Achieving Indoor Thermal Comfort Using AI-Controlled Shading in Hot Arid Climates in Office Buildings

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Abstract:

Hot arid and desert regions like the MENA, Middle East and North Africa, regions are characterized by high levels of solar radiation and high temperatures. Incoming solar radiation on buildings affect the thermal ad visual comfort of building occupants. Large glazed buildings allow solar radiation to get inside the building enhancing visual comfort, but also it affects thermal comfort and causes glare. The building envelope is the main mediator between the outdoor environment and solar radiation and the indoor of buildings in terms of visual and thermal comfort. Climate change resulted in excessive solar radiation which affects thermal and visual comfort in buildings. While solar radiation is considered a potential as renewable energy source, it is now a great challenge to be controlled inside buildings. Daylight can be optimized by different strategies in order to achieve thermal and visual comfort in buildings. This paper presents a study of how to achieve thermal comfort in hot arid climates using an Artificial Intelligence AI-controlled shading system. The proposed AI- controlled shading is applied to an office building in Egypt to check the reduction in energy consumption and enhancement in thermal comfort. This study concluded that the proposed AI- controlled shading system dropped the indoor temperature by 4°C and reduced energy consumption by 25% while thermal comfort complaints decreased by 77.78% and glare difficulties by 76%.

Keywords:

Thermal Comfort, Hot Arid Climate, Shading Device, AI-Controlled Shading

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1. Introduction:

The high levels of incoming direct solar radiation can cause significant thermal and visual discomfort in buildings with large glazed surfaces. It is vital to implement appropriate solutions that restrict incoming solar radiation, such as highly reflecting coatings or movable shade devices, in order to prevent excessive solar gains and glare difficulties for the occupants and also to limit solar gain through openings. However, these devices need to be carefully chosen, taking into consideration potential regulatory requirements as well as the building's position and the glazed facades' exposure. (1)

Hot arid regions constitute a big percentage of the earth's land area and are characterized by harsh weather conditions, high solar radiation, and almost clear skies throughout the year. Consequently, indoor thermal comfort is assumed mainly by consuming big amounts of energy. Despite the global and regional trend to achieve net zero energy buildings by enhancing building envelope thermal performance, the focus in hot arid regions is mostly on increasing the cooling capacity of the mechanical systems with no significant interest in the building envelope thermal performance. Meanwhile, it has been widely demonstrated that the successful application of shading strategies to the external façade can significantly contribute to the prevention of solar gain to achieve indoor thermal comfort, with the possibility of eliminating a significant percentage of the cooling demand without actual damage to the occupants' thermal comfort. High-performance building envelopes tend to provide natural daylight, prevent glare, and increase thermal comfort for indoor spaces.(2) Egypt is not an exception to the global concern over construction energy consumption (3).

Artificial intelligence (AI) is a technology that allows computers and machines to mimic human intelligence and problem-solving abilities. Whether used alone or with other technologies like sensors, geolocation, and robotics, AI can perform tasks typically requiring human intervention. The use of artificial intelligence (AI) to control the facade shading systems can significantly enhance the efficiency of its operation to maintain the desired level of thermal comfort. The AI controller, having access to both the weather pre-vision and the building envelope thermal properties, can provide early pre-cooling during the night when the thermal imbalance is negative and enhance shading during the day thermal peak to guarantee thermal comfort while minimizing the energy penalty. The efficient utilization of available daylight and the preservation of the outside view passively expose people in space to the relations with their external environment and when available through the proper facade window design can significantly contribute to reducing the energy demand of the building lighting and enhancing the psychological and physical well-being of the occupants.

According to K.A. Cort et al, using blinds and window shades saves an average of 18% energy in cooling seasons, mostly in hot arid zones [(4)]. This study is only for normal shading devices without studying the effect of using AI-controlled shading. The study concluded that energy performance varied according to the used strategy while attached window shades were capable of generating savings in both heating and cooling seasons [(5)]. A study by Alwetaishi M. et al concluded that in hot regions, the impact of using shading devices controls the sunlight coverage of indoor floor area to less than 20% which limits the penetration of daylight [(6)]. This is due to having manual control which limits the ability of controlling the daylight penetration in desired times as it's only affected by temperature factor not daylight also. As for the study by Dev, G. et al, the combination of horizontal and vertical shading devices gave optimum daylighting inside buildings giving consideration only to daylight and neglecting thermal comfort and how it is affected by shading devices [(7)]. As stated by Joshi, Neha & Patki, Pradnya, Some shading devices perform poorly in daylight because they cause maximum exposure to harsh sunlight which results in discomfort and glare, this is because they use regular manual control in terms of glare control and quality of daylight [(8)]. According to A Nocente et al, integrated shading devices reduced indoor illuminance and overheating as well but limited the view of surroundings and although integrated screens had an impact on solar radiation, it differed according to the control mechanism which modulated the transition from dark to light and lead to increased discomfort caused by the string contrast [(9)]

