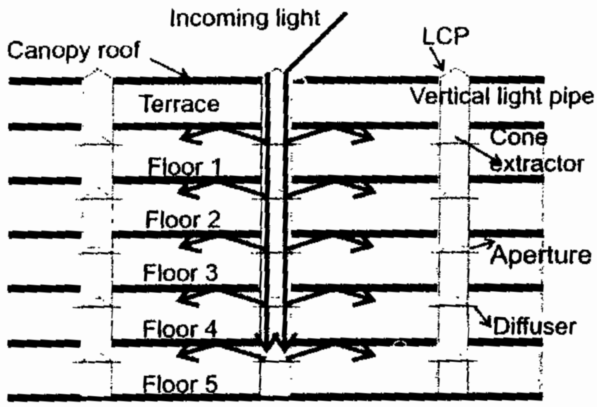

Fig. 4. Vertical light pipe proposal.
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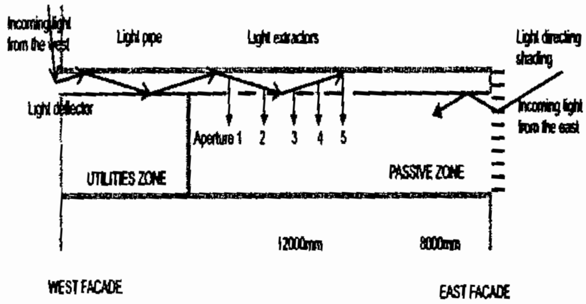

Fig. 5. Horizontal light pipes proposal.
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6. CASE STUDY

Nano-fillers is a case study located in Mansoura city "latitude 31.00°, longitude 31.4°", and it's sun path diagram shown in "Fig. 6". Which is design studio "B" located Mansoura University, faculty of engineering, department of architecture, in north laborites building, third floor. The building is double loaded, the northern zone is an electronic labs, and the southern zone is a design studios. The area of studio floor is 308 m2 "22 m×14 m", with a deep-plan floor plate of 14m, and height of the floor 3.85m "Fig. 7". 100 students and 5 stuff members occupy that. Studio southern area is naturally illuminated by side windows in the south faced "23% area" as shown in "Fig. 8". The dark rear area can't be illuminated by windows "77% area", and depend entirely on electrical light for illumination "20 illuminare", the average overail light levels from windows and illuminare 1130 lux as shown in "Fig. 9", As a college management to reduce the consumption of energy within the university facilities, the proposed was use of daylighting in illuminance, top lighting can't be used as a result of the future extension the use of the light pipes, and light pipes distributed to axial distances of 5.5 m with 4 units.

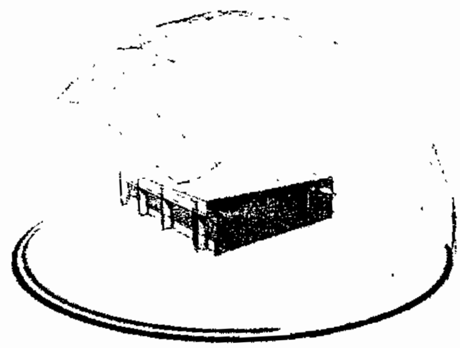


Fig. 6. Sun path diagram for Mansoura City.

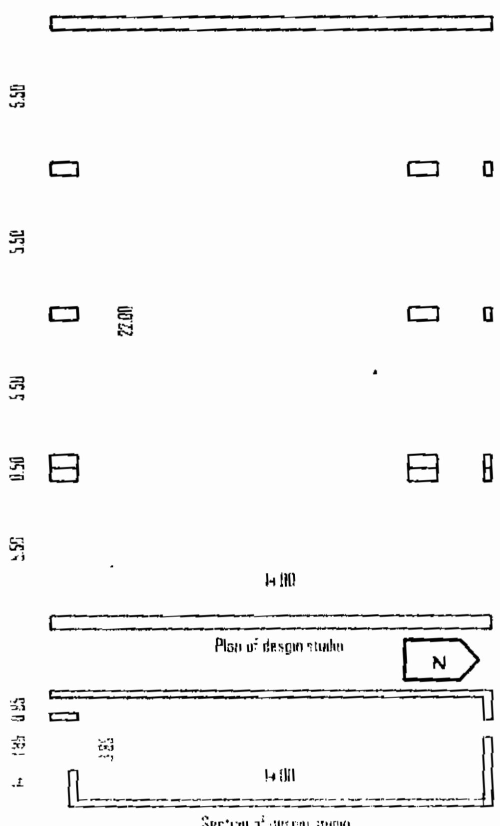


Fig. 7. Floor plan and section of studio.

Fig. 8. Daylighting Levels from windows "Case 0".

