Daylighting: An alternative approach to lighting buildings

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Abstract: An investigation to improve daylighting use in office buildings is presented in this paper. This investigation was initiated by a major company in Saudi Arabia which required proposals to reduce energy consumed by artificial lighting in its office building in Dhahran city. Measurements include the amount of daylighting required for the building with little changes the architectural design. Daylight Factor (DF) is used to measure the internal natural lighting of the building. Results indicate a great amount of energy will be saved in the application of daylighting and recommended amendments to improve natural daylighting in buildings.
[Sharaf F. **Daylighting: an alternative approach in lighting buildings.** *J Am Sci* 2014;10(4):1-5]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 1

Keywords: Daylighting; green building; daylight factor; sustainable architecture

1. Introduction

This paper investigates the use of daylighting in office buildings and the limitations and potentials of using daylighting. It investigates how to reduce energy consumption by artificial lighting in office buildings. The investigation and proposals to reduce energy consumption of lighting in an office building of a major company in Saudi Arabia is presented in this paper.

Daylighting in buildings is a term used to describe sunlight which is reflected to indoor spaces through openings and affecting its interior quality and function. The application of daylighting in buildings promotes the use of renewable energy sours and reduces energy coast (Janda 2011; Ne'eman and Hopkinson 1970; Cooper, *et al*, 1973). Direct sunlight is excluded because sun changes its location during daytime and seasons.

2. Advantages of Daylighting in buildings

The overall objective of daylighting is to minimize the amount of artificial light and to reduce electricity consumption and lower HVAC costs. Energy savings, sustainability and minimum maintenance are features designers initially opt for daylighting. Buildings incorporating daylighting can reach an overall energy savings of 15% to 40% (Alambeigi 2013; Robbins 1986; Dubois and Blomsterberg 2011). Studies suggest that daylighting has a direct impact on the well-being, productivity and overall sense of satisfaction of users, for example, students, employees and retail customers, as people have a natural attraction and need for daylight. Daylighting has positive psychological effects on users and more suitable for vision and eye health. In addition Daylighting energy is clean and produces no pollution in its production, transportation and distribution (Shemirani, *et al* 2011; Erenkrantz Group 1979; Daryanani 1983).

3. Daylighting Challenges

Although daylighting can provide positive results in regards to energy saving and better interior environment for users and work performance in office buildings, a daylighting system may have some disadvantages (Karmel 1965; Morgan 1967).

A good performance daylighting system initially requires a significant investment. But, if an integrated design approach is undertaken the overall long-term savings make up for the initial costs spent on daylighting. In the same way, for example, when using Photo Voltaic solar cells resulting in savings in energy in a building in a certain payback period (Salaima *at el*, 2010 ; Bryan and Carlsbery 1982).

One important issue is controlling glare. Direct sunlight penetration in interior spaces produces an unpleasant glare on work surface in office buildings making it difficult to work, such as viewing a computer screen. However, proper orientation of windows and skylights to allow direct and diffused daylight to enter the building, producing the best combination of light entering the building while controlling glare. The selection and placement of windows and skylights should be determined by the amount of light needed and based on climate and the architectural design (Shemirani, 2011).

Daylighting requires control of the amount of heat that enters a building. Sun is the source of light and heat entering a building, if not planned properly; using natural lighting can result in undesirable heat gains, particularly in hot areas. It may seem that it would be difficult to increase the amount of light without bringing in extra heat (Alambeigi 2013; Hollister 1968). However, the use of proper architectural design of elevations, window shadings and film glazing can help diffuse direct sunlight and minimize heat gain. Such treatments can reduce overall cooling loads, eliminating the need for a larger cooling system, resulting in additional overall savings. Too much heat and light are not the only challenges associated with daylighting strategies. Some architectural features, such as the roof of the building, atrium shapes or angles can impede daylight from entering the building. To prevent daylight obstruction, wall openings should be properly designed within the space.

For example, if elements that can block daylight are located high up in the space they should be as far from wall openings as possible. In a plan that features both open and enclosed spaces; open space areas should be close to the wall openings. This maximizes the effect of daylight by reflecting light deeper into the space (Baird and Thompson, 2012).

3. External lighting in Design

External lighting amount varies according to many factors such as geographical location, orientation, time in the day and in the year, weather conditions being clear or overcast sky. Generally, light from the North side is considered constant and openings to the north side bring in almost constant lighting to interior space. The question in regard to daylighting design is what is the amount of day lighting to be considered in the design of daylighting?

The answer requires detailed records of daylighting for one location including measurements of daylighting from the four directions, from sunrise to sunset over a long period of time reaching to 50 years. The amount of exterior daylight intensity considered in daylight design is the lowest daylight intensity during 90% of used time of the building. This amount is Estimated in Amman 10,000 lux (Hammad, 2000).

