GREEN DAYLIT INDUSTRY FOR DHAKA: AN EVALUATION OF INTEGRATED SKYLIGHTS AND SOLAR PANELS FOR RMG FACTORY BUILDINGS

[1]MD ASHIKUR RAHMAN JOARDER, [2]MD NAHID IQBAL

[1,2]Dept. of Architecture, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.
E-mail: [1]ashikj2000@gmail.com, [2] ar.md.nahid.iqbal@gmail.com

Abstract- Recent safety assessment on existing ready–made garment (RMG) factories in Bangladesh, has explored the necessity for quick shifting of approximately 46% of factories from converted and shared buildings to new buildings. This is an opportunity for Bangladesh to construct new green factories, proficiently. Following the principle of the energy pyramid, this paper proposes a concept for green daylit industry with maximum possible utilization of the sun power, where simple and less cost options were tried first (i.e., skylights in RMG roof structure for daylighting), before pursuing the more complicated and costlier options of renewable energy (i.e. installation of photovoltaic (PV) panels for electricity production. A dynamic annual Climate-Based Daylight Modeling (CBDM) method considering all weather sky luminance model (i.e. DAYSIM), was used to identify the most feasible skylighting configuration for industrial roof to incorporate maximum useful daylight in luminous environment of the production spaces. To integrate the PV panels to skylight system, effectively, further simulation analysis was done to refine the design parameters, e.g. slope of the skylight, width and spacing, for the most feasible skylight configuration, to achieve highest electricity production round the year. Initiatives were taken to improve the thermal and visual comfort, and aesthetic quality of the interior and exterior of RMG buildings. It is expected that the outcomes from this research will help to guide the development of green daylit RMG factories, in context of Dhaka, to increase productivity of workers and save energy for lighting purpose in RMG sector.

Keywords- green industry; daylit RMG; useful daylight; CBDM; dynamic metrics; photovoltaic; BIPV.

I. INTRODUCTION

In recent past, after a series of devastating casualties at different ready–made garment (RMG) factories and the tragic death of thousands of workers in Dhaka [1], (e.g. Rana Plaza building collapse on April 2013, and Tazreen Fashions factory fire incident on November 2012), different private, public and foreign organizations came together with the initiative to improve the physical and environmental condition of RMG sector in Bangladesh. Some preliminary safety assessment recommended 16% of existing RMG factories that are located in converted buildings (i.e. buildings approved for residential/ commercial purposes), and 30% that are located in shared buildings (e.g. RMG factories situated in buildings with other occupancy types, such as, markets and/or commercial buildings) are significant threat to life safety of the workers [2]. Buyers have also reservation to order for RMG products from these factories located at converted and shared buildings. Therefore, there is a need to shift 46% of Bangladeshi RMG factories to new constructed buildings and factory owners are also willing to do so. This situation opens the opportunity for developing new green factories in Bangladesh, competently, to house these shifted RMGs.

Beside the death incidents mentioned above, over the last few decades, RMG factories in Bangladesh have been heavily criticized for its working conditions; however, more than 78.15% export earning of Bangladesh come from the RMG sector [3]. In Bangladeshi RMGs, along with other physical condition, the quality of luminous environment is affected by poor natural lighting system and high internal heat gains from artificial lighting [4], creating an intolerably hot and uncomfortable working environment for the workers that is noncompliant with national and international standards. Since lighting directly affects visibility, light is critical to productivity, safety and healthy working conditions of workers [5]. Industrial workers spend more than 90% of their life in artificial luminous environment and in such condition natural light could work as medicine [6]. Different studies show that lighting is one of the biggest consumers of power in RMG sector, account for around 21-35% of the total energy consumption [7, 8]. Much work has been done to reduce the power consumption of machines, but development in the area of lighting is very limited [7]. Proper use of daylight can be an effective means to reduce the energy consumption and excessive cooling load caused by artificial lighting in RMG factories, which could be one of the primary steps to make Bangladeshi RMGs green.

