Energy Saving using Sky Windows to Augment the Artificial Lights to Maintain Required Illuminance

[1]Anitha Menon, [2]Magan P Ghatule

[1]Research Student, [2]Professor
[1]Department of Electronics,
R&D Centre, Department of Electronic Science, Modern College, Shivajinagar, Pune

***Abstract*: Effective utilization of daylight sky windows is used specifically for industrial shades. This utilization could prove to be beneficial in power saving. The main aim of the paper is to study energy saving for a closed room using an array of artificial light sources and sky roof widows for illumination. In order to maintain uniform intensity throughout the year in the room, a number of sky roof windows can be placed at different positions depending on the Sun path. This paper reports the energy saved while augmenting the existing electrical lighting system with sky roof windows. For the daylight simulation, the software used is DIALux Evo 10. The roof skylight windows can reduce the electrical energy consumption by effectively using the concept of day lighting without causing much discomfort to the occupants. An array of four 2x2 LED lamps placed at the four corners of the room can be selectively lit to maintain the required light intensity of around 300 lux to save energy by integrating daylight with electrical lighting using LED lamps.**

***Index Terms*: Illuminance, Light Intensity Roof skylight windows, Uniformity, Energy saving**

I. INTRODUCTION

LED is the most commonly used light source for energy saving as compared to CFL and tungsten lamps whose efficacy is comparatively less. The electricity consumption is a major cause of concern in homes and offices especially the electrical lighting during the day time. If we can harness the daylight during day time and make it pass through deep core regions of a building then we can minimize the usage of artificial lights thus reducing electricity consumption and saving energy. In most cases, roof skylight windows and anidolic day lighting systems are used for lighting the interior part of a room [1]. But care must be taken to reduce the effects of glare and temperature which make people uncomfortable. Day lighting depends on the weather conditions on a particular day. Daylight is a combination of sunlight and sky light and is an important factor which determines the illuminance at a particular place and time [2]. The psychological benefits of using natural lighting at homes and work places on human behavior has been proved to be very advantageous [3]. Hansen et al. studied the integration of daylight with electrical lighting and its effect on human behavior and found that the hybrid dynamic lighting arrangement helped to increase the productivity of the work by providing a comfortable and healthy environment [4]. All day lighting strategies make use of the luminance distribution from the sun, sky, buildings, and ground. Daylight strategies depend on the availability of natural light, which is determined by the latitude of the building site and the conditions immediately surrounding the building, e.g., the presence of obstructions. Day lighting strategies are also affected by climate; thus, the identification of seasonal, prevailing climate conditions, particularly ambient temperatures and sunshine probability, is a basic step in daylight design as concluded by Aschehoug, 2000, p. 31 [5].

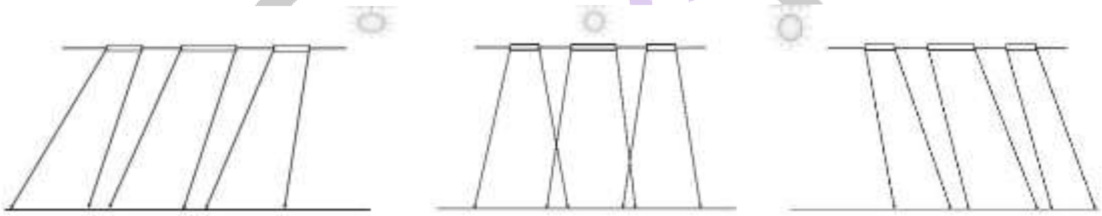
Karam M. Al-Obaidi et. al. evaluated natural light and thermal heat as variables of the roof skylight system on the basis of 1) External Environmental Conditions (EEC) 2) Skylight Roofing System (SRS) 3) Indoor Environmental Condition (IEC) [6]. In order to light the interior of a single-storeyed building there is a limitation to the ratio of the size and number of skylights to the height of the room. The thumb rule states that one skylight can light an area three times the height of the ceiling [7]. The number of roof windows and size are important for maintaining the elegance, cost and performance of the building. Remon Lipsa et al studied the skylight-roof ratio in a warehouse and found that in tropical conditions if the ratio of the area of the skylights is between 2.5 to 5% then it provides sufficient lighting up to 50% during daytime and the degree hour thermal discomfort is also reasonable [8]. Larger aperture areas provide more lighting but causes discomfort in terms of heating and cooling. The optimum design for roof windows was observed to be 15% of the aperture to floor ratio or AFR in the north and south direction [9]. Studies on the ceiling depth showed that it is an important simulation parameter which affects the energy performance of a skylight. The skylight-to-roof ratio and the ceiling depth has been optimized depending on the climatic conditions of a region [10]. Ghany & Salama observed that the increase in window to wall ratio (WWR), window area and window height can help in reducing the lighting energy consumption. Sloped ceilings can direct more light into the room [11]. Ignacio Acosts et al studied software simulations on four different skylight reflectors-rectangular, slanted, curved, and sawtooth on two opposite vertical openings. They concluded that the highest average daylight is obtained when the height to the width ratio was close to 1:1 for overcast sky conditions regardless of the reflector shape and the room ratio [12]. Mangkuto et al compared virtual natural lighting with real window under similar sky conditions and found that real window gives a higher average illuminance under clear skies whereas hypothetical real windows give better light distribution under overcast and partly clouded skies [13].

