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THERMAL-DAYLIGHTING BALANCE THROUGH BUILDING SHADING DEVICES: A REVIEW ON FACTORS AND METHODS

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ABSTRACT

Daylighting is interpreted as natural sunlight allowed into an indoor space. Passive lighting strategies are considered fundamental in achieving a high performing sustainable building, which affects the visual and thermal comfort, and energy performance of a building. Many strategies in controlling daylighting are known, however, the wrong implementation can lead to a negative effect. The results obtained need to reach a balance between daylighting and thermal performance. This review is conducted to analyse the concept and factors that affect the balance through different research parameters. The performance factors include energy, comfort and perception or view. The different methods of achieving the balance are categorized into three, which are parameter relation, combination, and multi-objective optimization. Building shading devices are considered as one of the major solutions to reach thermal-daylighting balance. Through a comprehensive review, adjustable shading control is recommended as a better option for building shading device for buildings to achieve the optimum balance.

Keywords: *Daylight, Thermal performance, Balance, Shading Device(s)*

INTRODUCTION

Daylighting is a direct linkage to the outdoor environment and the natural light that penetrates into a building, which portrays a dynamic distribution of light. Daylight that enters a building can be either direct sunlight, diffused skylight or light that is reflected from elements surrounding the space (Mohamed et al., 2020). The presence of light alone in a building can create and define the indoor environment and stimulate the occupants of the space. Husain (2016) explained that the amount of light differs depending on the individual's required task and visual capacity. Even more, it is said that light is not only related to the visual experience of form and space but is strongly connected to thermal qualities (Baker & Steemers, 2002). A new specific definition of daylighting combines daylight availability, occupant comfort and energy efficiency (Reinhart & Weissman, 2012). Moreover, daylight in its presence can supplement indoor lighting requirements and help to reduce the usage of artificial lighting. This can further help in the reduction of total building energy consumption (Sabry et al., 2014; Choi et al., 2017; Atzeri et al., 2018).

On the contrary, excessive, or insufficient daylighting into a building can impact negatively the productivity of its users and the building itself. Excessive sunlight fenestration may lead to overheating due to solar heat gains, and more energy consumption due to the cooling load. Insufficient daylighting, however, usually due to an attempt to minimize sunlight penetration, will increase the artificial lighting energy consumption and decrease the productivity and comfort of its users. The Malaysia Standard 1525:2019 was introduced and renewed to incorporate improvements for achieving sustainability in non-residential buildings. This is backed up by the Eleventh Malaysia Plan 2016-2020, where new buildings constructed are to incorporate energy-efficient strategies, while still following the requirements and recommendations of authorities and standards.

Therefore, it is crucial to control the amount of daylight that enters a certain building by finding the balance between both the daylighting and thermal performances. Specific care has to be taken into consideration when designing the daylight contribution in high usage buildings, such as offices and schools. This is particular so where constant light levels on visual task areas are recommended, due to the intellectual activities involved. On the other hand, the provision of an engaging environment, where occupants can perceive a contrast among different zones, and can look outside, is suggested to increase productivity. One of the key influencing methods is by the design of the building shading device. For desirable daylight and thermal comfort performance in a building, it is important to use the correct shading device type (Kim, 2010; Evola et al., 2017; Kirimtat et al., 2019). Building envelopes can influence daylight uniformity and can reduce total energy consumption and performance of the building.

The main objective of this paper is the systematic review of shading devices to reach thermal-daylighting balance. Thus, it is pursued by examining the concept, factors and balance method that affects the thermal and daylighting performance of a building and discussing solutions to achieve it through several building shading system configurations by synthesizing their content and summarizing the results and conclusions. The purpose of the paper is twofold. Firstly, it is to present the main research findings concerning the concept of thermal-daylighting balance and shading devices as technological methods in achieving it, and secondly, to analyse the results, trying to establish a common basis for some efficient and practical technological design rules.

PROBLEM STATEMENT

Natural lighting in excess can lead to a negative impact on the indoor thermal environment and lighting comfort, which will ultimately lead to the increment in energy consumption of the building. In contrast to other climatic conditions, Wagdy et al. (2015) indicated that hot climates are endowed with an abundance of clear skies, large openings which allow more fenestration but higher cooling loads, while small openings can decrease energy consumption but do not offer sufficient daylight. Saradj, Ahadi and Maleki (2014) even considered it as inappropriate to have an extensive glass surface and transparency in building facades in hot-humid areas, which will lead to overheating and disturbing the thermal comfort. Wasted energy even if it is 20-40% on openings of buildings will likely increase in tropical climates (Bulow-Hube, 2001). Extreme minimizing of daylighting can sometimes result in an insufficient daylight level and increase artificial lighting energy consumption. Therefore, Hee et al. (2015)

argue that fenestration requires the appropriate design to satisfy the required level and balance of user comfort and energy consumption in a building.

Thus, it is important to adjust or control the natural lighting intake to reach a balance between thermal and daylighting performances to create a "thermal-daylighting balance" as coined by Yu et al. (2020). The idea to separate them is known widely, but to find the ideal conceptual balance between the two major aspects has been a feat due to different assumptions and varying definitions. Specific studies that govern the daylighting and thermal performance as two separate metrics are varied and extensive. However, there is a limited number of studies that show the direct linkage of striking a balance between thermal and daylighting performance.