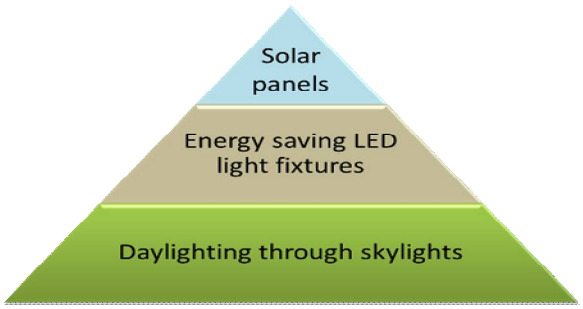


Fig 1: Energy pyramid for green daylit industry.

Green industry promotes energy savings by conservation techniques to minimise the carbon footprint, at the same time, increase the use of energy from renewable sources and reduce environmental pollution [9]. To address these prime goals of green industry, this paper proposes and analyses a concept of green daylit industry with maximum possible utilization of the sun power, in context of Dhaka. Following the principle of the energy pyramid (Fig 1), trials have been done to accommodate simple and less cost options first, i.e., incorporation of skylights in RMG roof structure to use maximum daylight to meet the visual and physiological needs of the workers, before pursuing the more complicated and costlier options of renewable energy, i.e. installation of photovoltaic (PV) panels for electricity production (Fig 2).

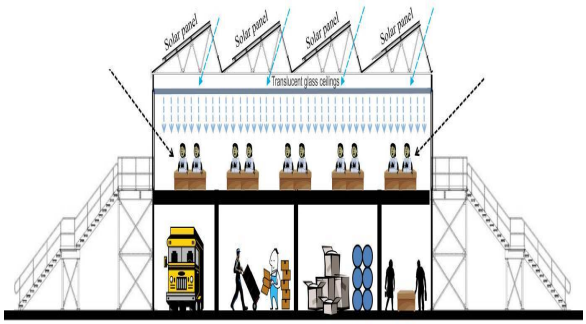


Fig 2: Concept of green daylit industry for Dhaka, Bangladesh.

II. RESEARCH OBJECTIVES

To present a concept for green daylit industry the following two objectives were developed.

a) To identify an effective skylight configuration for RMG industrial roof to increase useful daylight at production spaces in context of Dhaka.

b) To integrate PV panels to skylight system, practically, to achieve highest electricity production, round the year.

III. SKYLIGHTS AND PV PANELS

The skylight by definition permits daylight to enter from above, through a glazed opening in the roof protecting the interior from wind and weather [10]. For single-storey buildings, or the top floor of multi-storey buildings, the entire floor area can receive daylight from the roof. Literature shows that 800 lux illumination level is required for RMG sewing and cutting section [4], which is almost three times higher than typical office work illumination level of 250-300 lux [14]. As the sky is generally brighter at its zenith than near the horizon (Fig 3), a horizontal skylight is proportionately three times more effective as a source of daylight than a vertical window [11]. Therefore, skylight can be three times effective than typical vertical openings. That is the reason why skylight could be very effective for efficient daylighting at RMG factories.

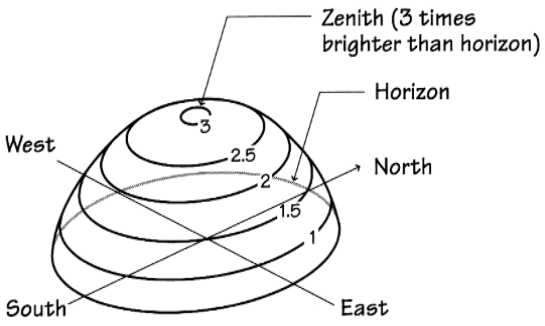


Fig 3: Luminance differs in overcast sky (Egan, 2002).

In case of skylighting, the incoming daylight is spread over an interior space in a more uniform way, and is less likely to be obstructed either internally or externally. A disadvantage of horizontal skylights is that, compared to vertical windows, horizontal skylights collect more light and heat in summer than in winter – usually the opposite of what is desired. For this reason vertical or near-vertical skylights, oriented to North, South, East or West as circumstances demand, and screened with conventional devices are often preferred. Direct sunlight from horizontal openings can be diffused by translucent glazing, and glare control by baffle systems. National Association of Skylight Manufacturers (NARM), UK [12] illustrate that from various skylight types continuous run in plane skylights are suitable for industrial buildings, as industries maintain production lines. Considering this and some local factors, Ahmed [13] identified six available skylight configurations (Fig 4) suitable for Bangladeshi RMGs: monitor roof with vertical glazing (SC 01); monitor roof with 60^o slope glazing (SC 02); monitor roof with 60^o north face glazing (SC 03); monitor roof with horizontal glazing (SC 04); continuous north light skylight (SC 05); and pitched roof with 30^o slope skylight (SC 06).