The skylight coverage is optimised between 9 and 18% [14]. Theodora Mavridou developed an algorithm based on target illuminance between 300 to 500 lx, uniformity (< 0.4 minimum to average illuminance) and number of roof opening in a given space and found that the distance between two roof openings can be in the range of 10m to 13m [15]. Karen Kensek and Jae Yong Suk studied computer-based day lighting simulations for overcast and clear skies and found that for checking the correct horizontal/direct normal illuminance level on a specific area are required for day lighting simulation calculations [16]. Roof windows having a glazing area between 13% and 17% of the floor area may be used for energy efficiency [17]. Deflectors are used in skylight to reduce the disturbing direct sunlight during certain times in a year to redistribute light [18].

Discomfort glare can be avoided by the proper design of the roof skylight window and its position with respect to the Sun path. Yawale et al found that discomfort is produced when the direct ray from the source in vertical plane enters in the eye at an angle greater than 76° [19]. Bangali 2015 found that field arrangements of luminaries give minimum glare [20]. Most of the studies using hybrid lighting systems mention about uninterrupted lighting with both daylight and electric light. The main scope of this paper is to: (a) Study the effect of a roof skylight window during different times in a day for clear and overcast sky (b) Augment sky roof windows with an array of LED lamps to maintain constant illuminance of 300 lux throughout the day by selectively switching OFF the lamps which is not required at that instant. (c) Determine the energy saved by this combination in a day from 6 AM to 7 PM for both overcast and clear sky conditions.

II. Experimental Section

The main aim of the experiment is to compare the energy saved by using roof windows and LED arrays on lighting a room naturally in the range comfortable for human interaction. It is a known fact that the natural lighting of a room depends on various factors like the geographical location of the building, position of the sun in the sky during various times in a day and the openings in the building. The effect of skylight on the room illuminance was studied for a room having dimensions 10mx10mx4.5m using the software DIALux Evo10 for overcast and clear sky from 6 am to 7 pm [21]. The reflection factors include ceiling 70%, walls 50%, floor 20%. The light loss factor is fixed at 0.80. The location taken is Mumbai having a latitude and longitude of 19.0760° N, 72.8777° E. The window constellation used is one roof window of 1.5mx1.5m at the room centre and four roof windows of 0.5x0.5m placed at the centre of each side. The schematic diagram for a single skyroof window having dimensions 1.5m x 1.5m and four satellite windows having dimensions 0.5m x 0.5m is shown in figure 1.



a) *Morning 8 AM* *b) Noon 12 PM* *c)Evening 4 PM*

Fig. (1) : Schematic diagram of skylight roof windows from morning to noon to evening

An illuminance of 300 lux is maintained in a 10m x10m room with a height of 4.5m illuminated using an array of four 2x2 SMD LED lamps PLS1203040 of 38.8W from 6 AM to 7 PM. The schematic diagram is shown in figure 2.