As mentioned in the literature review, the efficiency of conventional shading devices, whether manually operated or automatically controlled, is significantly compromised by the dynamic nature of sunlight and glare, which vary daily and hourly. Despite the installation of these shading solutions, several issues persist. These include problems with glare, inadequate daylight penetration, and challenges in effectively controlling heat transfer, thereby affecting the thermal comfort of the occupants. The lack of adaptability in current shading systems to the ever-changing environmental conditions highlights the need for more innovative and responsive solutions. Addressing these deficiencies is crucial for improving indoor environmental quality and energy efficiency in buildings.

2. Research Methodology:

This research adopts a deductive approach to investigate the impact of AI-controlled shading devices on indoor thermal comfort and energy efficiency in office buildings located in hot arid climates with New Cairo, Cairo, Egypt as the Case Study focus. The study is an applied research aiming to provide practical solutions for real-world problems employing both qualitative and quantitative methods to ensure a comprehensive analysis and accurate results as shown in Figure 1.

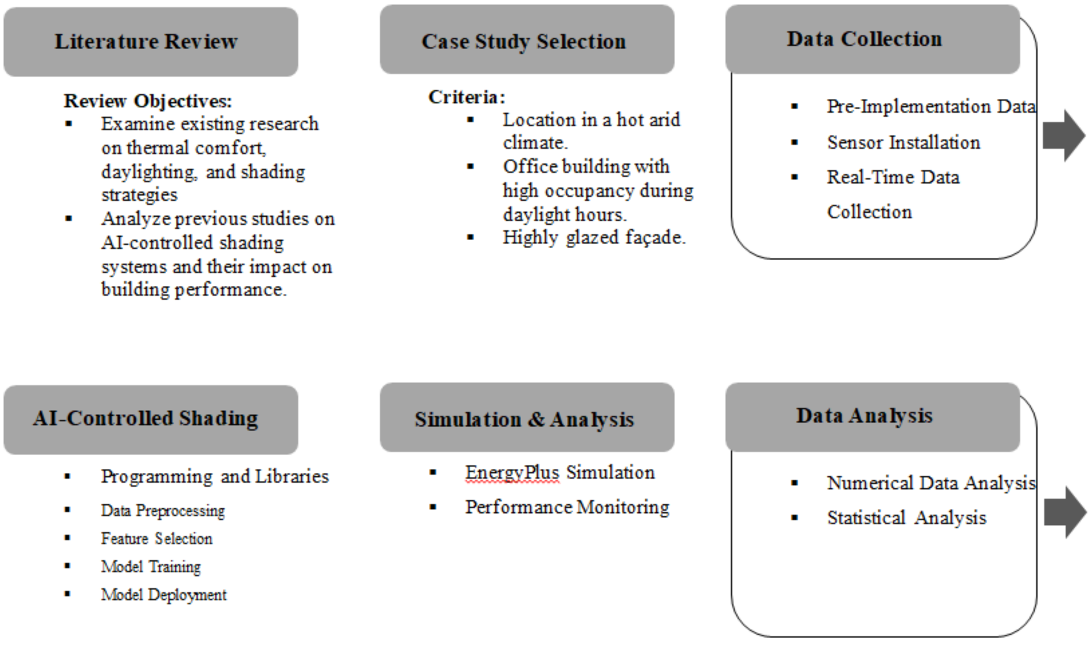

Fig. 1: Research Methodology

3. Thermal Comfort:

Given that most of the time that modern man spends indoors, thermal comfort a mental state that indicates happiness with the thermal environment is a crucial consideration in the construction of buildings. In order to organize these improvements around two primary themes thermal comfort models and standards and computer advancements this study covers the developments in indoor thermal comfort research and practice since the second half of the 1990s. The first theme discusses Fanger's PMV-model (Predicted Mean Vote), which was developed in the late 1960s, in light of the development of models for adaptive thermal comfort. The adaptive models relate to choices for individual control over the interior climate, psychology, and performance, and they are predicated on the adaptable opportunities of the inhabitants [10]. Thermal comfort influences people's working conditions and has the potent potential to evoke moods. To maximize comfort, a favorable setting can be established. One of the best ways to create a friendly environment is to employ shade devices. shading devices affect thermal comfort in creating a thermally comfortable atmosphere [11].