PV panels could be integrated to skylighting system, e.g. building integrated photo voltaic (BIPV). BIPV are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades. BIPV components displace conventional building materials and labour, results reduction in net installed cost of the PV system. The building itself becomes the PV support structure. Some other benefits of BIPV are: on-site generation of electricity offsets imported and often more carbon-intensive energy; building looks architecturally elegant; well-integrated systems increase market acceptance; and the systems provide the building owners a highly visible public expression of their environmental commitment. The performance of the BIPV is highly dependent on the tilt and azimuth angle. Since BIPV is related with fixed angle orientation of the solar modules, the optimum possible tilt angle orientation should be considered when integrated with skylights.

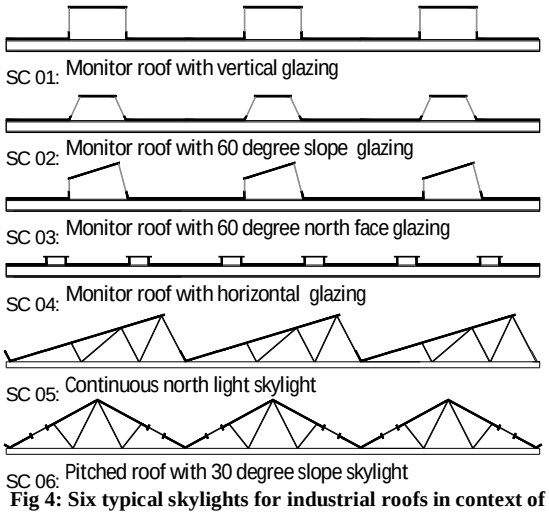


Fig 4: Six typical skylights for industrial roofs in context of Bangladesh (Ahmed, 1992).

IV. APPROACH AND METHOD

Through literature study and field survey, six typical skylight configurations for industrial roof under the climatic context of Bangladesh were identified (Fig 4). Daylight simulation was performed by creating a virtual production environment (case space) based on the information of an existing RMG building located in Dhaka, Bangladesh. A dynamic annual Climate-Based Daylight Modeling (CBDM) method considering all weather sky luminance model (i.e. DAYSIM), was used to find out the most feasible, passive skylight for the case RMG factory building to incorporate maximum useful daylight in the production spaces located at the top floor. The design parameters, e.g. slope of the skylight, width and spacing, for the most feasible skylight configuration (identified from above), were refined by further simulation analysis, to integrate PV panels to skylight system, effectively, considering PV array orientation, the most effective azimuth and tilts angles, and shadow mapping, to achieve highest electricity production round the year.

4.1 Sky conditions of Dhaka

The city of Dhaka lies between longitude 90°20'E – 90°30'E, and between latitudes 23°40'N-23°55'N. In context of Dhaka, during summer (Mar-May) the sky can be both clear (with sun) as well as overcast. However, during the warm-humid (Jun-Nov) period, which includes the monsoons, the sky remains considerably overcast at most of the time. It is only during the winter (Dec-Feb) that the sky remains mostly clear. In the cool period, Dhaka has more than eight hours of sunshine per day. During monsoon months this comes down to four hours per day due to cloud cover. It is after June and July that this once again increases steadily [14].

4.2 Case space in Dhaka

Apex Knit Composite Ltd., Gazipur, Dhaka, a three story steel structured RMG factory, was selected as case RMG building. The building is rectangular in shape with typical floor plans and has a vast opportunity of daylight exposure through roof and facades (Fig 5). The production floor (42.6m X 60.35m) located at the top floor (2nd floor) of the building with 4.5m clear height (with a maximum 2.5m high void space above ceiling), was selected as case space for the simulation study. The production lines (sewing and cutting lines) were elongated towards East-West. The building has a 6m wide road on the front, some service buildings on its north, an open field on the south, a small water treatment pond and open field on the west side.

