Research Journal of Applied Sciences, Engineering and Technology 11(6): 578-586, 2015
DOI: 10.19026/rjaset.11.2016
ISSN: 2040-7459; e-ISSN: 2040-7467
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Submitted: December 24, 2013 Accepted: January 02, 2014 Published: October 25, 2015

Research Article

The Impact of Using Light Transmitting Concrete on Energy Saving in Office Buildings-case of Jordan

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Abstract: Electric lighting is one of the major energy consuming items in many non-domestic buildings. Using day lighting schemes can help reduce the electrical demand and contribute to the visual comfort and green building development. Building energy saving for engineering structures have obtained the worldwide attention. There is an essential need to develop a new kind of building material, which can integrate green energy saving with self-sensing properties of functional material. This study presents a study on the impact of using light transmitting concrete on energy saving in office buildings by offering daylight scheme for the building. The results showed significant effects of using light transmitting concrete on reducing the electricity consume in office buildings by reducing artificial light demand. This will enhance the daylight indoor quality, worker's productivity and satisfaction. Further work needs to be done to explore the effects of light transmitting concrete on cooling in buildings.

Keywords: Daylight scheme and translucent concrete, energy saving, light transmitting concrete

INTRODUCTION

Energy is one of the most important factors in wealth generation, economic growth and social development in all countries. It is very important to think more efficiently about energy and new resources of renewable energy; start reducing energy consumption and to apply solar energy in our new designs of buildings (Hassouneh *et al*., 2010).

The constant fluctuation in oil prices, as shown in Fig. 1 has pushed people and institutions to think more seriously about renewable energy resources and somehow reduce their dependence on oil (Etier *et al*., 2010). Oil consumption is much faster than it is naturally produced; studies showed that oil depletion has been reached in 2006 (Boyle, 2004).

Jordan is among the low-income countries of the region with an average GDP per capita of about US$ 2550 in 2006, compared to US$ 10,000-18,000 for neighboring oil exporting Arab Gulf States (He *et al*., 2011;Zhou *et al*., 2009). Jordan suffers from an ever-present lack of sufficient supplies of natural resources including water, minerals, crude oil and natural gas. Being a non-oil producing country, there has been an increasing anxiety about energy consumption and its harmful impact on the national economy as well as the local environment. At present, Jordan depends profoundly on imported crude oil and natural gas from neighboring Arab countries as main sources of energy which causes a drain of scarce hard currency.

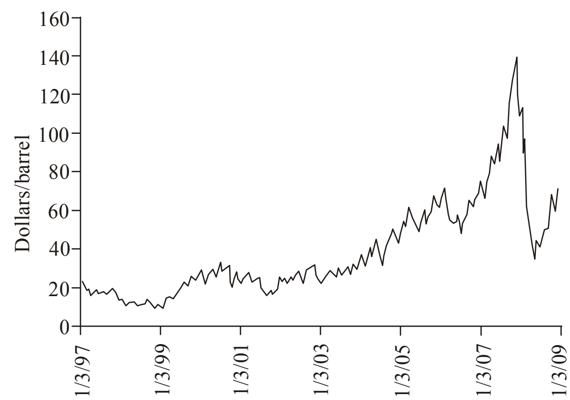

Fig. 1: Weekly oil prices from 1997 to 2009 (2)

The annual energy bill has been hurriedly escalating over the past few years and exceeded US$ 3billion in 2006 due to high rates of population and economic growth combined with the successive increase in the oil price (Awad and Al-Mofleh, 2012).

Proper use of daylight can reduce electric lighting operating costs and also have important environmental benefits. Daylight is an effective energy and sustainable development. It is also considered as the best source of light for good color rendering and its quality is the one light source that most closely matches the human visual response. It has been shown that good daylight enhances academic performance and contributes to a healthier study environment. Natural

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light helps reduce the electricity use of electrical lighting. Also, because of the high luminous efficacy, less heat will be dissipated for the same lighting requirement and, hence, there will be less demand for cooling. This is particularly beneficial to tropical and subtropical regions.