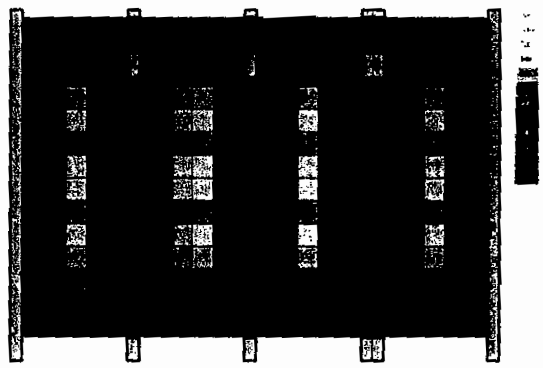


Fig. 9. Electric Light Levels.

7. LIGHT PIPES

The design of light pipes has taken from Waterfront House's light pipes, Malaysia. The performance of the long light pipes "14 meters long and 4 per studio" as shown in "Fig. 7", is enhanced with: 1) a laser cut panel light deflector at the input aperture to deflect high elevation light more directly along the axis of the pipe, 2) a light extraction system to extract the required proportion of piped light into the inner zone and 3) a light spreading plate to distribute the light away from the area directly below the light pipe and more evenly over the zone. Laser cut panel is produced by making parallel laser cuts in transparent acrylic panel – each cut becoming a thin mirror, which provides powerful deflection of off-normal light. The fraction of light deflected, Fd, depends on the angle of incidence, i, and the cut spacing to cut depth ratio, For effective light collection and deflection of incident sunlight into the light pipe the laser cut panel [10]is placed at an angle to the input aperture as shown in "Fig. 10". Incident sunlight is split into a deflected beam, "Fd", and the non deflected beam, "Fu = 1 – Fd". High elevation sunlight is deflected more axially down.

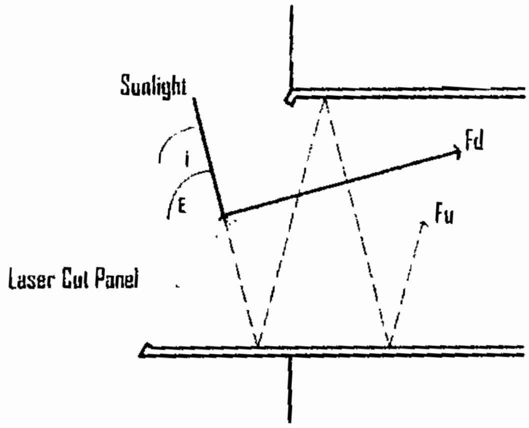


Fig.10. Detail of the laser cut panel as light collector.

The pipe makes fewer reflections in traversing the pipe than the non deflected beam. The transmission of light through the pipe is given by $T = RN$, where R is the reflectance of the pipe surface and N is the number of reflections along the pipe which bring the light to the point of interest. In the model used in this work the reflectance of the pipe material "aluminum" was 0.85. For example, if the defected beam makes two reflections before reaching an output aperture, the transmission is $T = 0.852 = 0.72$, while for the non deflected beam, for example, making 12 reflections before reaching an output aperture, the transmission is $T = 0.85^{12} = 0.14$.

In the present application the pipe input apertures are on the southern façade and sunlight enters the apertures, It is evident that the amount of light incident on the apertures and transmission of this light through the pipes depends in a fairly complicated way on the sun elevation angle and, therefore, on time of day.

As the light traverses, the pipe specified proportions of the light must be extracted at intervals along the light pipe to provide the desired light distribution "usually uniform distribution" below the light pipe. The principle of a light extraction system is illustrated in "Fig. 11", in this example; the same amount of light is extracted at each eight aperture. To achieve this, the first extractor panel is made sufficiently reflecting to deflect one eighth of the light. The second deflects one seventh of the remaining light, the third panel deflects one sixth and so on [10][11]. More complicated ratios may be derived to account for transmission loss in the pipe that occurs between each extractor, the transmission loss will vary with incidence angle of the light and hence with time of day. Therefore it is expected that the distribution of light from the light pipe will also vary with time of day.

10 Edmonds, I. R. , "Solar Energy Materials and Solar Cells, Performance of laser cut light deflecting panels in daylighting application", Lighting Res. Technol., pp.29, 1-26, 1993.