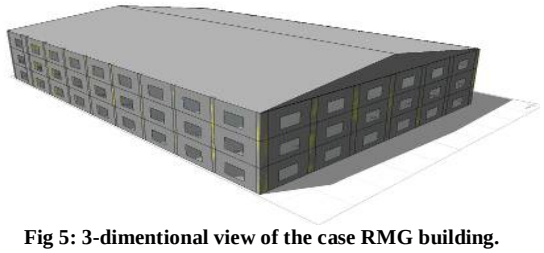


Fig 5: 3-dimentional view of the case RMG building.

4.3 Simulation Parameters

The simulation model was created with the existing surroundings, furniture arrangements, window size, work plane height and different material reflectance found during physical survey (Fig 6; Table 1). For simulation purpose, roof glaze to floor area ratios for the case space were kept as 20% [12] for the studied skylight configurations.

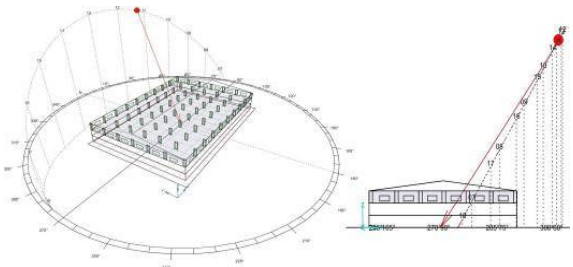


Fig 6: Modelling of the case production space.

Table 1: Material properties from field survey.

Building element	Material description	Material properties
Ceiling	Metal insulated with aluminum fuel paper	80% diffuse reflectance
Walls	Brick with plaster, either side	70% diffuse reflectance
Floor	Net cement finishing	40% diffuse reflectance
Window	single glazed low-e aluminum frame	90% visual transmittance
Furniture	Plywood	60% diffuse reflectance
Mullions	Aluminum	50% diffuse reflectance
External ground	Grass	25% diffuse reflectance
Skylight	Single glazed low-e aluminum frame	Transmission: 90% Pollution factor: 0.70 Framing factor: 0.90 Maintenance factor: 0.85

To analyses performance metrics, the same annual illuminance profile was used. The simulation time step was one hour. Nine hours of daylight time from 08:00 AM to 05:00 PM was considered as working hour. The design illumination level fixed at work plane height for sewing work (0.76m from floor level) is minimum 800 lux [4] and should not exceed 2000 lux to avoid glare [15]. Table 2 shows the annual CBDM parameters [14].

Table 2: Annual CBDM parameters (Joarder 2012)

Ambient bounces	Ambient division	Ambient sampling	Ambient accuracy	Ambient Resolution	Specular threshold	Direct sampling
7	1500	100	0.01	300	0.0	0.0

4.4 Performance Evaluation Process

With reference to structural grid, the entire production floor was divided into grids with 54 intersecting points at work plane height (Fig. 7). Six points on the EE' axis from the central south window façade towards the opposite central north window facade (Fig 8) were designated as core work plane sensor points.

Daylight autonomy (DA), and useful daylight illuminance (UDI), were measured on the individual core sensor points on EE' axis. The maximum daylight autonomy (DA_{max}) was measured with respect to 54 sensor points on the work plane [16].

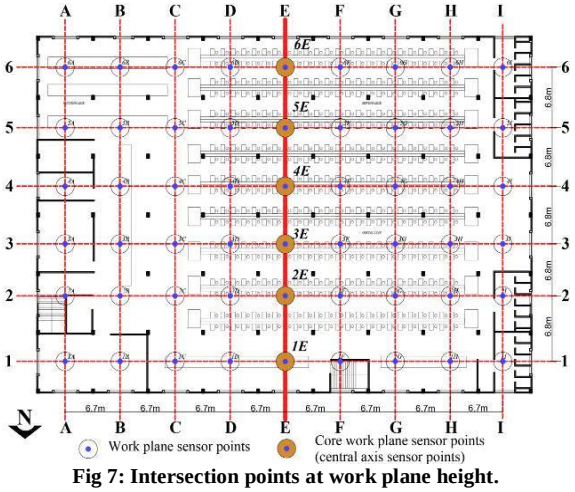


Fig 7: Intersection points at work plane height.