4. Daylight:

High illuminance and superior color rendering and discernment are made possible by daylight. Because of these two characteristics, daylight creates the ideal environment for clear vision. Good vision can be hampered by daylight's uncomfortably bright solar glare and extremely bright reflections on display screens. Therefore, how daylight is provided affects how well tasks are performed when exposed to it. Every one of these elements must be taken into account when designing buildings with daylighting [12]. The widespread usage of glass in building envelopes has long captivated architects and building owners. Currently, the heavily glassed facade nearly serves as a distinctive feature for a 'green building', offering natural light and a visible link to the outside world. There was no shortage of highly glazed building designs even prior to the present interest in green buildings. Yet, a large number of these structures either rejected sunlight—some of which linked daylight and views with highly reflective glazing—or they used highly transmissive glass and experienced severe issues with internal comfort that could only be resolved with substantial HVAC systems, carrying heavy financial, environmental, and energy costs [13].

4.1. Daylight Metrics:

Different daylight metrics shown in Table 1 are meant to help designers create pleasant workplaces and effectively manage daylight. These measurements use annual radiations to calculate the amount of daylight available within the spaces. The values were generated using meteorological data and utilized during the hours of occupancy.

Table 1: Daylight Evaluation Metrics [14] [15]

Daylight Performance Metrics						
Daylight metric	**Sky Type**	**Minimum Value**		**Maximum Value**		**Calculations**
Daylight Autonomy	All	300 Lux		N/A		Annual
Spatial Daylight Autonomy	All	300 Lux/ 50% or more of the occupied hours yearly		≥ 75% or more		Annual
Daylight Availability	Types					
	All	Dalylit	Partially daylit	Over lit		Annual
		300 to 3000 Lux/ 50% occupied hours yearly	Less than 300 Lux / less than 50% occupied hours yearly	More than 3000 Lux/ more than 50% occupied hours yearly		
Discomfort Metrics						
Annual Sunlight Exposure (ASE 1000 Lux/ 250 hours early)	Types					
	All	Accepted Less than 3%	Neutral Less than 7%	Unsatisfactory over 10% of the region has direct daylight for over 20 hours a year		Annual
Daylight Glare Probability	Types					
	All	Imperceptible	Perceptible	Disturbing	Intolerable	
		Daylight Glare Probability < 35%	35% ≤ Daylight Glare Probability < 45%	40% ≤ Daylight Glare Probability < 45%	Daylight Glare Probability ≥ 45%	Annual In Time

4.2 Daylight Control Systems

Natural light should be controlled in buildings to improve indoor visual and thermal comfort as well as to reduce energy consumption of HVAC besides lighting. While architects have employed passive design aspects to control daylight, there are also a number of daylight systems that employs the latest technology. Energy efficiency and environmental quality may be enhanced using ElectroChromic (EC) "dynamic" windows, which can alter their transparency characteristics in response to control factors incorporated in a natural and artificial illumination control system. Given that EC devices are ready for market release, the prospect of integrating EC materials into building windows as a commercial light control system component seems extremely intriguing these days.[16]

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5. AI-Controlled Shading:

Shading devices are low-maintenance elements placed inside or outside the building envelope to block the unwanted glare and heat in the building's indoor space [18]. Automated window blind control systems provide the ability to adjust the amount of lighting and reduce glare that can be uncomfortable for occupants with less waiting time than manually controlling motorized blind devices [19]. In summer, shading devices keep the sun from entering the structure, but in the winter, they let in the necessary solar gains. This results in improved thermal comfort and significant energy savings. AI-Controlled shading contributes to achieving seasonal thermal comfort and visual comfort [20]. Few theories have addressed this in the literature as of yet. In order to close this gap, this study presents a novel AI- controlled shading that conditionally optimizes the thermal comfort of indoor spaces.

