REVIEW ON WINDOWS OPTIMIZATION FOR ENERGY EFFICIENT BUILDINGS

[1]Sourav Kumar, [2]Sujal Agrawal, [3]Harpreet Singh, [4]Kaustuv Shandilya, [5]Pema, [6]Sunny Kaura

[1]UG Scholar, [2]UG Scholar, [3]UG Scholar, [4]UG Scholar, [5]UG Scholar, [6]Assistant Professor,
School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab, India.

Abstract: Traditional windows need to be effectively optimized and more efficient to reject the solar heat during summertime and trap the same heat in winters to make the building more comfortable. Also, reduce the heating and cooling energy consumption annually, to make that work properly we must adjust the building's orientation and fenestration system. The main aim of this review paper is to analyze the efficiency of the windows and compare their properties in a regular commercial building. Newly designed windows as a substitute for traditional windows are used in commercial buildings nowadays for various purposes such as reduction of air leakage and improvement in insulation properties, help with moisture control, reduced the occurrence of condensation on windows and reduce the load on system. These windows not only help in saving the overall energy of a building and reduce the annual electricity bill but also provide durability. To improve the thermal performance of the building we need to focus on certain elements and make them function properly such as the window glass required, frame type and the glazing.
These elements lead to an efficient building design having power saving capabilities and, also environment friendly.

Other elements, such as the U-factor, visible transmittance (VT), and solar heat gain coefficient, are also effective in improving the building's health and making it more feasible in the case of optimized window design (SHGC). These factors help the designers to build energy efficient buildings without compromising any area in the field of designing and analysis and a proper balance between these factors is must to get the desired window design. Glass material used in the window manufacturing must be robust in keeping the occupants safe from sudden impacts inside the building, helps in annual power consumption and enhanced the properties of a building. The process of designing windows and analyzing its performance should be done properly with the help of various techniques and 3D software to get an optimum window type with maximum output and it also contributes to the environment safety.

Keywords:

U-Value
Visual Transmittance
Thermal Comfort
Windows and Glazing systems Day Living System
Solar Heat Gain Coefficient
Window to Wall Ratio (WWR)

I. INTRODUCTION

Fenestration in a building plays a very crucial role in reducing the overall power consumption and annual energy savings. Efficient window type helps in reducing the amount of heat entering the building during summer and trapping the same heat to keep the rr›nm warm in winter without using any heating alternative. To calculate the total amount of heat gain from solar rays, the building orientation, window surface area, and solar irradiance must all be calculated. When it comes to wind architecture, visible transmittance (VT), U-factor, and solar heat gain coefficient (SHGC) are three significant variables to consider for further analysis.

VT: It is defined as the total amount of visible solar energy passes through the glazing of the window and enters to the building and it is considered more useful for aesthetics in a building in comparison to energy saving reasons. The higher the value of VT more will be the amount of daylight enters into the building and the need of artificial lighting will automatically decrease.

U-FACTOR: This factor helps in enhancing the insulating property of the window. The lower the U-Value the better the insulating value. A low U-Factor helps in reducing the load on heating and cooling system but on the other hand it can degrade the lighting performance of the building.

SHGC: It is known as the fraction of solar radiation that enters a building through the assembly of windows, and it is an important characteristic in improving the energy efficiency of windows. It aids in retaining heat in the winter but also overheats the room in the summer, so striking the right balance between the necessary factors is critical to achieving the best results.
These improved variables lead to a better and efficient HVAC system without putting any unnecessary load on the system. Nowadays different 3D simulation software is used for designing and analysis purpose and these software are easy to use, less complex and most importantly sax's time, energy, and money. Looking for the best window alternative one should look u pon for an early investment and the new windows should be budget friendly. Different materials having different properties such as alurninium, glass, fiberglass, vinyl, and composites and to find out the best out of these designers should research deeply regarding the properties of these materials and choose the material wisely.

While dealing with all these factors to reduce the annual energy cost of the building, replacement of old window with the optimum window type requires an early investment which could be high, but the long-term benefits cannot be ignored in terms of thermal comfort and annual energy saving. One should not forget about the environment friendly design and thinks of not putting the lives of occupants living inside the building at stake. Using natural lighting during the daytime instead of artificial lighting helps in reducing the emission of greenhouse gases to the environment which traps the sun's heat and not letting it go back. Switching to the sustainable and clean energy for window designing leads to a reduced carbon footprint and less emission of CO_2 to the environment plus stagnate the rate of climate change which leads to a better and healthy lifestyle. Energy efficient building provides comfort at an affordable price and energy construction provides heating and cooling savings up to 90% compared to the conventional homes and all this based on five principles: -

Insulated Envelope:

While insulation is the fundamental to achieve great energy efficient building thus a multiple layer of energy efficient insulating material is required to cover the energy surface from roof to wall. The only exception is windows or doors; this is used to minimize the heat exchange to outside environment. Some examples of these layers are boards, oriented strain board, tape shedding, and air barrier tape and plywood sheet. Several high-performance insulated materials are environment friendly which increases the advantages.