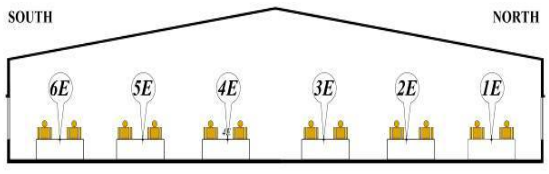


Fig 8: Six core sensor points on EE' axis.

V. RESULTS AND DESIGN POTENTIAL

Table 3 shows a summery of annual CBDM simulation results for recommended six skylight configurations for Bangladeshi RMG factories (Fig 4). Considering DA, SC 06 performs better to other skylight configuration types; however, in view of UDI>2000 and DAmax metrics, SC 06 scored considerably higher than the other types, that may cause glare in the case space. On the other hand, SC 05 and SC 01 have suitable value range of DA with lower value for UDI>2000 and DA_{max} metrics, that will ensure a uniform distribution of daylight, compared to other type of skylights.

Table 3: Dynamic performance of six skylights.

Skylight configuration	SC 01	SC 02	SC 03	SC 04	SC 05	SC 06
DA	72%-87%	91%-94%	80%-89%	91%-94%	85%-94%	94%-96%
DA_{max}	0.37%	18.5%	7.2%	5.9%	0.35%	12%
UDI < 100	1%-2%	1%	1%	1%	1%	1%
UDI 100-2000	51%-71%	20%-27%	40%-65%	19%-26%	41%-80%	15%-19%
UDI > 2000	35%-48%	72%-79%	34%-58%	73%-80%	20%-57%	82%-84%

5.1 Recommendations for skylight type

Use of rating system for the simulated performances, presented in Table 3, is easier to benchmark a skylight configuration against the pool of six alternative skylight types (Reinhart et al. 2006). Table 4 shows the ratings of the six alternative skylight configurations considering the different metrics, except UDI<100 as it was almost identical for the studied skylight configurations (Table 3). When a metric led to different ratings for the EE' axis of the space, the mean result, and the minimum to maximum ranges for six core work plane sensors were compared. From 1st to 6th place ratings, points were considered as '5' to '0' points respectively.

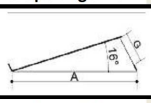
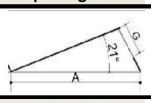
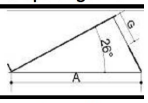
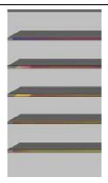
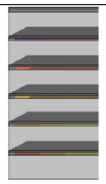
Table 4: Rating of different skylight configuration.

Types	SC 01 Point	SC 02 Point	SC 03 Point	SC 04 Point	SC 05 Point	SC 06 Point
DA	0	4	1	3	2	5
DA_{max}	4	0	2	3	5	1
UDI 100-2000	5	2	3	1	4	0
UDI>2000	4	2	3	1	5	0
Total Rating	13	8	9	8	16	6
Place	2nd	4th	3rd	5th	1st	6th

From the performance evaluation process and ratings, continuous north light skylight type (SC 05) was found as most feasible skylight for RMG factory buildings in climatic context of Dhaka. Further parametric study was conducted with the type SC 05, to fix different design factors, such as, slope of the skylight, width and spacing of roof monitors, to increase useful daylight at production spaces, round the year, in context of Dhaka. The same performance evaluation process was followed, as before, and analysis shows 21° slope angle with one segment (length of sloped surface 6.25m with 2.2m rise)

performs better compared to other studied configurations of the same skylight type (SC 05) (Table 5 and 6).

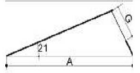
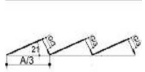
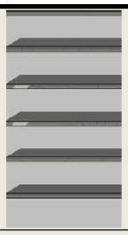
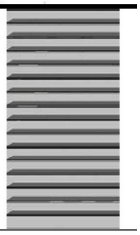
Table 5: Parametric analysis of slope angel of SC 05.