4. Measurement of internal natural lighting levels

Internal natural lighting in buildings is estimated in different ways; most common way is by using daylight factor, which is applied in this paper. Daylight factors are used in architecture and building design to assess internal natural lighting levels as perceived on an internal surface. The objective is to determine if the amount of light interring the building is sufficient for the internal space uses (BRE, 1970).

There are three paths along which light can reach a point inside a room through a window or a roof and affects the amount of daylight factor, these paths are:

● light from the patch of sky visible at the considered point, expressed as the Sky Component (SC).

● light reflected from opposing exterior surfaces and reaching the point, expressed as the Externally Reflected Component (ERC).

● light entering through windows and reaching the point after reflection on internal surfaces, expressed as Internally Reflected Component (IRC).

The sum of these three components is expressed as the daylight factor: DF= SC+ERC+ IRC
A daylight factor is the ratio of internal light level to external light level and is calculated as:
DF=(Ei/Eo) x100%
Ei = illumiance according to daylight at a point on the indoor working plane. *Ei* is the amount of light received from the outside to the inside of a building.
Eo=simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky (Bryan and Carlsbery 1982).

Daylight Factor (DF) is used in this paper to measure internal lighting in the case study presented in the next section.

5. Case Study: An office Building in Saudi Arabia

This building is located on the East Coast of Saudi Arabia in Dhahran City. The building was designed by an international company. The building elevations are made of pre cast concrete and glass as shown in Figure 1.

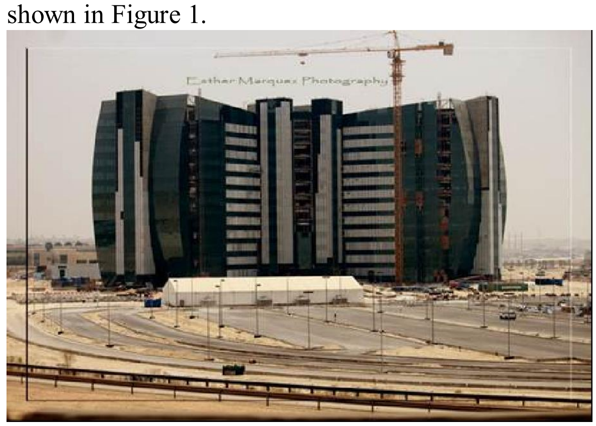

Figure 1. Office building in Dhahran in Saudi Arabia, elevations contain large area of windows and glass

The case study building in Dhahran city consists of two parts connected by a circulation and service core, as shown in the floor plan (Figure 2). The floor area is 3500m^2 and the total building area is about 45000m^2. Each part of the building consists of open office area in addition to services.

The author noted that daylighting was not used in this building although the floor plan shape and openings are suitable for using daylight which is available all day and almost everyday of the year. Promoting the use of daylighting in office buildings is an approach adopted in this paper as an option to reduce energy consumption by artificial lighting in the case study building in Dhahran city.

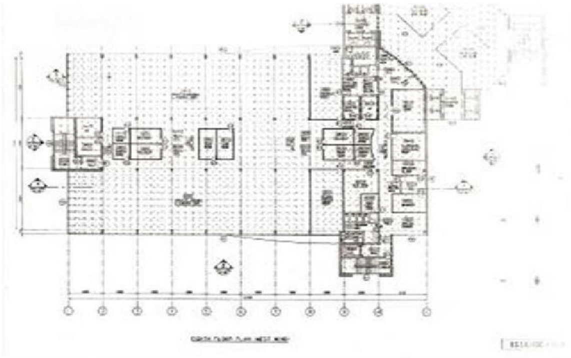

Figure 2. Plan of one of the levels of the case study building in Dhahran city

6. Measurement of Daylighting

An elastration model scale 1:50 of one of the standard floors of the case study building was made. The model was placed inside an artificial sky dome to measure the daylighting factor of a set of points in a grid pattern on the floor of the model (Figure 3).

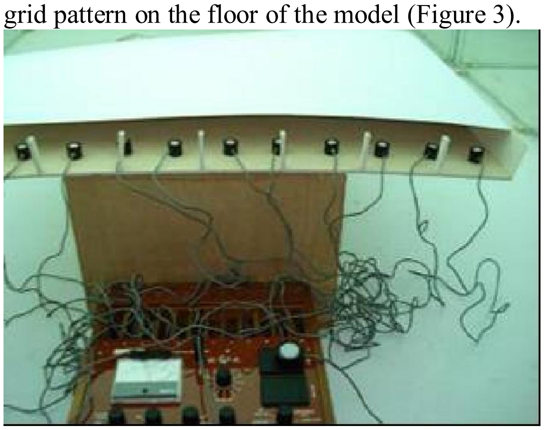

Figure 3. The model and daylighting factor meter

Illumination of the same points was measured using a daylighting factor meter, which could measure the illumination of 12 points at the same time (Figure 4).