In subtropical Amman (latitude = 32), it is not difficult to understand that daylight controls can result in significant energy savings. Energy-efficient building strategy is also employed in schools. The theories of visual performance and electric lighting savings due to daylight are well understood. The actual savings and benefits can convince the building owners and occupants to implement appropriate energy conservation strategies and management programs.

Problem statement: Jordan suffers from an ever-present lack of sufficient energy resources. There is an increasing anxiety about energy consumption and its impact on the national economy as well as the local environment. Using new materials in building that depend on renewable energy will help Jordan overcome these problems. Light transmitting concrete is a new material that effectively transmits daylight from outside to inside the building. Using light transmitting concrete will help reduce electricity consumption in buildings during daytime. In buildings like offices that have a daytime function light transmitting concrete could substantially replace electricity. A further corporate benefit is the connection between natural sunlight and human behavior.

Objectives: The primary goal of this research is to use renewable energy resources to decrease electricity demand in office buildings thus sustainability will be achieved plus reduction in greenhouse gases emissions. Additionally this research will contribute in providing architects with information about the impact of using light transmitting concrete on energy saving in office buildings and getting benefit from the positive impact of daylight on; productivity, mood and satisfaction of office buildings occupants' in Jordan and worldwide.

Daylight and views: Human preferences on designing buildings are based on occupants' satisfaction with their indoor environments. As one of the components, views and daylight through windows in buildings are recognized as an important factor in increasing Indoor Environment Quality (IEQ) (Prakash, 2005).

Daylight in buildings is preferred by most occupants, offers dynamic interiors and view, maximizes occupant comfort and provides both a more pleasant and attractive indoor environment that can foster higher productivity and performance. It also provides higher luminance than can be economically provided with electric light alone, can lower energy use and its associated environmental emissions and can reduce peak electrical load. Day lighting is an important and useful strategy in terms of visual comfort and energy efficient building designs (Li, 2007).

Daylight versus artificial: Day lighting is dynamic in nature, composed of diffuse skylight, reflected light and intense, directional sunlight, all changing in intensity, direction and spectrum as time and weather change. Day lighting is an effective approach to allow architectural design and construction practices to have a more flexible building facade design and to enhance a more energy-efficient and greener building development (Rqaibat, 2009). Daylight has a "better light quality" than electric lighting. Light quality is a holistic term which includes attributes like light distribution, color rendition, flicker, sparkle, variability and influence on circadian Photobiology (Hashmi, 2006).

Preference for daylight: There is no doubt that people find daylight more pleasant than electric lighting as their primary source of light. Wells (1967), Manning (1967) and Markus (1967) in the UK; Cuttle (1983) in the UK and New Zealand; Heerwagen and Heerwagen (1986) in the USA; and Veitch (1993) in Canada, have all shown that high percentages of survey respondents prefer to work by daylight. Similarly, people prefer to sit at desks that are beside windows rather than further back in the room, especially when those windows have access to direct sunlight (Markus, 1967; Aldworth and Bridgers, 1971; Collins, 1975; Ludlow, 1976; Cuttle, 1983; Heerwagen and Heerwagen, 1986; Hashmi, 2006).

Dasgupta (2003) found a small but statistically significant reduction in negative mood for people who worked for about 20 min in a private office with a large window during daytime; but no reduction in negative mood for the same people in the same office at night. Ruys (1970) also found that occupants of small offices disliked the absence of windows. Some studies have suggested that people have an innate desire to be in contact with nature (White and Heerwagen, 1998); windows provide a means for establishing a visual contact with nature while at work (Hashmi, 2006).

Several studies have documented the importance of light in reducing stress and discomfort of users. Day lighting has been associated with improved mood, enhanced morale, lower fatigue and decreases the occurrence of headaches, SAD and eyestrain. High brightness and glare cause complaints about headache and eye strain. Dry or itching eyes, migraines, aches, pains and other symptoms, often known as Sick Building Syndrome, can be caused by poor or inappropriate lighting instillations.