6. Materials and Methods:

6.1 Description: Coding Language: Python Programming Language, Python is a high-level, interpreted programming language known for its simplicity, readability, and versatility. It supports multiple programming paradigms, including procedural, object-oriented, and functional programming. Python is widely used in scientific computing, data analysis, artificial intelligence, and machine learning due to its extensive ecosystem of libraries and frameworks. Its ease of use and robust community support make it a popular choice for researchers and developers.

6.2 Libraries Used:

1- Pandas Scientific Term: Python Data Analysis Library (Pandas)

Description: Pandas is an open-source data manipulation and analysis library for Python. It provides data structures like DataFrames and Series, which are essential for handling structured data efficiently. Pandas offer a wide range of functions for data cleaning, transformation, and analysis, making it a vital tool for data scientists.

2- Scikit-Learn Scientific Term: Scikit-Learn Machine Learning Library

Description: Scikit-Learn is a powerful machine learning library for Python, built on NumPy, SciPy, and Matplotlib. It provides simple and efficient tools for data mining and data analysis, including classification, regression, clustering, and dimensionality reduction algorithms. Scikit-Learn is known for its easy-to-use interface and comprehensive documentation.

3- TensorFlow and Keras Scientific Term: TensorFlow Machine Learning Framework and Keras API

6.3 Description:

TensorFlow is an open-source machine learning framework developed by Google Brain. It provides comprehensive tools for building and deploying machine learning models. Keras is an open-source neural network library written in Python and integrated into TensorFlow. It offers a high-level API for building and training deep learning models quickly and easily.

6.4 Model Training Examples

6.4.1 LSTM Model Training

Long Short-Term Memory (LSTM): Scientific Term: Long Short-Term Memory Neural Network (LSTM)

Description: LSTM is a type of recurrent neural network (RNN) designed to capture long-term dependencies in sequential data. It overcomes the vanishing gradient problem commonly encountered in traditional RNNs, making it suitable for tasks such as time series prediction and natural language processing.

6.5 Description of AI-Controlled Shading Model

The AI-controlled shading system is made to minimize energy usage and maintain ideal indoor thermal comfort by dynamically adjusting shading devices based on real-time data. Utilizing machine learning techniques, the system anticipates and reacts to variations in environmental factors including temperature, occupancy, and solar radiation. The AI-controlled shading system code is available and can be retrieved from: https://github.com/users/Mahafawzyaly/projects/1/views/1?visibleFields=%5B%22Title%22%2C%22Assignees%22%2C%22Status%22%2C%22Repository%22%2C%22Milestone%22%5D&pane=issue&itemId=72806171. The following are the main elements and procedures that make up the AI-controlled shading system:

6.5.1 Data Collection Sensors

Data Gathering The building's outside and interior temperatures, occupancy, and sun radiation are all measured via sensors positioned throughout. These sensors give the AI system access to real-time data so that it can make defensible conclusions.

6.5.2 Data Preprocessing

Preparing Data Preprocessing is done on the gathered data to deal with missing values and eliminate noise. This stage makes sure the clean and trustworthy data that is put into the machine learning model. To standardize the data, methods like scaling and normalization are used.

6.5.3 Feature Selection

Choosing Features Relevant characteristics that affect energy usage and indoor thermal comfort are chosen. Intensity of sun radiation, temperature both inside and outside, daytime, and occupancy levels are some of these characteristics. Feature selection lowers computing complexity and increases model accuracy.

6.5.4 Model Training

Training Models for machine learning are trained using the processed data. To find the best-performing model, a variety of methods are examined, such as neural networks, decision trees, and regression models. To assess the performance of the model, the data is divided into training and validation sets during the training process.

6.5.5 Model Deployment

Model Implementation The model is sent to the building's control system after it has been trained and verified. The shading devices are adjusted by the AI model based on real-time data that is continuously received. By balancing natural light and thermal comfort, the system seeks to reduce the need for HVAC systems.

6.5.6 Performance Monitoring

Monitoring Performance The performance of the AI-controlled shading system is regularly assessed to make sure it achieves the targeted energy efficiency and thermal comfort levels. Occupant feedback and additional information gathered over time to help improve its performance.

7. System Flowchart:

Figure 2 shows the system flow chart showing the diagrammatic representation which illustrates how the AI-controlled shading system works.