Thermal Bridge Free:

Heat like to escape towards colder side of the building so heat inside the building try to go outside, if its cooler using the easiest path, they can find these are called thermal bridges which are specific area of building envelope where insulation is lowest value comparing to other forming cold spot in the building. These spots become too cold lead to formation of moisture and condensation, so energy efficient buildings are built with concept of Thermal Bridge Free. House’s stud can act as Thermal Bridge. The same for homes footing and basement slab. It continues layer of insulation from first principle is essential. But one way to make easier by minimizing the corner, bum bout, cantilever, and domes because they create geometric thermal bridges.

Optimize Orientation:

Better orientation combined with low performance low performance window and doors can cause significant heat gain and loss in a house. In energy efficient building, Triple pain windows, Insulated frame are usually used. Triple pain window is composed of three panel glass separated by spacer. The air take gap is filled with inert gas like argon which is poor conductor of heat transfer. Even with high performance windows and doors there can be inefficiency if they are not well positioned. For instance, optimize heat gain window that feature high solar heat through which is ideal for winter month and then in summer month when sun is higher in sky you have large roof overhang to keep the sun out.

Airtight Container:

Energy efficient building is designed to minimize the holes in their envelope. All leaks are around doors, windows, exterior electrical outlet, and steel plate. They are properly sealed to not only stop heat loss but also help reduce moisture buildup loss in cold weather reducing cold spot and places where condensation can happen not only provide comfort but also improve air quality by eliminating the risk of mound growth. Airtight container envelope brings some problem in breathing.

Mechanical Ventilation:

You might think that with airtight design people do not open their doors and windows, but they do. But when you are trying to maintain comfortable temperature at home and the outside temperature is not ideal or imbalanced that is when you must rely on mechanical ventilation like Heat Recovery Ventilator (HRV) and Energy Recovery Ventilator (ERV). HRV and ERV can transfer heat to achieve maximum efficiency and healthy inside air quality but only ERV transfer moisture as well as heat. ERV as usually preferred in area of high humidity and wide temperature ranges.

II. LITERATURE REVIEW

2.1. Optimization Parameters

(R.M. Reffat, 2020 [1]) has conducted a window design study by evaluating the optimum collection of Integrated Day Lighting Systems into building windows with various orientations for enhancing energy efficiency output of buildings in the hot desert environment. (J. Zhao, 2020 [2]) focuses on a multi-objective strategy for improving windows to save energy, they have systematically considered window design and shading devices, as well as heating, cooling, artificial lighting, and indoor thermal comfort. Building orientation is important for windows and shading design, according to (J. Zhao, 2020). Since this author assumes that the windows system and shading devices have a reciprocal impact on heating, cooling, lighting energy usage, and visual comfort, he argues that studying the windows system alone is insufficient.

Many papers (Nur Laela Latifah, 2020 [3]; R.M. Reffat, 2020; McNicholl, 1994 [4]; and others) have included common research parameters based on thermal specifications such as Solar Heat Gain Coefficient (SHGC), Visible Transmittance (VT), U-Value, Window to Wall Ratio (WWR), including the form and material of glass used and building orientations, among others, as well as the climate of the local region to optimize the design of the windows.

2.2. Methodology

(Luisa Caldas, 2016 [5]) has performed multiple regression analysis of window factors based on the huge database of the existing windows certified by NFRC. Then, integrated those regression models into EnergyPlus energy simulation software to determine optimal window properties for specific locations. (Luisa Caldas, 2016) has basically used a small office setup and simulated the variable data for three different cities using EnergyPlus. In their optimization approach they have also implied genetic Algorithms. This author had used independent values for VT, U-factor, and emittance (E), in the GENE-ARCH's interface. However, SHGC was a dependent variable, resulting from the regression equation: *SHGC= f (VT,* U*, and E).*

Different window sections were driven by the values produced for each variable. (R.M. Reffat, 2020) has proposed an f-phased approach for improving the energy efficiency value of office windows. Generation, analysis, and refinement 1, refinement 2, and analysis, selection, and validation of alternatives with the best energy efficiency are the four phases, (J. Zhao, 2020) has also used four common goals related to window and shading configuration, as shown in figure 3. Heating, ventilation, lighting, and indoor thermal comfort are all included. To derive the optimized solution, this author has used genetic algorithms (NSGA-II) and a few notable applications such as EnergyPlus, Design Builder, and the jEplus+EA framework.

2.3. Discussion

It has been discovered that the office's energy consumption pattern is primarily influenced by the efficiency of the windows, specifically solar radiation. A single or multi-objective optimization of windows and shading devices has been the subject of some study. (Lee, 2013 [6]) used an optimization band to evaluate the effects of various types of usable windows and buildings on property energy consumption for cooling, heating, and lighting in five different climatic zones across China. Also, it has been observed through statistically studied the relationship between window properties and building energy efficiency as a function of heat transfer coefficient, solar heat gain coefficient, visible transrnittance, window to wall ratio (WWR), solar aperture, and orientation, which can provide a fundamental understanding of window selection.

The incorporation of Day lighting Systems (DLS) aims to increase energy efficiency performance and achieve visual and thermal comfort to the user, according to (Kim, 2012 [7]). Furthermore, maximization of the benefits of solar light to reduce the energy usage for cooling and heating purpose. The efficient use of Day lighting Systems is necessary to increase the penetration of daylight into workspaces. Several approaches to the integration of artificial lighting and day lighting systems have been suggested in previous studies. For improving overall energy efficiency and achieving visually comfortable lighting, these techniques in volve dimming control (DC) and shading devices by the illuminance levels in the atmosphere (Ochoa ,2006 [8]; Al-Ashwal, 2011 [9]).