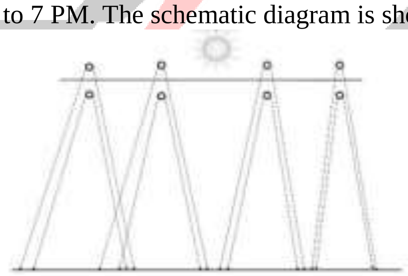
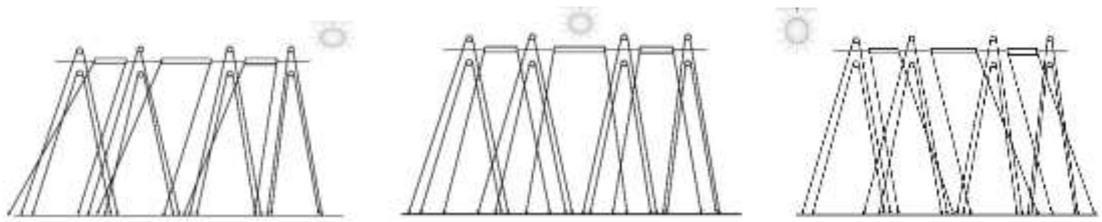


Fig. (2) : Schematic diagram of room lighting using LED lamps

The skylight roof windows and the array of LED lamps are integrated together as shown in figure 3.



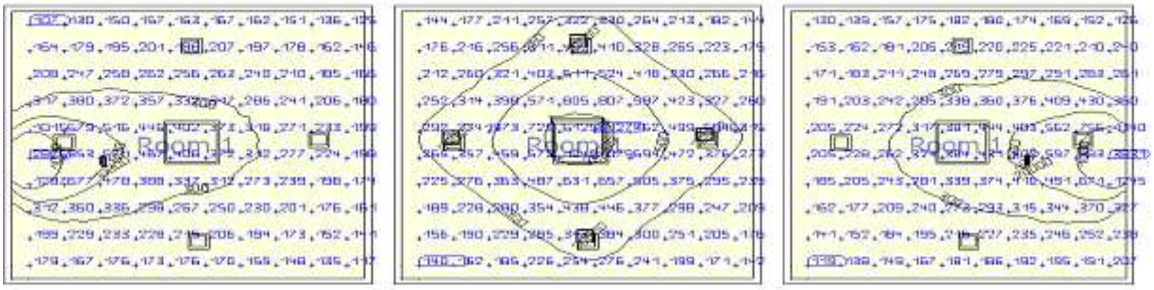
a) *Morning 8 AM* *b) Noon 12 PM* *c)Evening 4 PM*

Fig. (3) : Schematic diagram of room lighting using LED lamps and skylight roof windows.

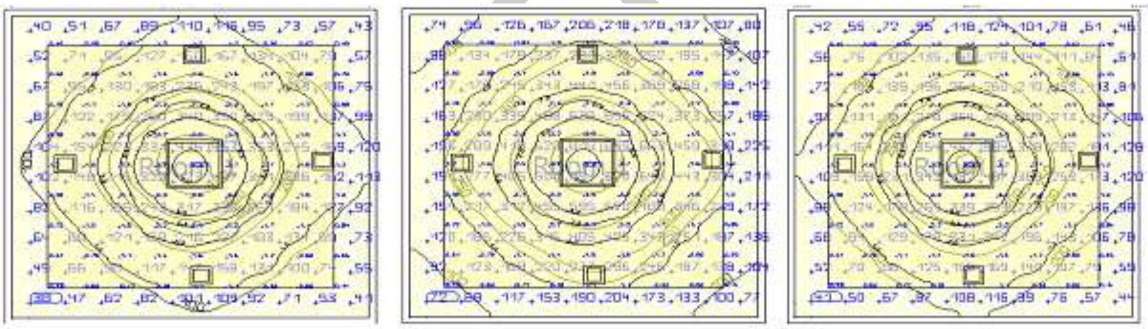
The illumination is performed in a controlled manner by switching ON and OFF the lamps from morning 6 AM to 7 PM on 5th May 2021 to maintain required illuminance. The readings are taken for both overcast and clear sky for calculating the energy saved in the process.

III. RESULTS AND DISCUSSION

The roof skylight window with dimensions 1.5mx1.5m at centre and 0.5mx0.5m at the four centre corners are simulated using DIALux Evo10.1 from morning 6 am to evening 7 pm as shown in figure 4(a) for clear sky and in figure 4(b) for overcast sky.



a) *Morning 8 AM* *b) Noon 12 PM* *c)Evening 4 PM*



a) *Morning 8 AM* *b) Noon 12 PM* *c)Evening 4 PM*

Fig. (4) : Illumination pattern during morning, noon and evening for (a) Clear Sky (b)Overcast Sky

Similarly simulation is performed using LED lamps. Since the simulation is performed in a closed room the illumination remains constant throughout the day as shown in figure 5.