	Slope angel 16°	Slope angel 21°	Slope angel 26°
Slope angel			
Shadow mapping (maximum shadow coverage on 21 December at 4:00 pm)	Max. 26%	Max. 22%	Max. 36%
			
DA	85%-95%	87%-94%	84%-93%
DA max	0.37%	0.42%	0.41%
UDI100-2000	41%-80%	49%-89%	46%-73%
UDI>2000	20%-57%	20%-50%	26%-53%
Slope angle	16	21	26
Ranking	2nd	1st	3rd

5.2 Recommendations for BIPV integration

Since PV modules are to be oriented at a fixed tilted south surface of skylights, the tilt angle recommended for skylight should not differ far from the optimum tilt angle suggested for BIPV for Bangladesh for optimization of power. In context of Bangladesh, it was found that, if tilt angle is decremented from 90° to 1°, the power of arrays is incremented by 7.88% keeping azimuth angle fixed at 0°. If azimuth angle is incremented from 0° to 180°, the power is decremented by 46.72% keeping tilt angle fixed at 21° [17].

Table 6: Parametric analysis of size of SC 05.

	1 Segment	2 Segments	3 Segments
SEGMENT			
Shadow mapping (maximum shadow coverage on 21 December at 4:00 pm)			
Shadow coverage [%]	Max. 22%	Max. 28%	Max. 32%
DA	87%-94%	79%-93%	83%-93%
DA max	0.42%	0.37%	1.88%
UDI100-2000	49%-89%	36%-75%	40%-77%
UDI>2000	20%-50%	24%-62%	22%-59%
Ranking	1st	3rd	2nd

Considering the location of the city in Bangladesh and temperature dependency and power output of the BIPV application on various tilt and azimuth angle, it was found that, if tilt angle is fixed between 21° - 25° (Dhaka: 23°; Chittagong: 22°; Rangpur: 25°; Sylhet: 24°; and Khulna 21°), it acquires maximum solar radiation throughout the year and produces maximum electricity than other tilt angles. Conveniently, under this research the best configuration of skylight (SC 05), recommended after parametric analysis to increase useful daylight at production spaces, round the year, matches with the PV angle (21°) for highest electricity production in context of Bangladesh for southern region, and slight adjustment (upto +4°) will be required for other cities, such as Dhaka (+2°); Chittagong (+1°); Rangpur (+4°); Sylhet (+3°), which could be accommodated by simple structural modification during installation process. Therefore, integration of PV panel with type SC 05 will be highly effective.

The length of the tilted south surface of skylights was fixed by considering the size of PV cells and the panel width (99cm) (Fig 9). Shadow mapping analysis for whole year and maximum shadow coverage at 4:00 pm of 21st December was done (Table 5 and Table 6) to keep the PV panels out of the shadow range of the elevated roof monitors. Fig 10 shows recommended skylight configuration with necessary dimensions with PV cells installed.

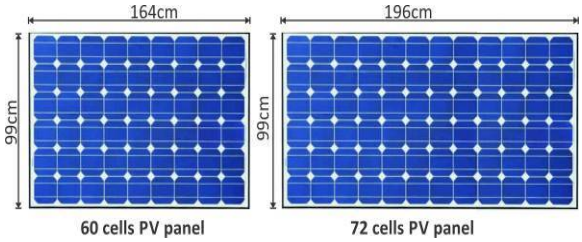


Fig 9: Size of unit PV cell and the panel dimension.

The light entering the production space, located at top floor, through the skylights could be further moderated by translucent UV protected glass ceiling (Fig 11) to protect solar radiation, increase visual comfort and aesthetic quality of the interior. Energy saving LED light fixtures are recommended to provide supplimentery light at production area to reduce energy damand for lighting purpose.



Fig 11: 3d-visualization of the RMG interior production space with recommended skylighting.

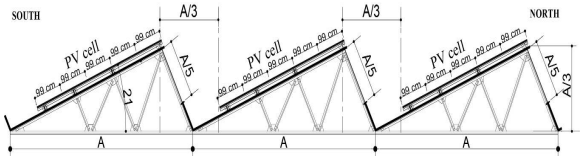


Fig 10: Recommended skylight configuration with PV cell.