One of these methods is to use a sun-breaker with various configurations to increase the percentage of day lighting within the room, which saved 34% of the annual energy consumption (Gadelhak, 2013 [10]). Another approach is to use modern style external and internal light shelves, which resulted in a 24.5°/c reduction in lighting and cooling energy consumption (Al Waary, 2012 [11]). Using complex exterior loss and alternative facade design are two other techniques (Harnmad, 2010 [12], Al-Ashwal, 2011, Lim, 2017[13]). For example, combining natural and artificial lighting has resulted in a 35% reduction in lighting energy and a 13% reduction in overall energy consumption (Al- Ashwal, 2011).

(Hamrnad, 2010) investigated the energy efficiency of dynamic facade louvers in Abu Dhabi's office buildings. The combined use of light dimming technologies and shading systems resulted in substantial energy savings of 34.02 %, 30.31%, and 28.5% for the South, West, and East facade orientations, respectively. The orientation of a building's facade has a significant effect on solar energy gain; for example, the solar energy for a south-facing facade is higher than for a north-facing facade (Abd Alla, 2020 [14]).

As a result, overall energy savings can be used as a criterion for determining design recommendations (Abd Alla, 2020). The effect of integrating day lighting design techniques into the facade and interior design of two office buildings in Malaysia was investigated (Lim, 2017).

In workplaces, energy consumption for artificial lighting has decreased from 41% to 53%. In addition, (Leung, 2013 [15]) proposed a powered semi-silvered reflective louver device with the aim of increasing daylight penetration, improving visual comfort, and lowering energy consumption.

The reflective louver device offered up to 70% of additional illuminance at the work-plane level under clear sky conditions, according to the experimental results. (Eltaweela, 2020 [16]) suggest an advanced day lighting design for a deep-plan office room to achieve a more consistent and uniform daylight delivery during working hours. It used a parametrically operated louver with reflective slats to funnel sunlight onto a ceiling to provide a source of diffuse light to illuminate a space.

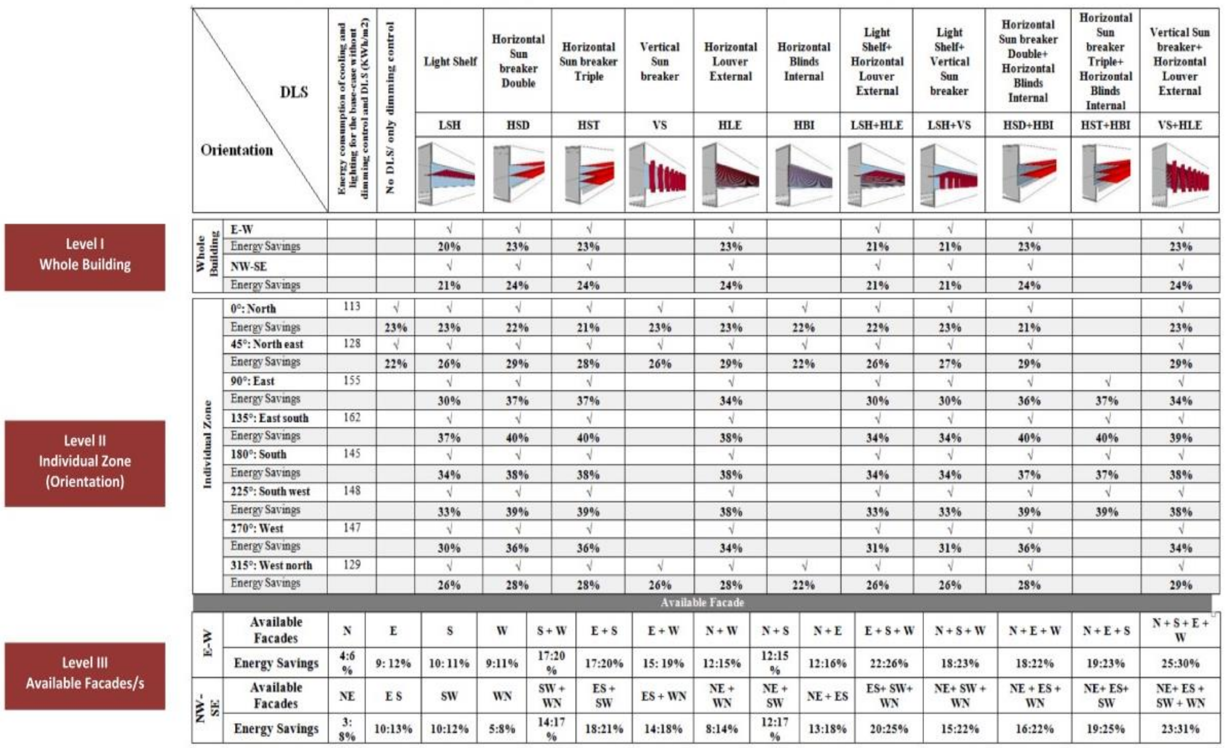
(R.M. Reffat, 2020) has provided a list of Day Lighting Systems (DLS) and relatively the building orientation that suits a particular configuration for optimal energy conservation, the same can be found in figure 1. lt took (J. Zhao, 2020) them 50 iteration to reach optimization result. In addition, they have obtained Pareto charts separately for different climatic region to better understand the co-relation among different optimizing variables. Besides, this article also reports the conflict between four objectives functions as claimed by others. However, to better understand the end effect that article prepared the Pareto optimal solution between two objective functions.