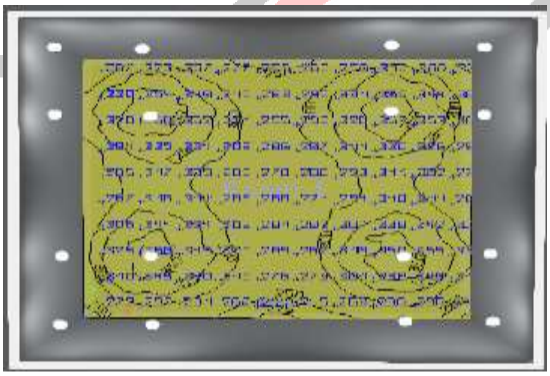


Fig. (5) : Illumination pattern using four 2X2 arrays of LED lamps.

The skylight roof window integrated with an array of four 2x2 LED lamps can provide illuminance of around 300 lux while saving energy for both overcast and clear sky conditions. The illumination pattern obtained after simulation is shown in figure 6.

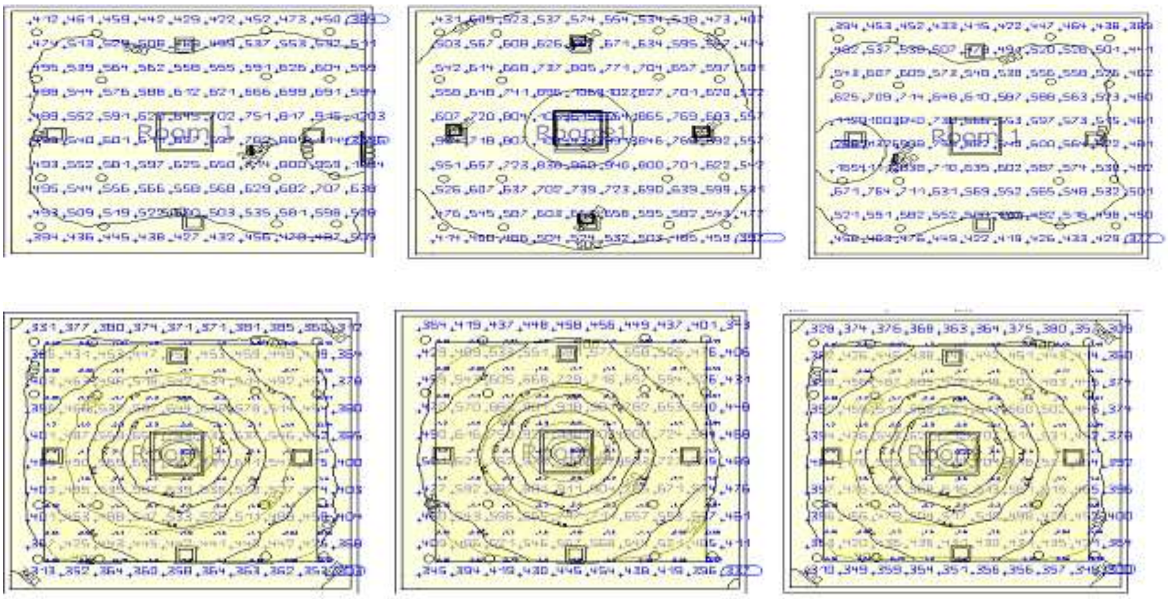


Fig. (6) : Room illuminance pattern after integrating roof skylight windows with LED lamps for
a) **Clear Sky (b) Overcast Sky**

The graph of average illuminance is shown in figure 7 for clear sky and an overcast sky. It can be seen from both the graphs that illuminance increases gradually reaches peak at noon and then reduces.