11 Smith, G. B. and Franklin, J., "Sunlight collecting and transmitting system", United States Patent, 2000.

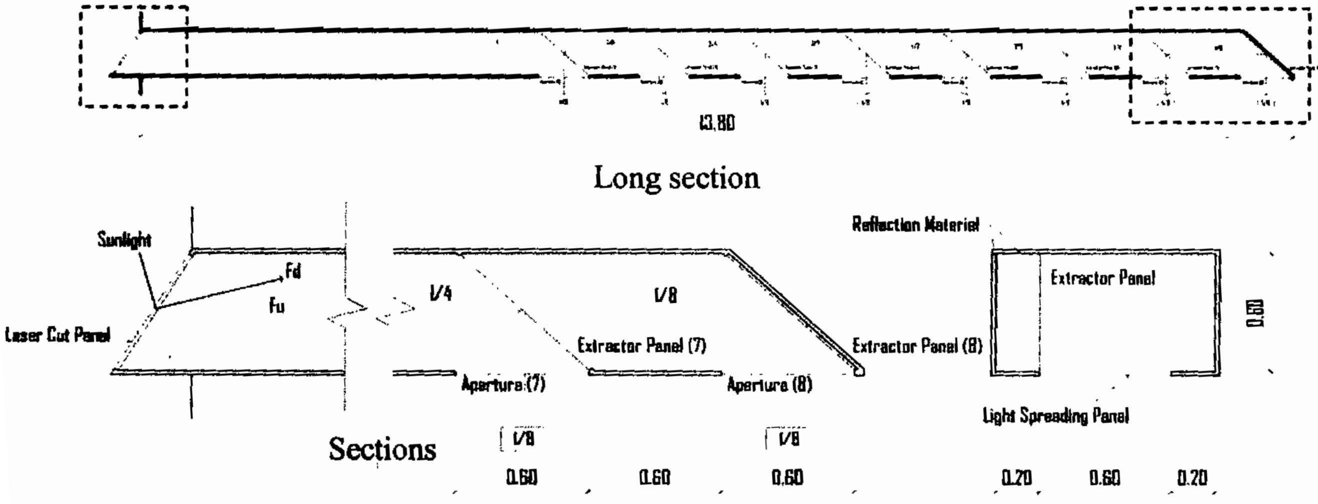


Fig.11. Detail of Light pipe.

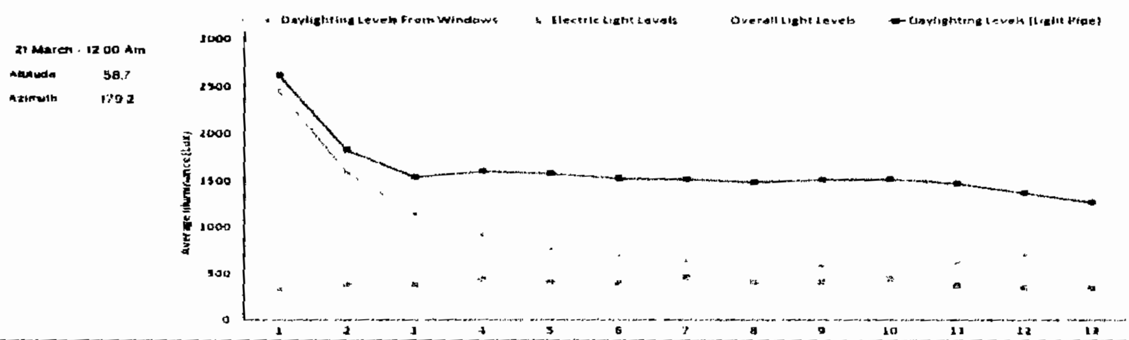
8. ANALYSIS

In our case study there are three cases will exists, and as seen from the "Fig. 12", and "table 1, 2" we can conclude:

Case 0): Daylighting Levels, from the Side windows, the average illuminance levels is less than 800 lux, the area above 1000 lux equals 22.34% of studio area, because this case does not meet the requirements of lighting level in the studio, it will be excluded from the comparison.

Case 1): Overall Light Levels, from the Side windows and illuminare, the average illuminance levels is 1130 lux, the area above 1000 lux equals 71.06% of studio area as shown in "Fig. 13", and illuminare consumed annual energy about 6480 Kwh with annual cost approximately 842.4 E£ as shown in "Fig. 15".

Case 2): Daylighting Levels with light pipes, from windows and light pipes, the average illuminance levels is 1604 lux, 98.17% of the studio area greater than 1000 lux as shown in "Fig. 14". In this case is not energy consumption for illuminance.



	1	2	3	4	5	6	7	8	9	10	11	12	13
Daylighting Levels From Windows	2461	1597	1148	932	776	695	643	604	590	600	624	709	733
Electric Light Levels	349	390	383	445	417	408	459	409	414	445	375	358	347
Overall Light Levels	2810	1987	1532	1367	1193	1103	1103	1013	1004	1045	999	1065	1082
Daylighting Levels (Light Pipe)	2619	1834	1545	1611	1582	1536	1516	1484	1512	1515	1472	1364	1268

Distance from the front window (m)

Fig. 12. Interior average illuminance levels.