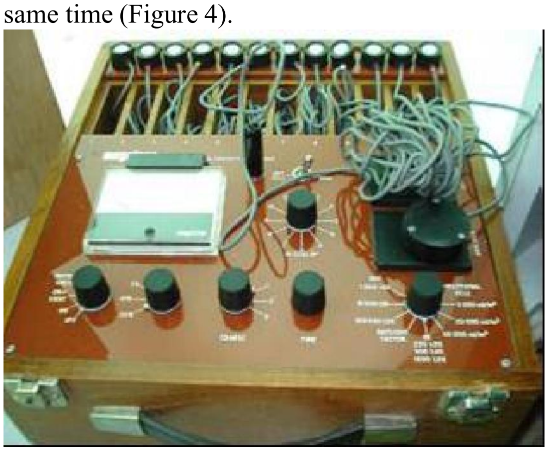

Figure 4. Daylighting factor meter

7. Measurement results of the simulation model

Table1 shows measurements of daylighting factor (DF) on 9 points in one of the spaces inside the model which is a hall in the real Building. Location of the measured points and daylighting factor amounts in the simulation model are shown as contour lines in Figure 5. DF is demonstrated in a three dimensional diagram in Figure 6. Exterior illumination value for the model was set to 6000 lux.

Table 1 Measurements of Daylight Factor on 9 points distributed in the simulation model of hall in

(معدل ضوء النهار %)DAYLIGHT FACTOR, %												
	1	2	3	4	5	6	7	8	9	10	11	12
A"	10.8	10	9.2	8.0	10.2	8.4	8.4	10.4	9.8	12.6	11.8	12.8
B"	6.8	4.0	3.5	4.5	3.8	4	5.5	4.7	5.5	43	4.8	3.0
C"	5.5	2.4	1.6	2.0	1.5	1.6	23	2.1	2.9	21	2.4	2.1
D"			1.2	1.5	1.0	1.0	1.5	1.2	1.9	1.0	1.4	1.2
E			1.2	1.3	1.0	1.0	1.3	1.1	1.8	1.0	1.4	3.2
D			1.2	1.5	1.0	1.0	1.5	1.2	1.9	1.0	1.4	1.2
C	5.5	2.4	1.6	2.0	1.5	1.6	23	2.1	2.9	21	2.4	2.1
B	6.8	4.0	3.5	4.5	3.8	4	5.5	4.7	5.5	43	4.8	3.0
A	10.8	10	9.2	8.0	10.2	8.4	8.4	10.4	9.8	12.6	11.8	12.8

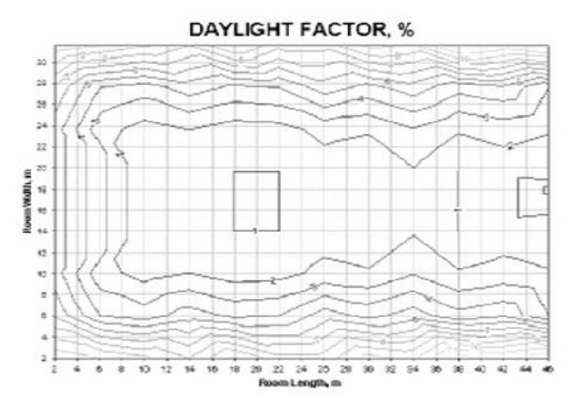

Figure 5. DF contour lines as measured in the simulation model of the hall and location of measured points

DF ranges from 12.8% on the point near the window to about 1% on the middle point between two windows as shown in the Figures 4 and 5.

Converting this amount to illumination in lux, DF is multiplied by the outdoor illumination value *Eo*, as mentioned in section 4. If the outdoor design lighting is considered 10,000lux, then the minimum illumination is 100 lux and maximum is 1290 lux. These values are before any treatment to improve indoor illumination or organized distribution of lighting (Li DHW 2010; Moor 2000).

In the simulation model of the hall, the illumination value in the middle area of the hall was measured 100 lux, and near windows was more than 700 lux. Comparing these measurements with standard values recommended for offices which is 500 lux, the measured daylighting at existing conditions before treatment covers up about 1/3 of the hall area (Figure 6).