8. Case Study:

Crédit Agricole Egypt Headquarters design aims to create a high-standard, flexible office building for Crédit Agricole Egypt, meeting international standards and future-proofing for 10-20 years. It emphasizes a strong street presence, an interior garden, and clear separations for services, staff, and visitors. The campus-like layout maximizes site use and ensures future adaptability. Figures 3 & 4 show the building design and layout plan while Table 2 shows the building data.

Table 2: Case Study Building Data

Building Name	Crédit Agricole Egypt Headquarters
Location	New Cairo City, Cairo Governorate, Egypt
Building Type	Office Building
Size	25000 Sqm
Construction Year	2016
Building Envelope	Highly glazed façade with double-glazed low-emissivity windows

8.1 Case Study Choosing Criteria:

1- **Climate Suitability:** The building is located in New Cairo City, Egypt, which experiences a hot arid climate. This climate is characterized by high solar radiation and high temperatures, making it an ideal setting to evaluate the effectiveness of AI- controlled shading devices in mitigating heat and glare.

2- **Building Type and Usage:** The selected building is an office building. Office buildings typically have high occupancy rates during daylight hours, which aligns with the peak times for solar radiation. This makes them suitable for studying the impact of shading devices on thermal and visual comfort during working hours.

3- **Building Envelope Characteristics:** The Crédit Agricole Egypt Headquarters features a highly glazed façade with double-glazed low-emissivity windows. Such buildings are particularly prone to issues related to solar gains and glare, making them ideal candidates for evaluating the benefits of advanced shading systems.

4- **Technological Infrastructure:** The building is equipped with modern technological infrastructure that supports the integration of advanced AI systems. This includes the availability of sensors for temperature, occupancy, and solar radiation, which are necessary for the AI-controlled shading system to function effectively.

5- **Representative Nature:** As a prominent office building in a hot arid region, the Crédit Agricole Egypt Headquarters serves as a representative case study for other similar buildings in the Middle East and North Africa (MENA) region. The findings from this case study can potentially be generalized to other buildings facing similar environmental and comfort challenges.

These factors provide a strong baseline for assessing the improvements brought by the proposed AI- controlled shading system.

Fig. 3: Crédit Agricole Egypt Headquarters

Fig. 4: Crédit Agricole Egypt Headquarters plan

8.2 Thermal Comfort Assessment in Base Case

The base case conditions are shown in table 3, the average indoor temperature and energy consumption resulting from HVAC system.

Table 3: Base case conditions

Average Indoor Temperature	29°C
HVAC Energy Consumption	400,000 kWh/year
Occupant Thermal Comfort Complaints	15 per month
Glare Issues Reported	Glare Issues Reported

8.3 Applied AI- Controlled Shading:

The AI- Controlled shading device in the Crédit Agricole Egypt Headquarters' AI-controlled shading system are controlled by a machine learning algorithm. In order to maximise shade, this model makes use of room temperature, occupancy levels, real-time solar radiation data, and weather forecasts. To collect data, the system makes use of occupancy, temperature, and solar radiation sensors. TensorFlow was used to create AI models, EnergyPlus was used to simulate energy, and Python was used to analyze data.

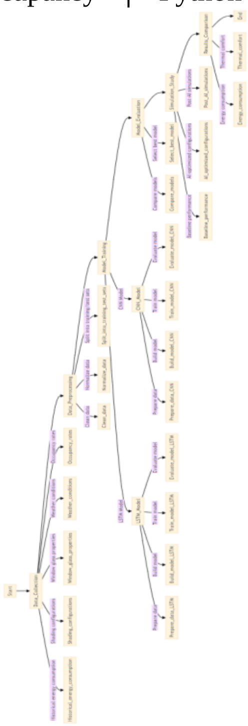

Fig. 2: system flowchart

8.4. Post-Implementation Thermal Comfort Assessment:

Table 4 shows the improved conditions resulting from using the AI-controlled shading system.

Table 4: Improved conditions

Average Indoor Temperature	25°C
HVAC Energy Consumption	300,000 kWh/year
Occupant Thermal Comfort Complaints	3 per month
Glare Issues Reported	5 Glare Issues Reported per month

8.5 Numerical Data Analysis

The data was collected and analyzed using Energy Plus for simulating building energy performance and Tensor Flow for developing the AI model. Python was used for data preprocessing, feature selection, and result visualization. These data are shown in tables 5, 6 and 7.