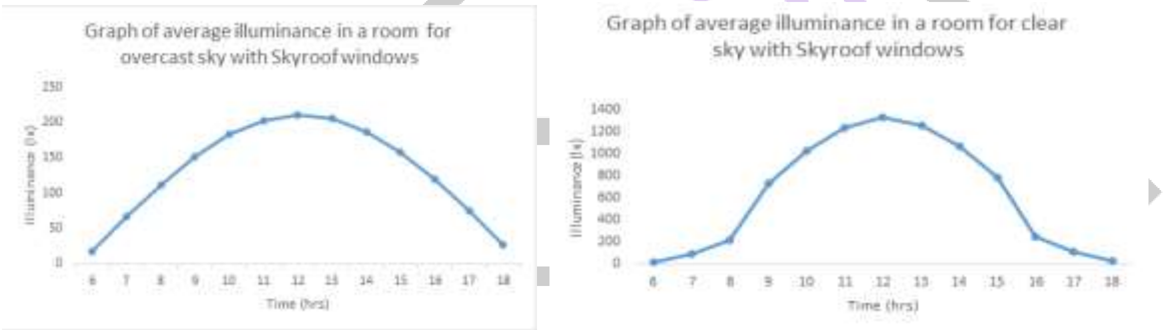


Fig. (7) : Graph of average illuminance with respect to time for (a)Clear Sky (b) Overcast sky with Skyroof Windows.

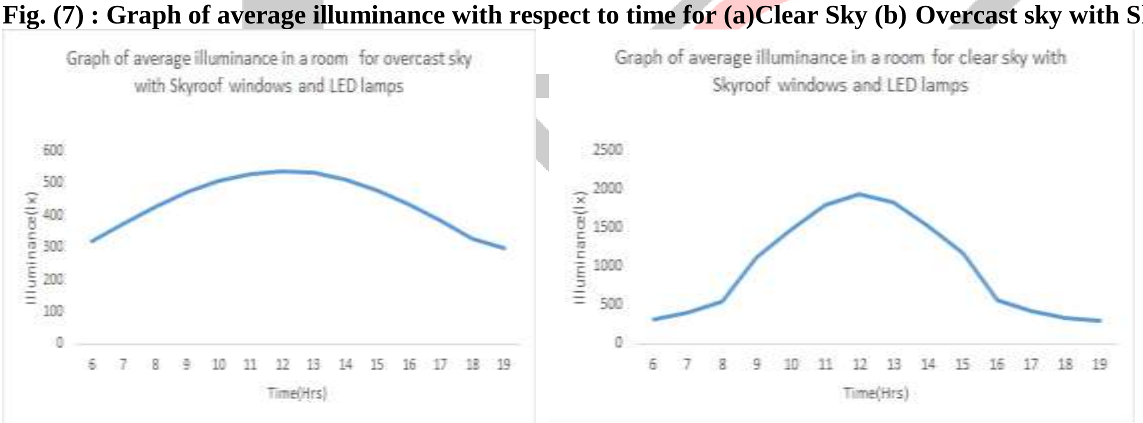


Fig. (8) : Graph of average illuminance with respect to time for (a) Clear Sky (b) Overcast sky with Skyroof Windows and LED lamps.

The energy saving is obtained by switching OFF the LED lamps in a systematic manner to obtain a constant illuminance of around 300 lux. For this an array of light detectors is required which can turn ON and OFF an array of switches in a systematic manner depending on the light intensity in the room throughout the day. For this smart lighting can be used with solid state lighting and IP enabled lights. Smart lighting allows lighting to be dynamically controlled and adaptive to ambient conditions. Wireless enabled and internet connected lights can be controlled remotely using IoT architecture as shown in the block diagram in figure 9.

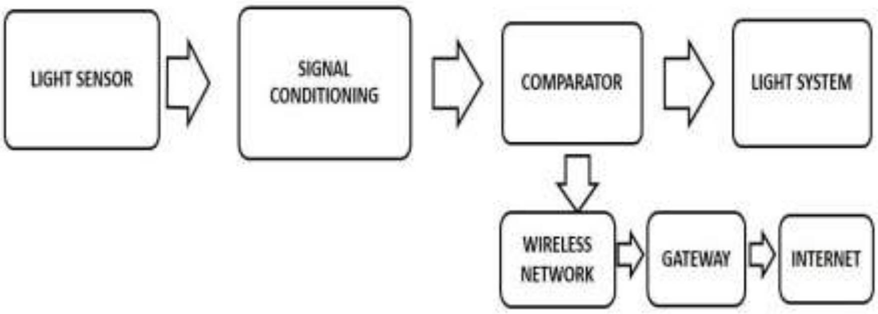


Fig. (9): Block diagram of Smart Lighting to augment Skyroof windows

It is observed that if 16 LED lamps of 38.8 Watts were to remain ON from 6 AM to 7 PM then the total energy consumed will be 8.07 KWatt-hour. But if the LED lamps are switched off by detecting the light intensity greater than or equal to300 lux then 5.7KWatt-hour energy is saved per day under clear sky condition and 2.6KWatt-hour energy can be saved per day even for an overcast sky condition as shown in table 1.