For window optimization, (Jing Zhao, 2020) employs a multi-objective optimization approach. Window and shading priorities include heating, ventilation, illumination, energy consumption, and indoor thermal comfort, to name a few. This multi-objective design problem is defined in these papers, and it is based on multi-objective mathematical functions (Delgarrn, 2016 [17]; Bingham, 2019 [18]; Taghdisian, 2015 [19]). The three elements of a multi-objective optimization case can be seen as objective functions, design variables, and constraints. However, in practice, a set of design variables that satisfy all the constraint functions is referred to as a potential solution and is built into the feasible domain of the optimization problem, as shown in fig.4.

Clearing is the most recommended inner layer material of the windows for cities with retention, according to (J. Zhao, 2020). The recommended parameters for the middle layer material, inner layer material of windows, installation angle, and depth of overhangs vary by city to city, according to the study. As shown in fig 2, these parameters are consistently fair in Hohhot and Tianjin, but they vary greatly in Shanghai and Guangzhou.

The results showed that using a multi-objective optimization approach decreased heating energy usage by 6.00 %, 4.82 %, and 7.69 %, respectively, using a multi-objective optimization approach. The use of cooling energy drops by 81.25%, 55.33%, 44.44%, and 44.03%, respectively. In four cities, 2.88 %, 12.50 %, 15.38 %, and 9.09 % electricity can be saved with minimal lighting energy usage. The discomfort hour's optimization range is relatively limited, and the four climatic regions decreased them by 2.00 %, 4.63 %, 0.87%, and 2.02%, respectively.

III. FIGURES



	DLS / Orientation	Energy consumption of cooling and lighting for the base-case without dimming control and DLS (KWh/m2)	No DLS/ only dimming control	Light Shelf (LSH)	Horizontal Sun breaker Double (HSD)	Horizontal Sun breaker Triple (HST)	Vertical Sun breaker (VS)	Horizontal Louver External (HLE)	Horizontal Blinds Internal (HBI)	Light Shelf+ Horizontal Louver External (LSH+HLE)	Light Shelf+ Vertical Sun breaker (LSH+VS)	Horizontal Sun breaker Double+ Horizontal Blinds Internal (HSD+HBI)	Horizontal Sun breaker Triple+ Horizontal Blinds Internal (HST+HBI)	Vertical Sun breaker+ Horizontal Louver External (VS+HLE)
Whole Building	E-W			√	√	√		√		√	√	√		√
	Energy Savings			20%	23%	23%		23%		21%	21%	23%		23%
	NW-SE			√	√	√		√		√	√	√		√
	Energy Savings			21%	24%	24%		24%		21%	21%	24%		24%
Individual Zone	0°: North	113	√	√	√	√	√	√	√	√	√	√		√
	Energy Savings		23%	23%	22%	21%	23%	23%	22%	22%	23%	21%		23%
	45°: North east	128	√	√	√	√	√	√	√	√	√	√		√
	Energy Savings		22%	26%	29%	28%	26%	29%	22%	26%	27%	29%		29%
	90°: East	155		√	√	√		√		√	√	√	√	√
	Energy Savings			30%	37%	37%		34%		30%	30%	36%	37%	34%
	135°: East south	162		√	√	√		√		√	√	√	√	√
	Energy Savings			37%	40%	40%		38%		34%	34%	40%	40%	39%
	180°: South	145		√	√	√		√		√	√	√	√	√
	Energy Savings			34%	38%	38%		38%		34%	34%	37%	37%	38%
	225°: South west	148		√	√	√		√		√	√	√	√	√
	Energy Savings			33%	39%	39%		38%		33%	33%	39%	39%	38%
	270°: West	147		√	√	√		√		√	√	√		√
	Energy Savings			30%	36%	36%		34%		31%	31%	36%		34%
	315°: West north	129		√	√	√	√	√	√	√	√	√		√
	Energy Savings			26%	28%	28%	26%	28%	22%	26%	26%	28%		29%

Available Facade

E-W	Available Facades	N	E	S	W	S + W	E + S	E + W	N + W	N + S	N + E	E + S + W	N + S + W	N + E + W	N + E + S	N + S + E + W
	Energy Savings	4:6 %	9: 12%	10: 11%	9:11%	17:20 %	17:20%	15: 19%	12:15%	12:15 %	12:16%	22:26%	18:23%	18:22%	19:23%	25:30%
NW-SE	Available Facades	NE	E S	SW	WN	SW + WN	ES + SW	ES + WN	NE + WN	NE + SW	NE + ES	ES+ SW+ WN	NE+ SW + WN	NE + ES + WN	NE+ ES+ SW	NE+ ES + SW + WN
	Energy Savings	3: 8%	10:13%	10:12%	5:8%	14:17 %	18:21%	14:18%	8:14%	12:17 %	13:18%	20:25%	15:22%	16:22%	19:25%	23:31%

Fig. 1. Day lighting system with suitable building orientations for different regions.