Table 1. Area percentage of illuminance level.

Case	Illuminance Levels (lux) (from-to)	0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
Case0 Daylighting Levels from windows	Within(%area)	0.00	77.66	8.06	6.59	3.30	4.40
	Above(%area)	100.00	100.00	22.34	14.29	7.69	4.40
Electric Light Levels	Within(%area)	100.00	0.00	0.00	0.00	0.00	0.00
	Above(%area)	100.00	0.00	0.00	0.00	0.00	0.00
Case1 Overall Light Levels	Within(%area)	0.00	28.94	49.45	10.26	4.76	3.66
	Above(%area)	100.00	100.00	71.06	21.61	11.36	6.59
Case2 Daylighting Levels with light pipes	Within(%area)	0.00	1.83	45.42	35.90	11.36	5.49
	Above(%area)	100.00	100.00	98.17	52.75	16.85	5.49

Fig.13. Overall Light Levels (Case 1)

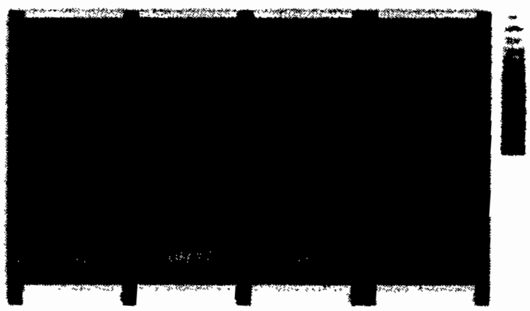


Fig.14. Daylighting Levels with light pipe (Case 2)

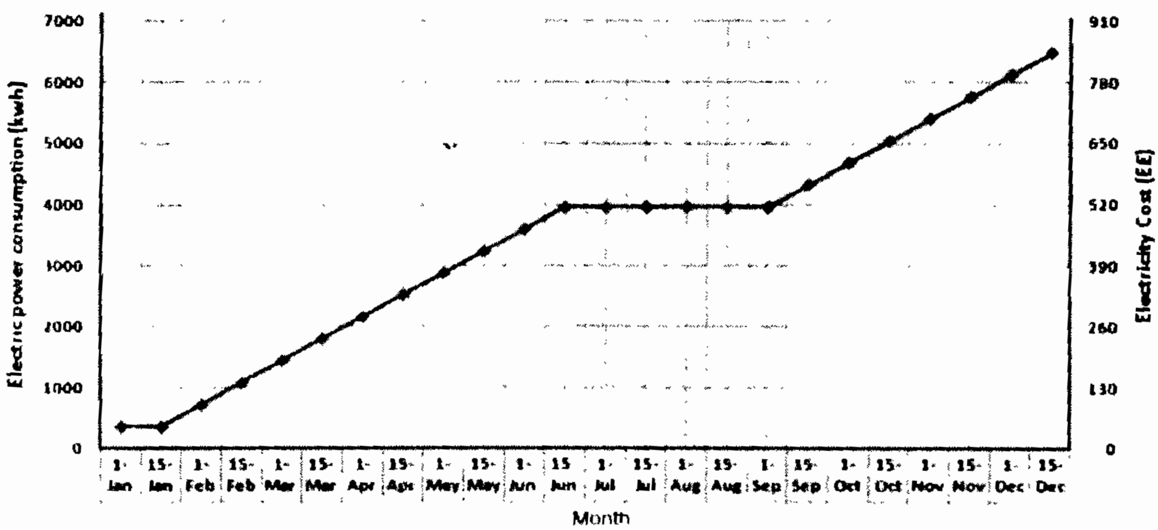


Fig.15.Annual cost and energy consumption fore electrical lighting.

Table 2: Comparison between case 1 and case2

parameters		Case (1)	Case (2)
Illuminance	Area < 1000 Lux	28.94 %	1.83 %
	Area >1000 Lux	71.06 %	98.17 %
	Average Illuminance (lux)	1130	1604
Energy Consumption (Kwh) for 20 year		129600	-
Cost for 20 year (E£)	Primary Cost	1800	2400
	Maintenance Cost	1500	400
	Energy Costs	16900	-
	Total Cost	20200	2800

9. CONCLUSION

The study find by comparing between case1 and case2 in term of the levels of illuminance, the amount of energy consumption, and cost over 20 years, as shown in Table 2,that :

- Case2 using light pipes system provides 86.14% of the total cost in Case1 using artificial lighting for illuminance.
- Case2 is characterized by the achievement of requirements of lighting to an area larger than Case1.
- Case2 also provides the energy consumption by 129600 Kwh than Case1.
- By using light pipes system in design studio of area 308m, we provides the energy consumption by 129600 Kwh over 20 years, and provides 17400 E£ in total cost .

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