Table 1: Energy saving for overcast and clear sky condition

OVER CAST			CLEAR		
Time	Lamp OFF	Energy saved	Time	Lamp OFF	Energy saved
6	0	0.0	6 AM	0	0.0
7	3	116.8	7 AM	4	155.2
8	6	232.8	8 AM	12	232.8
9	8	310.4	9 AM	16	465.6
10	10	388.0	10 AM	16	620.8
11	11	426.8	11 AM	16	620.8
12	12	465.0	12 PM	16	620.8
13	11	426.8	13 PM	16	620.8
14	10	388.0	14 PM	16	620.8
15	8	310.4	15 PM	16	620.8
16	6	232.8	16 PM	14.5	504.4
17	3	116.4	17 PM	9	194.0
18	2	77.6	18 PM	2.5	0.0
19	0	0.0	19 PM	0	0.0

IV. CONCLUSION

To maintain illuminance between 300 to 500 lux and uniformity, the roof skylight windows can be configured as a constellation of a single higher dimension roof window at the centre surrounded by four smaller windows. There should be a hybrid lighting system which should switch on artificial lighting whenever the light intensity falls less than 300 lux and switch off when the light intensity goes above 300 lux. In order to maintain illuminance around 300 lux, a hybrid illumination system using roof windows and an array of LED lamps is seemed to be effectively used thereby saving sufficient energy.

V. ACKNOWLEDGMENT

The author would like to acknowledge Dr. Arvind Shaligram CEO, SPPU Research Park Foundation and Emeritus Professor, Department of Electronic Science for his valuable guidance.

REFERENCES

[1] Manju G. Nair, Ramamurthy K (2014), *Classification of indoor daylight enhancement systems*, Lighting Research and Technology, April 2014; Vol. 46: 245–267, DOI:10.1177/1477153513483299, (https://www.researchgate.net/publication/274538578)

[2] Allen Jong-WoeiWhang, Tsai-Hsien Yang, Zhong-Hao Deng, Yi-Yung Chen, Wei-Chieh Tseng and Chun-Han Chou (2019), *A Review of Daylighting System: For Prototype Systems Performance and Development*, Energies 2019, 12, 2863; doi:10.3390/en12152863, www.mdpi.com/journal/energies .

[3] Veitch, J. A., Galasiu, A. D. (2012), *The Physiological and Psychological Effects of Windows, Daylight, and View at Home: Review and Research Agenda*, Research Report (National Research Council Canada. Institute for Research in Construction), 2012-Feb-28. http://doi.org/10.4224/20375039,

[4] Ellen Kathrine Hansen , Thomas Bjørner , Emmanouil Xylakis and Mihkel Pajuste (2021), An experiment of double dynamic lighting in an office responding to sky and daylight: Perceived effects on comfort, atmosphere and work engagement, Indoor and Built Environment 0(0) 1–20 ,The Author(s) 2021, Article reuse guidelines: sagepub.com/journals- permissions DOI: 10.1177/1420326X21991198 journals.sagepub.com/home/ibe

[5] Oyvind Aschehoug, Samil Aydinli, Jens Christoffersen, Ian Edmonds Solartran (2000), *Daylight in buildings- A sourcebook on daylighting systems and components*, A report of IEA SHC Task 21/ ECBCS Annex 29, July 2000 https://www.researchgate.net/publication/37410170.

[6] Al-Obaidi, K.M., et al. (2014), *A study of the impact of environmental loads that penetrate a passive skylight roofing system in Malaysian buildings*, Frontiers of Architectural Research, http://dx.doi.org/10.1016/j.foar.2014.03.004

[7] Francesco De Luca Raimo Simson Jarek Kurnitski Hendrik Voll (2018), *Ruukki Daylighting Report. Skylight design and daylight contribution analysis* at: https://www.researchgate.net/publication/328307394, 16 October 2018.

[8] Remon Lapisa, Arwizet Karudin1, M. Martias, K. Krismadinata, A. Ambiyar, Zaid Romani, Patrick Salagnac (2019), *Effect of skylight–roof ratio on warehouse building energy balance and thermal–visual comfort in hot-humid climate area*, Asian Journal of Civil Engineering, Received: 4 September 2019 / Accepted: 23 March 2020 © Springer Nature Switzerland AG 2020, https://doi.org/10.1007/s42107-020-00249-9

[9] Ladan Ghobad, Wayne Place, and Soolyeon Cho, North Carolina State University (2013), *Design optimization of daylight roofing systems: roof monitors with glazing facing in two opposite directions*, Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28.