Light transmitting concrete: Light transmitting concrete, also known as translucent concrete, is the brightest building material development in recent years; it is one of the newest, most functional and revolutionary elements in green construction materials. Strands of optical fibers are cast by the thousands into concrete to transmit light, either natural or artificial, into all spaces surrounding the resulting translucent panels. The material can be used in a variety of architectural and interior design applications. Using light transmitting concrete in our designs can reduce the need for artificial light and maximize the benefit from daylight. Transparent concrete is an important development in concrete technology.

Light transmitting concrete is the combination of conventional materials, such as cement, likes and water, but the glass fibers. It was created with the aim of providing better appearance to light, without neglecting fundamental properties such as compressive strength.

As one can imagine, a concrete with the characteristic of being translucent allows better interaction between the building and its surroundings, creating better environments naturally lit, while significantly reducing the cost of installation and maintenance of concrete. With the aim to eliminate these and other problems, it was thought in the development of a translucent concrete, to be protected by means of the present application, because it is a formulation of concrete while allowing the passage of light to through it, so mechanically works more efficiently than a traditional concrete (Yohana, 2008; Cázares and Gutiérrez, 2009).

In April of 2007, Sergio Galvan and Joel Sosa in México registered a new formulation using a mixture of polycarbonate and epoxy materials, as well as glass fibers, optical fibers, colloidal silica, silica, diethylentriamine (DETA) and Portland cement. Gravel and sand are replaced by resins and fibers (Fastag, 2011).

The inventive formulation used to obtain the light transmitting concrete mixture comprises a type of concrete that is different from those currently available, which combines the advantages of existing concrete with translucency. They called it "Illum". The product is distributed by Latin American Concrete Mexico, Manufactured by S.A.P.I. Translucent Concrete de CV (Cázares and Gutiérrez, 2009).

They claim the invention has greater mechanical strength properties than those of a standard concrete, with lower density and mechanical characteristics that enable same to be used in both a structural and architectural manner, allowing strengths to reach up to 4500 kg/cm^2, while traditional concrete has a compression resistance from 210.9 to 351.5 Kg/cm^2. That means it is 15 times larger. The volumetric weight of 2,000 kg/cm^3 and that its final setting is under 7 days (Ibid.).

This light transmitting concrete is 30% lighter which makes it the ideal building material for earthquake zones or areas where the weight of construction material plays an important role. It comes in a variety of colors. While allowing 80% light transmittance. That will create a brighter environments, indoors, also a reduction in the use of artificial light, allowing a reduction in emissions of greenhouse gases. Additionally, this new concrete can be introduced objects, lights and images, as it has the virtue of being translucent to two meters thick, with no obvious distortion (Ibid.).

Flexural strength of 2.55 KN and deflection maximum of 1.55 mm. Permeability of 0.05%. It is resistant to corrosion, also has fungicidal properties, which makes it useful in Clinical and laboratory applications. Light transmitting concrete does not absorb water; concrete forming panels can be removed after 48 h -one day earlier than the common procedure- and is translucent up to 2 m in thickness, with no obvious distortion. This is desirable in larger constructions such as public, government, civic and cultural buildings.

Last but not least, it allows the passage of undistorted light, never rots, is resistant to corrosion and does not require any special pouring method, therefore, any construction company, in any site can handle it without the need of acquiring special machinery or having to provide workers with special training (Ibid.).

Management and cost: The preparation of the concrete does not require special equipment, it is performed with conventional machines. Traditional curing is also equal to that used in the study, without requiring heat treatments or special laboratory.

While the price difference is only 15 or 20% more expensive than commercial high strength concrete, still there are enormous advantages as high strength and aesthetic faculties. These virtues have had great success both in architecture and construction.

On their use in the construction of houses in a hurricane or earthquake zones would be used as traditional concrete, it does not change its nature, both are brittle and usually do not provide much resistance to earthquakes. In the case of hurricanes, the resistance itself is higher. Using this light transmitting concrete will minimize maintenance costs as it has a life-in normal-about 50 years (Yohana, 2008).

Sustainability and environmental criteria: The sun or the light has been a major factor since the beginning of architecture. It is known that the light shines directly into the mental state of the people, enables visual relief and improves mood; and therefore the light quality of the spaces is one of the most important factors to consider in the design.