CONCLUSIONS

The analysis of this research show, the most feasible skylight configuration for RMG factories to maximise useful daylight at production space, also satisfies the PV array orientation and the most effective azimuth and tilt angles for highest electricity production in context of Bangladesh by incorporating slight installation adjustment, considering the location of the city. Therefore, the potential of the development of an integrated skylight-BIPV system as one of the criterias of green industry could be highly beneficial, considering the present context of Bangladesh, where shifting of approximately 46% of existing RMG factories to new constructed buildings is urgent.

ACKNOWLEDGMENTS

We acknowledge Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, for technical support and funding for this research.

REFERENCES

[1]. Bhuiyan, K. Bangladesh Garment Factory Disaster Timeline. Stein & Partners. 2013. http://www.steinandpartners.com/sustainability/compliance/bangladesh-garment-factory-disaster-timeline. Accessed on April 19, 2015.

[2]. Rashid, M., Islam, B. Rana Plaza collapse: Awareness and actions. Lightcastle Blog. 2014. http://lightcastlebd.com/blog/2014/04/rana-plaza-collapse-awareness-actions. Accessed on April 19, 2015.

[3]. IFC. Ready-made Garments: Challenges in Implementing a Sector Strategy. Dhaka: Bangladesh International Finance Corporation. 2011.

[4]. Hossain, M. and Ahmed, K. S. Illumination Conditions and Visual Comfort in Production Spaces of Ready-Made Garments Factories in Dhaka. IACSIT International Journal of Engineering and Technology, 5(5). 2013.

[5]. Zohir, S.C. and Paul-Majumder, P. Garment Workers in Bangladesh: Economic, Social and Health Condition. Dhaka: Bangladesh Institute of Development Studies. 2008.

[6]. Gligor, V. Luminous Environment and Productivity at Workplaces. Thesis (Licentiate). Espoo: Helsinki University of Technology. 2004.

[7]. Godiawala, P., Anand, N., and Patel, J.M. 2014. Sky lighting - A solution to reducing energy consumption in Apparel Sector. International Journal of Scientific and Research Publications, 4(4).

[8]. EAC. Energy Management Study on Abony Textile Limited and Abony Knitwear Limited, Hamayatpur, Savar, Dhaka. Energy Audit Cell, Ministry of Energy and Mineral Resources, BD. 2009.

[9]. FAWI. Selected Definitions of Green Industries and Green Jobs, Florida Agency for Workforce Innovation, Labor Market Statistics 2009. enter.http://www.floridajobs.org/library/pubs/green/green_definitions.pdf. Accessed on Apr 19, 2015.

[10]. Phillips, D. Daylighting: Natural Light in Architecture. Burlington: Architectural Press. 2004.

[11]. Egan, M.D. and Olgyay, V.W., Architectural Lighting. New York: McGrew-Hill. 2002.

[12]. NARM. Natural daylight design through roof lighting. UK: National Association of Skylight Manufacturers. 2009.

[13]. Ahmed, N.U. Industrial Architecture for Developing Countries. New Delhi: Vikas Publishing House Pvt Ltd. 1992.

[14]. Joarder, M.A.R, and Ahmed, Z.N. Daylighting inside Glass Box: Responsiveness of Interior Design to External Facade. Athens: ATINER'S Conference Paper Series. 2013.

[15]. Nabil, A., and Mardaljevic, J., Useful daylight illuminance: a new paradigm for assessing daylight in buildings. Lighting Research & Technology. 37(1), pp. 41-59. 2005.

[16]. Reinhart C.F., Mardaljevic J., Rogers Z. Dynamic Daylight Performance Metrics for Sustainable Building Design. Leukos: 3(1). 2006.

[17]. Rahman, M.H. and Afrin, J. Performance Analysis of Building Integrated Photovoltaic Application with Tilt and Azimuth Angle in Bangladesh. Global Journal of Researches in Engineering Electrical and Electronics Engineering, 13 (8). 2013.

★★★