[10] Amina Irakoze, Young-A Lee and Kee Han Kim (2020), *An Evaluation of the Ceiling Depth's Impact on Skylight Energy Performance Predictions Through a Building Simulation*, Received: 20 March 2020; Accepted: 10 April 2020; Published: 13 April 2020, Sustainability 2020, 12, 3117; doi:10.3390/su12083117 www.mdpi.com/journal/sustainability

[11] Usama A. Abdel Ghany , Mohamed A. Salama (2021), *The effect of day ligthing on reducing energy consumption in buildings*, Al-Azhar University Civil Engineering Research Magazine (CERM) Vol. (43) No. (2) April . 2021, p361-381

[12] Ignacio Acosta, Jaime Navarro, Juan José Sendra (2014), *Towards an analysis of the performance of monitor skylights under overcast sky conditions*, Energy and Buildings 88 (2015) 248–261, 12th Dec 2014, http://dx.doi.org/10.1016/j.enbuild.2014.12.011 0378-7788/© 2014 Elsevier B.V.

[13] R.A. Mangkuto, S. Wang, M.B.C. Aries, E.J. van Loenen, J.L.M. Hensen (2014), Comparison between lighting performance of a virtual natural lighting solutions prototype and a real window based on computer simulation, Frontiers of Architectural Research (2014) 3, 398–412, Received 26 February 2014; received in revised form 10 July 2014; accepted 10 July 2014 HOS, http://dx.doi.org/10.1016/j.foar.2014.07.001 2095-2635/& 2014.

[14] Abdelkrim Trabelsi1, Emmanuel Bozonnet, Patrick Salagnac, Rafik Belarbi and Rémi Perrin (2011), Roof design and skylight effects on the energy performance and comfort of low energy industrial roof design and skylights effects on the energy buildings, Conference Paper · January 2011, DOI: 10.18086/swc.2011.02.08, https://www.researchgate.net/publication/258642043.

[15] Theodora Mavridou and Lambros T. Doulos (2019) Evaluation of Different Roof Types Concerning Daylight in Industrial Buildings during the Initial Design Phase: Methodology and Case Study, Received: 25 June 2019; Accepted: 12 July 2019; Published: 16 July 2019, Buildings 2019, 9, 170; doi:10.3390/buildings9070170, www.mdpi.com/journal/buildings

[16] Karen Kensek, Jae Yong Suk, Daylight Factor (overcast sky) versus Daylight Availability (clear sky) in Computer-based Daylighting Simulations.

[17] S. Robertson & M. Thompson (2006), *Guidelines for sizing roof windows*, Eco-Architecture: Harmonisation between Architecture and Nature 351, WIT Transactions on The Built Environment, Vol 86, 2006 WIT Press, www.witpress.com, ISSN 1743-3509 (on-line), doi:10.2495/ARC060351

[18] Francesco De Luca Raimo Simson Jarek Kurnitski HendrikVoll (2016), *RuukkiDaylighting Report-Skylight design and daylight contribution analysis*, Tallinn University of Technology, Technical Report · April 2016(16 October 2018).https://www.researchgate.net/publication/328307394

[19] P. R. Yawale, V. G. Wagh, A. D. Shaligram (2021), *Reduction of discomfort glare through relative positioning of LED luminary and observer*, The Optical Society of India 2021, J Opt Received: 8 March 2021 / Accepted: 9 August 2021, https://doi.org/10.1007/s12596-021-00756-1.

[20] Jayshri Bangali (2015), *Evaluation of Discomfort Glare by using Lighting Simulation Software for Optimal Designing of Indoor Illumination Systems*, International Journal of Emerging Engineering Research and Technology, Volume 3, Issue 12, December 2015, PP 173-178 ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

[21] Pont, Ulrich (2014), Dialux - Tutorial // Visual building performance Simulation - Summerterm Dialux Tutorial Control Groups Auto-Determinating of necessary luminaires Daylight in Dialux a Table of Content: af', Working Paper · March 2014 DOI: DOI: 10.13140/RG.2.1.3923.3683 CITATIONS, https://www.researchgate.net/publication/299521756