In addition, sustainability is now a major issue for all designers and architects, since we live on a planet that is devastated and is degraded by the day. Using this new product also has environmental advantages. It helps reduce energy consumption for lighting, which in turn significantly reduces greenhouse gas emissions.

Additionally, the creators state that its adequate use promotes optimal temperature control inside buildings. In cold areas, it takes advantage of sunlight; in hot climates, it reduces heat. "The product could be valuable in the construction of green buildings and that would enable moderation and even heat mitigation step, "said Galván (Ibid).

Advantages: The light transmitting concrete has many favorable physical and chemical properties compared to traditional concrete. It is up to 15 times stronger than traditional concrete with high durability while it is 30% lighter. It is 100% waterproof, supports high temperatures. The translucency can be moderate from the time of manufacture, it allows the passage of 80% of the light thus it is energy saving through reducing lighting and cooling costs.

Light transmitting concrete can accommodate a variety of architectural designs. Is operated in different types of finish, can be pigmented with a wide range of colors and suitable for both indoors and exterior. It has many advantages; it resists attack salts, great cohesiveness and it gives an opportunity yo design element with lower thicknesses (for their high mechanical properties).

Disadvantages: Light transmitting concrete increases costs of demolition because it is a destruction resistant concrete is very difficult. This concrete is 15 to 20% more expensive. Finally, because of its high degree of transparency, the internal structures of the building are visible, which after a while may be unsightly but thanks to technological advances civil engineering is looking for ways to that with a good finish, the iron columns and other materials [fill], may be pleasing to the eye to obtain a degree of natural and very organic appearance.

MATERIALS AND METHODS

After reviewing related literature and studying case studies, a study area is selected in Amman city where there are many office buildings and the climate condition is moderate. The research selected an office building as a model. Data will be collected through literature review, technical specifications for the material, case studies and electricity calculations manuals.

Finally the research will compare between two situations, existing case (regular concrete construction) and the new case. The comparison will take into consideration: *the construction cost, lighting energy consume cost, efficiency and sustainability*.

Climate: Amman city is located at 32°N and its climate is that of the eastern Mediterranean region where it is hot and dry in summer and rainy in winter. The average temperature in Amman is 8°C in January, 16°C in April and 28°C in July. The Sunshine duration for Amman is variable during the year as shown in Fig. 2. Figure 3 shows the average temperatures of Amman city during the whole year as a function of months. It is clear from the data shown in Fig. 3 that the cold season extends from the beginning of November month till the end of April month since the average value of the ambient temperature during theses month is less than 19°C or 18.3°C.

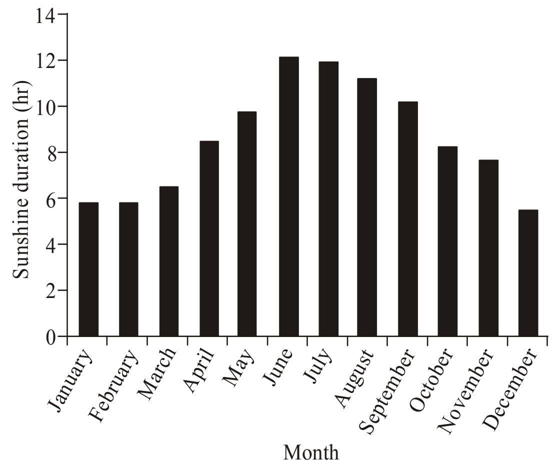

Fig. 2: Sunshine duration in Amman (Hassouneh *et al*., 2010)

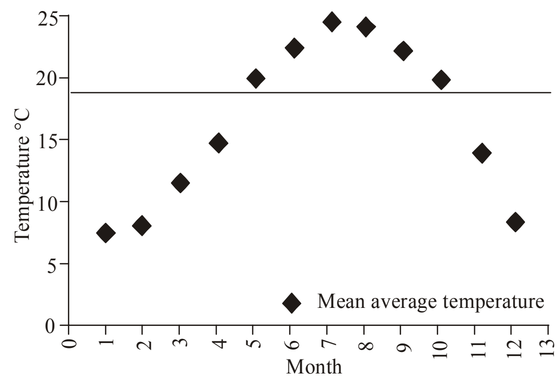

Fig. 3: Average means temperature (Hassouneh *et al*., 2010)

Hours of sunshine range between 6.5 h per day in December and 13.1 h per day in July. On balance there are 3602 sunshine hours annually and approximately 9.9 sunlight hours for each day.