Table 5: Energy consumption rates, savings and reduction percentage

Condition	Energy Consumption (kWh/year)	Energy Savings (kWh/year)	Percentage Reduction
Before Implementation	350,000	-	-
After Implementation	250,000	100,000	28.57%

Table 6: Thermal Comfort Complaints

Condition	Complaints Per Month	Percentage Reduction
Before Implementation	15	-
After Implementation	3	80%

Table 7: Glare Issues

Condition	Glare Issues Per Month	Percentage Reduction
Before Implementation	20	-
After Implementation	5	75%

The AI-controlled shading system that was installed in Credit Agricole headquarters building greatly enhanced indoor thermal comfort while using less electricity. By 4°C, the average indoor temperature dropped to a level that was more comfortable for occupants. A significant financial savings and beneficial environmental impact are represented by the annual reduction of 100,000 kWh in HVAC energy usage. The success of the shading system in improving thermal and visual comfort is further demonstrated by the notable drop in occupant complaints about glare and thermal discomfort.

9. Results and Discussion:

Promising outcomes have been observed when an AI-controlled shading system is used in hot, arid areas. A case study carried out in a building in Egypt representing this climatic zone has shown notable savings in energy use and increases in indoor thermal comfort. Significant energy savings, increased thermal comfort, and better visual comfort were reported by buildings with AI-controlled shading systems. In line with net-zero energy goals, the dynamic shade adjustments optimized natural light lowered HVAC loads, and lessened discomfort from solar radiation and glare. The system works well in a variety of building types and climates because of its scalability and versatility.

The average indoor temperature dropped by 4°C after the AI-controlled shading system was installed, greatly improving thermal comfort. 25% less energy was used, saving 100,000 kWh annually and lessening the load on the HVAC system. Improved occupant satisfaction and visual comfort were demonstrated by a 76% decrease in glare difficulties and a 77.78% decrease in thermal comfort complaints. These outcomes highlight the system's usefulness in maximizing interior environment quality and energy efficiency, which makes it an advantageous addition to structures in hot arid areas.

10. Conclusions:

An effective way to achieve both indoor thermal comfort and energy efficiency in buildings situated in hot and arid areas is to integrate AI-controlled shading systems. These systems use machine learning algorithms and real-time data to dynamically change shading devices in order to minimize solar gains and maximize natural light. Case study results show notable reductions in energy consumption and increases in thermal and visual comfort. Future studies ought to concentrate on improving the AI models, investigating novel sensor technologies, and extending the use of AI-controlled shading systems to a wider variety of structures and environmental conditions.

11. Recommendations:

To improve indoor thermal comfort and reduce energy consumption in office buildings in hot arid climates, it is recommended to implement AI-controlled shading systems that adjust in real-time based on environmental data such as temperature, occupancy, and solar radiation. Building designs should incorporate high-performance envelopes and consider the integration of advanced materials like

ElectroChromic dynamic windows to optimize daylight use and minimize glare. For future research, it is suggested to refine AI algorithms for better predictive accuracy, explore innovative sensor technologies to enhance data collection and expand studies to include diverse building types and climates to validate and generalize the effectiveness of AI-controlled shading systems.

References:

1- Gianpiero Evola, Federica Gullo, Luigi Marletta "The role of shading devices to improve thermal and visual comfort in existing glazed buildings", Energy Procedia, Volume 134, 2017, Pages 346-355, ISSN 1876-6102,https://doi.org/10.1016/j.egypro.2017.09.543.

2- Awad, Jihad & Abd-Rabo, Lamia. (2020). Daylight and Energy Performance Optimization in Hot - Arid Regions: application and adaptation guide for designers in the UAE. Procedia Manufacturing. 44. 237-244. 10.1016/j.promfg.2020.02.227.

3- Anber, M. (2024) The Efficiency of Using Mineral Insulating Solutions in Buildings in Egypt, International Design Journal, Volume 14_Issue 1_Pages 371-379. DOI: 10.21608/idj.2023.249201.1099

4- K.A. Cort, J.A. McIntosh, G.P. Sullivan, T.A. Ashley, C.E. Metzger, N. Fernandez, (2018) Testing the Performance and Dynamic Control of Energy-Efficient Cellular Shades in the PNNL Lab Homes [Online], Office of Scientific and Technical Information (OSTI), https://doi.org/10.2172/1477792.