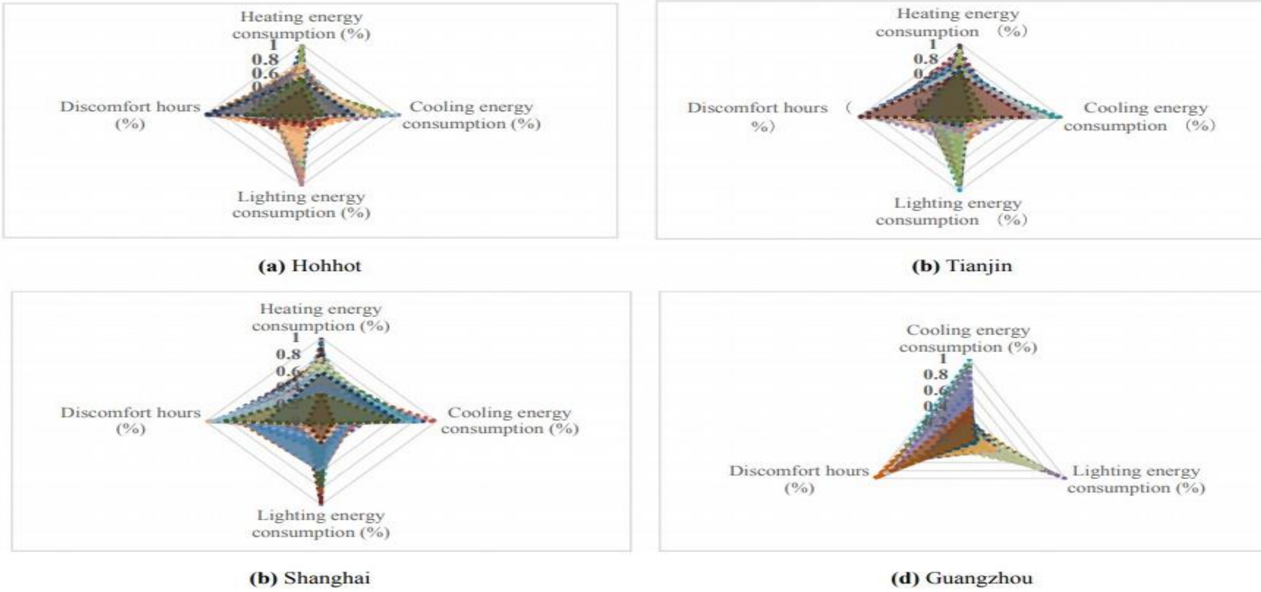


Fig. 2. Building results in different cities based on multi-objective functions.