The model: Office Building consists of four typical floor plans (floor plan area is 12*20 m^2) as shown in Fig. 4, located in Shafa Badran, Amman. Considering that office working hours are usually from 8:00 to 4:00 as 8 h average in a day. Sunshine ranges between 6.5 hours per day in December. Additionally the privacy in offices is not highly recommended since as mentioned above light transmitting concrete has a high degree of transparency, the internal structures of the building are visible and all the objects inside will appear as shadows on the other side. Getting benefit from previous studies in Italy pavilion case study the degree

Fig. 4: Ground floor plan for the suggested of model, all the four floors are typical (Authors)

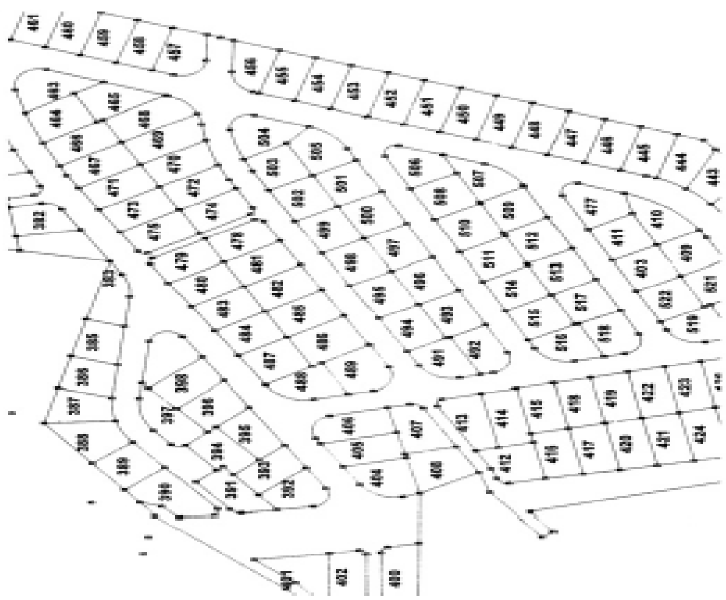

Fig. 5: Land divisions according to residential land use for type C

of transparency should not be larger than 50% as regulated and from the material specifications, the company said that the transparency level could be controlled.

RESULTS

Calculating incident solar energy: Getting benefit from previous studies that calculated the incident solar energy in Shafa Badran district on 240 m^2 façade area in December 21st, as shown in Fig. 5. The researchers Alzoubi and Al-Shboul (2010) used Lightscape software to conduct the simulation of the incident sunlight on building facades in the case study. The simulation took into consideration the maximum possible land use, as shown in Fig. 6. The study assumed a full land occupation utilizing the maximum allowable height and area, as shown in Fig. 7. To