5- C. Shum & L. Zhong (2023) A review of smart solar shading systems and their applications: Opportunities in cold climate zones, Journal of Building Engineering 64 (2023) 105583, ELSEVIER.

6- Alwetaishi M., Al-Khatri H., Benjeddou O., Shamseldin A., Alsehli M., Alghamdi S., Shrahily R., (2021). An investigation of shading devices in a hot region: A case study in a school building, Ain Shams Engineering Journal, Volume 12, Issue 3, pp. 3229-3239, ISSN 2090-4479, https://doi.org/10.1016/j.asej.2021.02.008.

7- Dev, G.; Saifudeen, A.; Sathish, A. (2021) Facade control systems for optimal daylighting: A case of Kerala. IOP Conf. Ser. Earth Environ. Sci. 2021, 850, 012014.

8- Joshi, Neha & Patki, Pradnya. (2022). Relationship of shading devices and its effects on daylight in Commercial buildings in Pune. IOP Conference Series: Earth and Environmental Science. 1084. 012079. 10.1088/1755-1315/1084/1/012079.

9- A Nocente et al (2021) Comparative field tests of an electrochromic shading device - thermal and visual comfort . J. Phys.: Conf. Ser. 2069 012222. doi:10.1088/1742-6596/2069/1/012222

10- Hoof, Joost & Mazej, Mitja & Hensen, Jan. (2010). Thermal comfort: Research and practice. Frontiers in Bioscience. 15. 765-788. 10.2741/3645.

11- Asim Ahmad, Om Prakash, Anil Kumar, S.M. Mozammil Hasnain, Puneet Verma, Ali Zare, Gaurav Dwivedi, Anukul Pandey, "Dynamic analysis of daylight factor, thermal comfort and energy performance under clear sky conditions for building: An experimental validation", Materials Science for Energy Technologies,Volume 5,2022,Pages 52-65,ISSN 2589-2991, https://doi.org/10.1016/j.mset.2021.11.003.

12- Ruck, N. & Aschehoug, Øyvind & Aydinli, Samil & Christoffersen, Jens & Edmonds, Ian & Jakobiak, Roman & Kischkoweit-Lopin, M. & Klinger, M. & Lee, Eleanor & Courret, Gilles & Michel, L. & Scartezzini, Jean-Louis & Selkowitz, Stephen. (2000). Daylight in Buildings - A source book on daylighting systems and components.

13- Selkowitz, Stephen & Aschehoug, Øyvind & Lee, Eleanor (2003). Advanced Interactive Facades - Critical Elements for Future GreenBuildings?. the annual USGBC International Conference and Expo, November 2003. LBNL-53876.

14- A. W. &. Fatma Fathy, "A parametric approach for achieving optimum daylighting performance through solar screens in desert climates," Journal of Building Engineering, vol. 3, pp. 155-170, 2015.

15- W. P. &. A. M. A. Jianxin Hu, "Using diva for assessing climate-based leed daylight credit," in The 43rd Annual National Solar Conference, 2014.

16- Gugliermetti, F. & Bisegna, Fabio. (2005). Static and dynamic daylight control systems: Shading devices and electrochromic windows. IBPSA 2005 - International Building Performance Simulation Association 2005.

17- Galal, Omar & Sailor, David & Mahmoud, Hatem. (2020). The impact of urban form on outdoor thermal comfort in hot arid environments during daylight hours, case study: New Aswan. Building and Environment. 184. 107222. 10.1016/j.buildenv.2020.107222.

18- V. Costanzo, R. Yao, E. Essah, L. Shao, M. Shahrestani, A.C. Oliveira, M. Araz, A. Hepbasli, E. Biyik, "A method of strategic evaluation of energy performance of Building

Integrated Photovoltaic in the urban context", Journal of Cleaner Production, Volume 184,2018, Pages 82-91, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2018.02.139.

19- Maria Konstantoglou, Aris Tsangrassoulis, (2016) Dynamic operation of daylighting and shading systems: a literature review, Renew. Sustain. Energy Rev. 60, 268–283.

20- Luo, Z., Sun, C., Dong, Q., & Yu, J. (2021). An innovative shading controller for blinds in an open-plan office using machine learning. Building and Environment, 189, 107529. doi:10.1016/j.buildenv.2020.10752