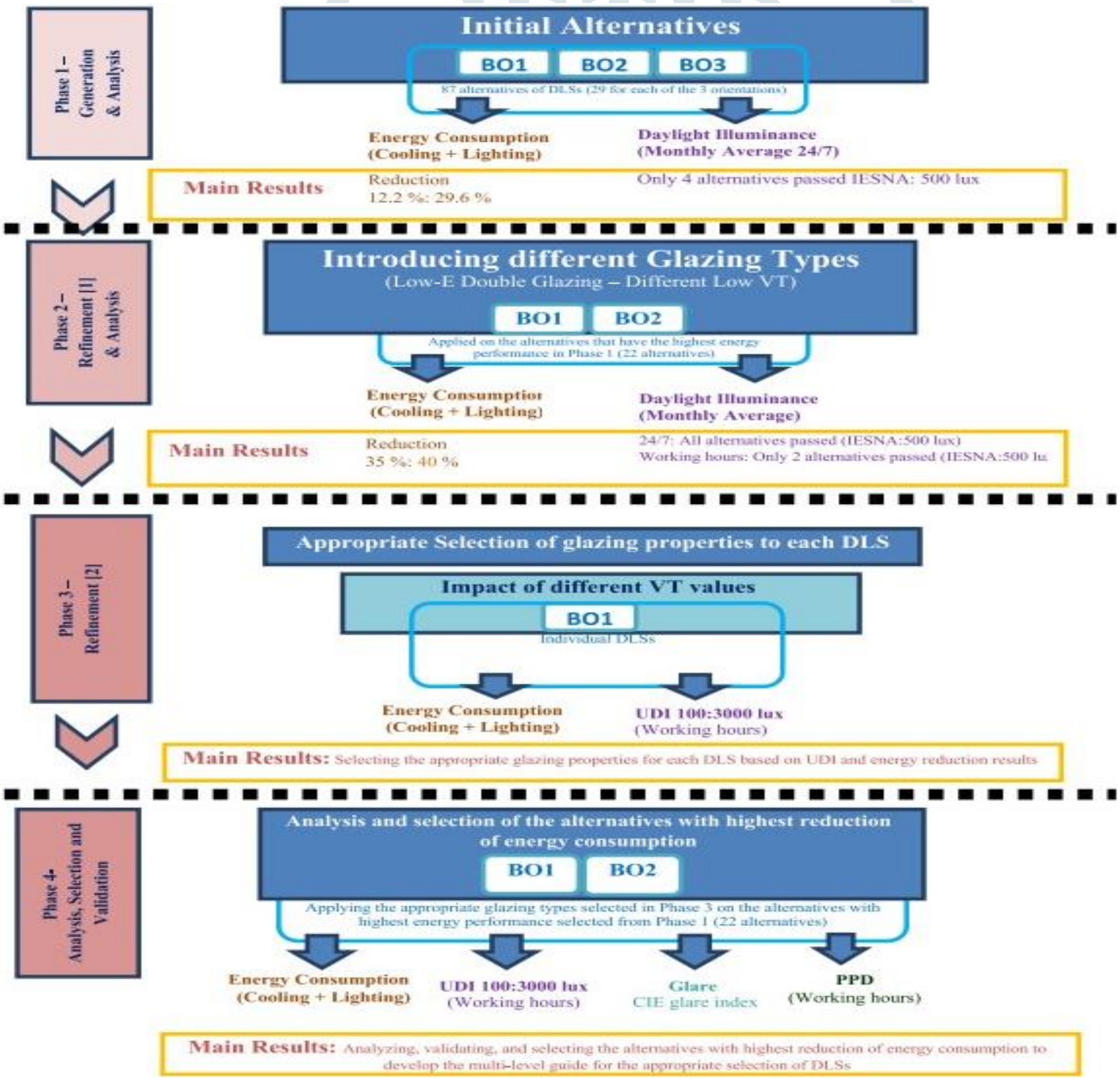
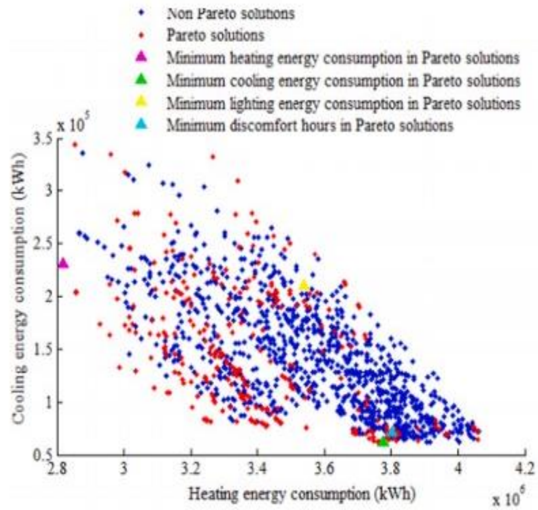
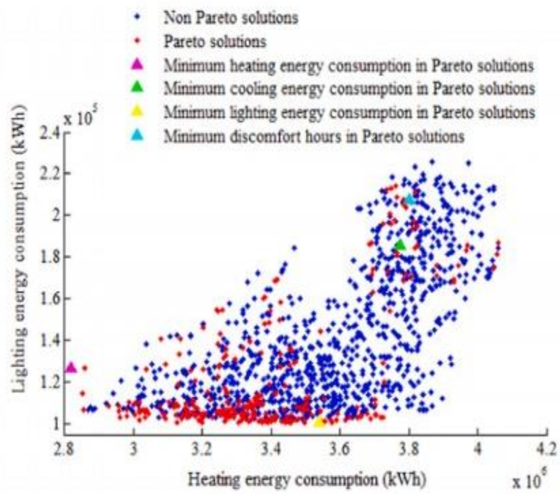


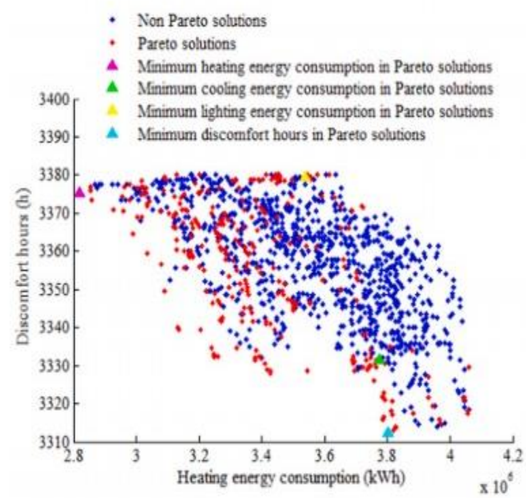
Fig. 3. Day lighting orientation method for optimizing windows performance.



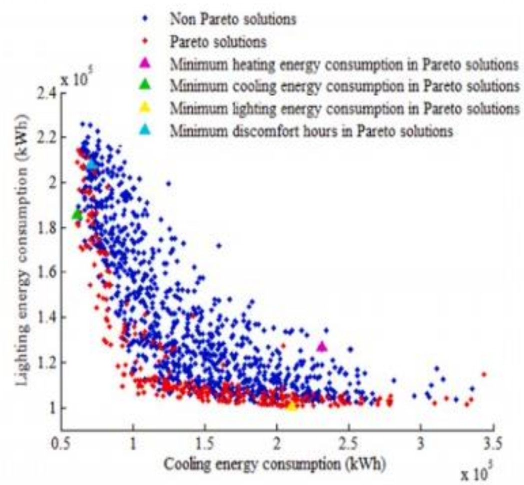
(a) Heating, cooling energy consumption optimization results