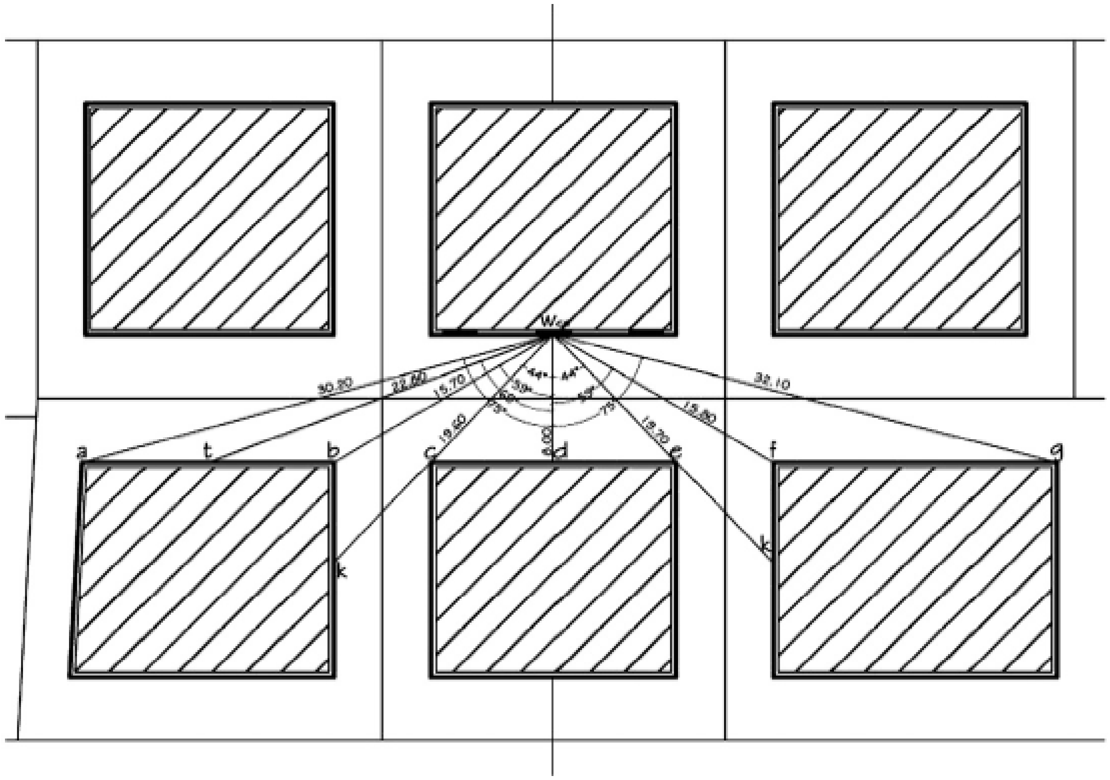

Fig. 6: The incident solar radiation with respect to orientation and setbacks between apartment blocks (Alzoubi and Alshboul, 2010)

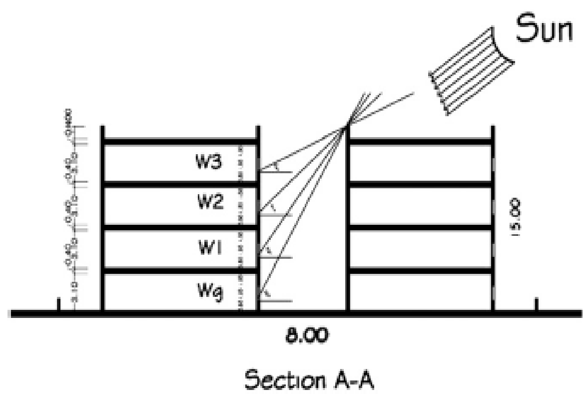

Fig. 7: Section shows the sun-building relationship within minimum allowable setbacks (Alzoubi and Alshboul, 2010)

Table 1: Solar energy values and percentages on southern elevations during daytime hours on December 21st

Time	Solar power (KW/m^2)	Facade area (m^2)	Total solar power on unblocked facades (KW)	Percentage of shaded area %	Actual incident solar power on facades (KW)	Obstructed solar power (KW)
8:00	0.34	240	80.98	90	8.010	72.89
9:00	0.58	240	138.51	80	27.70	110.80
10:00	0.71	240	171.05	70	51.31	119.73
11:00	0.79	240	189.97	63	70.29	119.68
12:00	0.82	240	196.03	61	76.45	119.58
13:00	0.79	240	189.97	63	70.29	119.68
14:00	0.71	240	171.05	70	51.31	119.73
15:00	0.58	240	138.51	80	27.70	110.80
16:00	0.34	240	80.58	90	8.10	72.89
Sum	5.65	240	1357.05		391.26	965.79