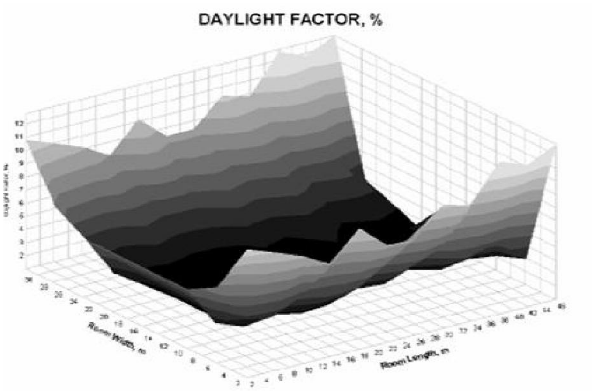

Figure 6. Three dimensional diagram of DF as measured in the simulation model

Figure 7 shows the measured illumination (lux) in the simulation model of the hall. It indicates that the middle area of the hall forms 2/3 of the hall area and needs additional lighting of about (100-350) lux.

To improve daylighting distribution in the hall treatments include light reflectors on the windows or enlargement of the windows, in addition to light colors on the walls and other techniques used to improve indoor light distribution (Figure 7).

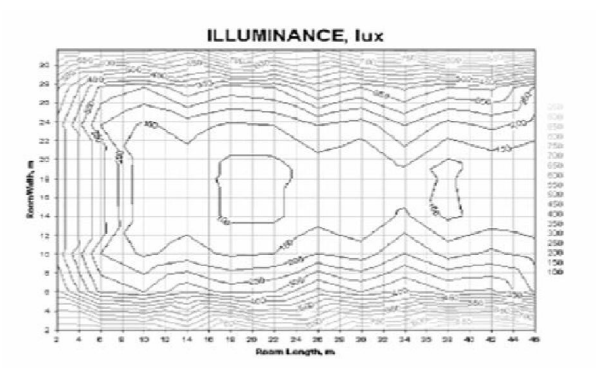

Figure 7. Measured illumination (lux) in the simulation model of the hall.

8. Artificial lighting calculation

Recommended illumination in offices according to standards is 500lux (2011 Building energy data book, 2012).

The Hall dimensions are: 46m, 36m, 2.7m, height above work level= 2.7-0.7=2m.

Space ratio of the hall=
2.5 X (2.7-0.7) X2(46+36)\(46X36)=0.5

Reflection factor (RF) for ceiling= 0.5
RF walls= 0.7, and RF floor= 0.2
Correction Factors= 0.9
Benefit factors from tables of used light units= 0.55.

Artificial lighting units use 4 lights of 32 power each and light quantity 2500 each, with two way aluminum reflectors.

Total light quantity= 4X2500 (90% of original light quantity used in the hall)
Required lighting units=
500X46X36X\(4X2500X0.55X0.9)= 168
Electricity power required for lighting units in Watt = 168X32X4\(46X36)
= 13Wt\m^2.

Adding a balancing factor of 7.5wt makes the total power required for the hall about 20 Wt\m^2, which is the recommended amount for offices.

9. Energy Saving

The amount of energy savings is estimated according to the calculations in section 8. Daylighting can be applied in one third of the hall; the remaining area illumination average is 225 lux, which saves almost half of the required energy for artificial lighting.

The amount of energy savings per m^2 = 1/3+ (1/2 X 2/3)= 2/3 X 30= 20wat/ m^2

Total floor Area of the building is about 40,000m^2, the amount of daily energy savings during day light hours = 40,000X20/1000= 800klwat.

Yearly savings= 800X360/1000=2160 Megawatts. Energy saving can be increased up to 3000 Megawatts a year using simple treatments such as enlarging windows and installing light reflectors.

The energy saving amount in a buildings' lifetime of about 50 years will recover indicial construction costs of daylighting treatments.

Conclusion

Daylighting in an office building was measured in this paper without introducing any daylight improving treatments. Measurements showed that energy savings from using daylighting in the case study office building was more than 2000 Megawatts a year. Energy savings can be increased by one third by using proper daylighting design of window size, light reflectors, colors and interior materials. Artificial lighting during daylight time will not be used if proper daylight design is applied.

Application of daylighting in office buildings as suggested in this paper can reduce energy consumption of artificial lighting by 2/3 per m^2. Daylighting is a green energy which produces no pollution in production nor in its transportation. Implementation of dayliighing in buildings does not need maintenance nor spare parts.

Effective implementation of daylighting in buildings will save great amount of energy on a national scale reaching more than 40%. Reduction of energy consumption at national scale brings positive impact on the environment and pollution reduction.

This paper strongly recommends the application of natural daylighting in building design and implementation, particularly office buildings and in locations where daylighting is available most of the year such as the Middle East.

Acknowledgements:

The author is grateful to the company in Dhahran in KSA for the support to carry out this research.

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3/11/2014