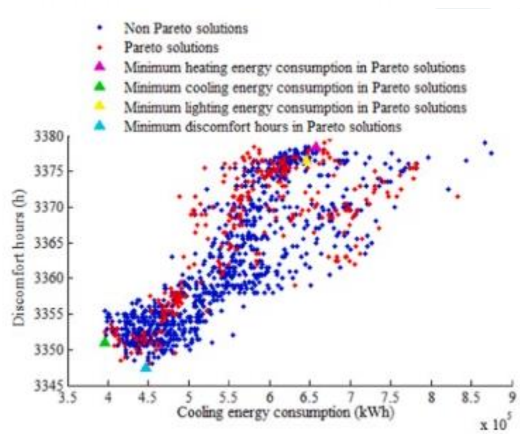
(b) Heating, lighting energy consumption optimization results



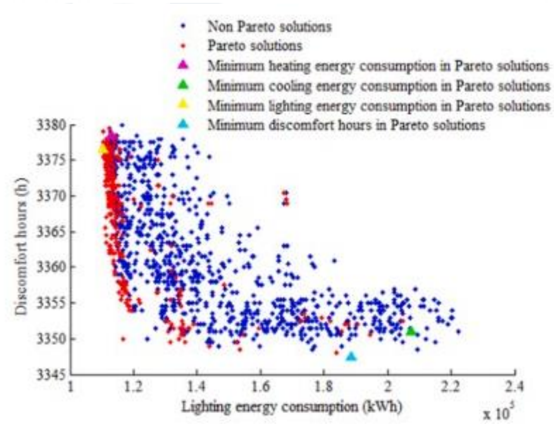
(c) Heating energy consumption, discomfort hours optimization results



(d) Cooling, lighting energy consumption optimization results

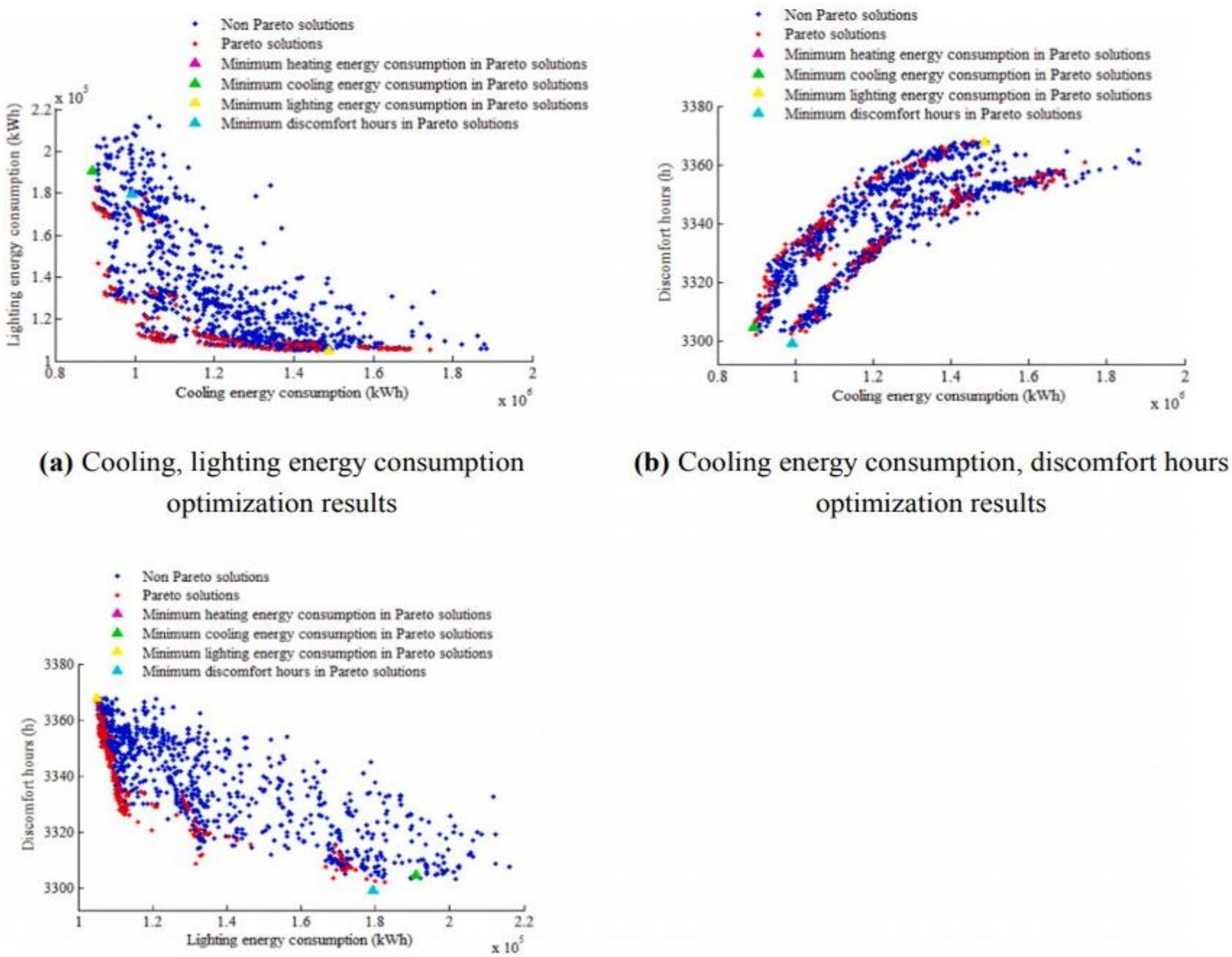


(e) Cooling energy consumption, discomfort hours optimization results



(f) Lighting energy consumption, discomfort hours optimization results

Fig. 4. Two objective optimization results for Shanghai.