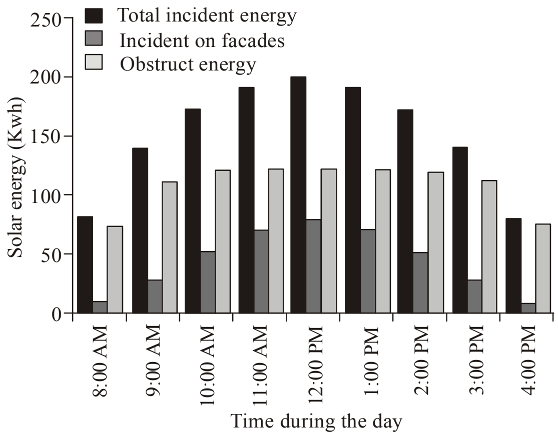

Fig. 8: Solar energy received by south facades on December 21st when class C lands are fully occupied with minimum allowable setbacks amongst building blocks (Alzoubi and Alshboul, 2010)

examine the performance of the solar envelope for each land lot class, the simulation was conducted for the whole period of the cold season in Amman (Alzoubi and Alshboul, 2010).

Calculating the percentage of irradiation was estimated based upon the height of the shaded areas on building facades and the width of the building itself. Table 1 shows the solar energy values and percentages on southern elevations during daytime hours on December 21^{st} and Fig. 8 illustrates the solar energy received by south facades on December 21^{st} when class C lands are fully occupied with minimum allowable setbacks amongst building blocks (Ibid).

In order to know the amount of lx the solar radiation gives us on the southern façade we have to convert from watts to lx. Using an online calculator will do the job.

Average solar power derived from Table 1, for 21^{st} December * 80% = 5660*80% = 4528 watt.

For 240 m area (southern façade area), the luminance value = 1981 lx.

The following process is to calculate the required number of lighting units, luminance and electricity consumption:

$$N = E \times \frac{A}{nF_l \times U_f \times M_f} \quad N = E \times \frac{A}{nF_l \times U_f \times M_f}$$

(AlHimsi, 2010)

where,

N : Number of luminaries
E : Luminance
A : Area of space
n : Number of lamps in the lighting unit
Fl : Lighting fixture efficiency

Table 2: Lighting fixture schedule (Al Himsi, 2010)

Function	Lighting unit type	Power
Offices	4*18	72 Watt 1300 Lumen
Toilets	2*18	36 Watt 1200 Lumen
Corridors, Lobbies	2*26	52 Watt 1800 Lumen

Table 3: Maintenance factor table (Al Himsi, 2010)

Condition	Mf value
Normal	0.8
Dirty	0.7
Too dirty	0.6

Table 4: Required luminance table (Al Himsi, 2010)

Function	Luminance
Office	500 lx
Reception	400 lx
Corridor	150 lx
Bathroom	100 lx

Uf : Utilization Factor
Mf : Maintenance Factor (Table 2)

$$K_r = L \times \frac{W}{H_m\ (L+W)} \quad K_r = L \times \frac{W}{H_m\ (L+W)}$$

…. (Al Himsi, 2010).

where,

Kr : Room Index
Hm : Hanging height for the lighting units
L : Space length
W : Space width

Hm = H – Hl – Hp ….. (Al Himsi, 2010)

H : Ceiling Height
Hl : The distance between ceiling and the lighting units
Hp : The height of the work surface
Mf : Maintenance Factor (Table 3)

The required luminance for each room is conducted from Table 4.

Uf is calculated from Kr value using Table 5 to 7.

DISCUSSION

Comparing that 7600 lx in needed in the normal case for the rooms located on the southern façade and calculating that 1981 lx can be available if we use light transmitting concrete on the same façade area. That means electricity use reduction can reach up to 26% in an average day in December.

Calculating the lighting electricity consuming for the whole month = 1.496 KW*8 hours*30 days = 359.040 KW. Lighting electricity bill = 360 KW * 0.06 (KW prices from the local electricity company)* 4 (no. of floors in the building) = 86.4 JD.