(a) Cooling, lighting energy consumption optimization results

(b) Cooling energy consumption, discomfort hours optimization results

(c) Lighting energy consumption, discomfort hours optimization results

Fig. 4 (continued) Two objective optimization results for Shanghai.

IV. CONCLUSION

This review paper tried to critically review various papers regarding windows optimization to conserve energy. The main objective to design optimization is related to few parameters as discussed above, also greatly depends on the climatic region under consideration. There are various methods that has been used to come up with a solution, some solely used computer-based design and simulation software backed by the data from department of energy, multi-objective optimization approach, and some other used types of day lighting systems. Nevertheless, it has observed that the most effective approach to design optimization is multi-objective strategy with the implication of simulation software and other parameters.

It can be understood that to further improve the energy conservation, we can integrate the most effective methods to arrive at even better result, as at the end of the day the goal is to conserve as much energy as possible. Additionally, there is a potential chance of discovering the optimal thickness of the windows and shading device, as very little has been discussed in terms of it and clearly optimizing thickness may also result in saving tones of glass material. Besides, there is a great scope in further research of the windows design. Perhaps, with increasing demand of aesthetics architectural building and ever evolving technology, windows too need to be updates simultaneously which can further aid to energy conservation and sustainable growth.

Declaration of Competing Interest

The authors declares that there is no competing interest of any matter whatsoever, as it might have appeared on this article.

REFERENCE

[1] R.M. Reffat, 2020; Determination of optimal energy-efficient integrated daylighting systems into building windows, Solar Energy Volume 209, October 2020, Pages 258-277.

[2] J. Zhao, 2020; Multi-objective optimization design for windows and shading configuration considering energy consumption and thermal comfort: A case study for office building in different climatic regions of China, Solar Energy, Volume 206, August 2020, Pages 997-1017.

[3] Nur Laela Latifah, 2020; Energy Saving Building Strategies through The Application of Solar Control Glass, Department of Architecture, Institut Teknologi Nasional Bandung, Indonesia, Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika, Volume 8, No. 2, page 388-403.

[4] McNicholl, 1994; Daylighting in Buildings. Dublin: Energy Research Group, University College Dublin for the European Commission Directorate-General for Energy (DG XVII).

[5] (Luisa Caldas, 2016; Simulation-Based Optimization of Window Properties Based on Existing Products, Conference: Building Simulation and Optimization 2016.

[6] Lee, 2013; Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. Renew, Energy 50, 522–531.

[7] Kim, 2012; Comparative advantage of an exterior shading device in thermal performance for residential buildings, Energy and Buildings Volume 46, March 2012, Pages 105-111.

[8] Ochoa, 2006; Evaluating visual comfort and performance of three natural lighting systems for deep office buildings in highly luminous climates. Build. Environ. 41 (8), 1128–1135.

[9] Al-Ashwal, 2011; Energy savings due to daylight and artificial lighting integration in office buildings in hot climate. Int. J. Energy Environ. 2 (6), 999–1012.

[10] Gadelhak, 2013; High-performance facades: the effect of sun breakers on daylighting performance and energy consumption in south-oriented office spaces. AEI 2013: Building Solutions for Architectural Engineering,776-784.

[11] Al Waary, 2012; Enhancing Daylight and Improving Energy Usage through the Utilization of Lightshelves in Deep Plan Office Buildings in Dubai. The British University in Dubai (BUiD), Dubai, UAE Dubai.

[12] Harnmad, 2010; The energy savings potential of using dynamic external louvers in an office building. Energy Build. 42 (10), 1888–1895.

[13] Lim, 2017; Daylight performance and users' visual appraisal for green building offices in Malaysia. Energy Build. 141, 175–185.

[14] Abd Alla, 2020; An innovative approach to local solar energy planning in Riva Trigoso, Italy. J. Build. Eng. 27, 100968.

[15] Leung, 2013; Performance of a daylight guiding system in an office building. Sol. Energy 94, 253–265.

[16] Eltaweela, 2020; Advanced parametric louver systems with bi-axis and two-layer designs for an extensive daylighting coverage in a deep-plan office room. Sol. Energy 206, 596–613.

[17] Delgarm, 2016; Multi-objective optimization of the building energy performance: A simulation-based approach by means of particle swarm optimization (PSO). Appl. Energy 170, 293–303.

[18] Bingham, 2019; Whole building optimization of a residential home with PV and battery storage in The Bahamas. Renew Energy 132, 1088–1103.

[19] Taghdisian, 2015; Multi-objective optimization approach for green design of methanol plant based on CO2-efficeincy indicator. J. Clean Prod. 103, 640–650.