Table 5: Lighting calculation table (Al Himsi, 2010)

Utilization factor in %										
Q	Ceiling	0.8				0.7	0.5		0.3	0
	Walls	0.5		0.3		0.5	0.3	0.3	0.3	0
	Floor	0.3	0.1	0.3	0.1	0.2	0.3	0.1	0.1	0
k	0.6	35	33	28	27	33	26	25	24	18
	0.8	44	42	37	35	41	34	32	31	24
	1.0	51	48	44	41	48	40	38	36	30
	1.25	58	53	50	47	54	46	44	42	35
	1.5	64	58	56	52	58	51	48	46	39
	2.0	72	64	65	59	65	58	55	52	45
	2.5	77	68	70	64	70	63	59	56	49
	3.0	81	71	76	68	73	67	62	59	52
	4.0	85	74	81	71	76	71	65	62	5.5
	5.0	89	76	84	74	79	74	68	64	57

Table 6: Lighting calculation for the whole spaces (Authors)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Office No.			FC Height										
2		L	W	H	(H_L)	(H_P)	(H_m)	(K_f)	E	A	n×F_L	(U_f)	(M_f)	N
3		(m)	(m)	(m)	(m)	(m)				(m^2)				
4	O-01	7.40	4.65	2.50	0.00	0.80	1.70	1.68	500	34.41	5200	0.67	0.80	7
5	O-02	6.75	4.00	2.50	0.00	0.80	1.70	1.48	500	27.00	5200	0.64	0.80	6
6	O-03	3.66	4.65	2.50	0.00	0.80	1.70	1.20	500	17.02	5200	0.57	0.80	4
7	O-04	3.90	4.65	2.50	0.00	0.80	1.70	1.25	500	18.14	5200	0.58	0.80	4
8	O-05	3.90	4.65	2.50	0.00	0.80	1.70	1.25	500	18.14	5200	0.58	0.80	4
9	O-06	3.75	4.65	2.50	0.00	0.80	1.70	1.22	500	17.14	5200	0.57	0.80	4
10	C-01	2.00	3.14	2.50	0.00	0.80	1.70	0.72	150	6.28	1800	0.40	0.80	2
11	C-02	2.00	5.35	2.50	0.00	0.80	1.70	0.86	150	10.70	1800	0.46	0.80	3
12	L-01	4.50	3.65	2.50	0.00	0.80	1.70	1.19	400	16.43	1800	0.56	0.80	9
13	R-01	4.15	3.75	2.50	0.00	0.80	1.70	1.16	400	15.56	1800	0.55	0.80	8
14	T-01	3.00	4.65	2.50	0.00	0.80	1.70	1.07	100	13.95	1200	0.53	0.80	3
15	T-02	2.00	2.40	2.50	0.00	0.80	1.70	0.64	100	4.80	1200	0.37	0.80	2

Table 7: Lighting calculations for targeted spaces, functions on the southern facade (Authors)

Room	Required luminance	Lighting fixture unit type	Quantity of lighting fixture units needed in regular case	Electrical absorption power for each unit	Electrical absorption power for all units
Office O-05	500 lx	4*18	7	72 watt	504 watt
Office O-06	500 lx	4*18	4	72 watt	288 watt
Office O-01	500 lx	4*18	4	72 watt	288 watt
Reception R-01	400 lx	2*26	8	52 watt	416 watt
Sum	1900 lx				1496 watt

While using light transmitting concrete we will save 26% from the electricity bill, which means in this case we can save 22.464 JD from electricity bill in December. Imagine the savings in summer when the sun solar radiation is higher and the sunshine durations are longer. Imagine the amount of savings when calculated to the other facades.

CONCLUSION

This study explored the impact of using light transmitting concrete on electricity demand in office buildings and the effects of daylight on employers' productivity, psychology, mood and satisfaction. These were examined using literature review, previous studies, case studies, data interpretations and calculations on the suggested model. The results showed significant effects of light transmitting concrete on reducing the electricity consume in office buildings, reducing artificial light demand and will help us getting benefit from daylight, enhance the daylight indoor quality and the positive impact of daylight on employers' satisfaction, productivity and other issues.

FUTURE STUDIES AND RECOMMENDATIONS

Further studies are necessary which would provide more data and investigate other variables. As explained in the first chapter, this study began with some limitations. Further work needs to be done to explore the effects of light transmitting concrete on cooling in buildings.

In addition further studies should be done on other months especially in summer and should take in mind the indoor environmental variables that link to various indoor design parameters that may affect occupants' physical and psychological conditions; indoor air quality, thermal condition, acoustics, etc. should also be considered.

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