METHODOLOGY

This paper adopts a qualitative method through analytical studies of literature reviews of books, journals, articles, and thesis reports. The websites used for this purpose are MySE, ScienceDirect, Google Scholar, ResearchGate and Semantic Scholar. The reviewed work of literature was organized to understand the concept of thermal-daylighting balance and building shading technologies involved as a method to control the balance. Besides building shading devices, other types of design solution methods that can affect the thermal and daylighting performance, such as building location and orientation, space functionality, glazing systems, opening areas, building material and interior decorations are not referred to in this paper.

THERMAL-DAYLIGHTING BALANCE

Concept

Thermal and daylighting aspects is a very large topic in itself, whereby it touches on energy performance, comfort, visual comfort, and more. To find the balance between the two is also difficult as some studies evaluate more on a single metric, while others consider it to be equally important to cater to as many metric aspects or factors as possible. Lan, Wood and Yuen (2019) stated that "the social need is mapped to human comfort and nature contact while the environmental need is mapped to energy efficiency, and the financial need is mapped to life cycle cost." Thermal comfort is achieved through natural cooling or heating and visual comfort is achieved by daylighting.

In the total of 20 papers reviewed in this study from 2010 to 2020, there were all found to have defined the concept of thermal-daylighting balance differently. There are three main performance factors that influence both aspects, which are energy, comfort, and perception (Table 1). The parameters of energy factor include lighting and energy demand or load, energy consumption, solar heat gain and also heat transfer process. Under the comfort factor include illuminance, thermal indoor environment, visual comfort, and glare index, and also daylight factor. The last factor is the user perception or view towards outdoor visibility.

The parameter of energy performance factor is the most widely applied amongst all the reviewed papers. Energy performance is expressed as energy consumption in most papers evaluated in this paper in terms of timesteps of annual, monthly, daily, or even hourly. However, Wankanapon and Mistrick (2011), Katsifaraki, Bueno and Kuhn (2017) and Atzeri et al. (2018) evaluated the energy demand/load in terms of heating, cooling and lighting load. Choi et al (2017) aptly put that energy consumption is largely affected by the envelope of the building. Atzeri et al. (2018) defined solar gains as solar heat gain coefficient or lower solar transmittance in cooling-dominated climates. In terms of the comfort performance factor, the daylight factor is usually approached by using simulation tools, such as EnergyPlus and Daysim. For example, Daysim is used as a daylighting simulation tool to compute daylighting coefficients and illuminance values to provide artificial illumination and is used by many authors throughout this research (Manzan & Clarich, 2017; Atzeri et al., 2018; Gutierrez et al. 2019). Illuminance on the other hand was stated by de Almeida Rocha (2020) as a combination of natural and artificial light to achieve 300 lux on the work plane, but most research papers categorise the average illuminance level as at least 500 lux. Daylight illuminance distribution can be calculated by several means, such as radiance-based tool (Ecotect Analysis), Radiance and many others. The thermal environment was expressed by Choi et al. (2017) as the prevention of discomfort to the occupants by preventing other comfort parameters such as illuminance and glare. Evola, Gullo and Marletta (2017) described thermal discomfort as the formula of the Intensity of Thermal Discomfort (as introduced by the same author in previous work), which is the time integral over the occupancy period of the positive difference between the current indoor operative temperature and the upper threshold for comfort. Visual comfort and glare index were introduced by Choi et al. (2017); there is a difference in luminance due to the light source or ambient lighting brightness. Outdoor visibility under the perception or view factor is mentioned as a balancing metric towards achieving thermal and daylighting balance (Xiong and Tzempelikos, 2016), but it is not discussed widely in recent research when compared to the other two factors.

Table 1. The Thermal-daylighting Balance Concept Performance Factors and Parameters

Factors	Parameter Keywords
Energy	Energy consumption
	Lighting & energy demand / load
	Solar heat gain
Comfort	Daylight factor
	Illuminance
	Thermal environment (air, surface, etc)
	Visual comfort & glare index
Perception/View	Outdoor visibility

(Source: Author, 2021)

The most common combination of performance factor parameter is the energy and comfort factor. This is due to the larger and wider scope of research parameter and this has allowed many studies to be conducted with different combination of parameters. The perception or view factor is considered as a complementing factor to the other two factors. This is due to the lack in research findings on maintaining a balance in thermal and daylighting performance. There are some studies that were carried out only on a single performance factor, but the explanation on the presence of a balance between the thermal and daylighting metric was highlighted at the end of the research. However, these studies will not be introduced in the further discussion section.

Balance Method

Other specific studies focussed on achieving a balance in daylighting and thermal performance are also varied and extensive. Most of the studies reviewed described the balance from multiple factors with multiple parameters governing their research, while some are more focused on a single factor but was evaluated through multiple parameters to help direct their research. To determine and evaluate the achievement of balance between daylighting and thermal performance, they are categorized into three balance methods, which are through parameter relation, parameter combination and multi-objective optimization (Refer to Table 2)

Parameter Relation

This method of finding the thermal-daylighting balance is to first optimize one parameter and then move on to calculate or optimize the next parameter after the feedback from the former is taken into consideration. This allows each parameter to be understood properly and at each stage and the parameter is maintained or ensured at the next mode of the experiment. For example, Choi et al. (2017) conducted a three-stage mode, using parameters of energy consumption, glare, and illuminance, and with each mode having an additional parameter optimized during the experiments to find the suitable balance among the parameters. This allows the reduction of the amount of repetition in conducting the experiments is compared to when being conducted separately. Wagdy et al. (2015) conducted a two-stage kaleidocycle system process to understand the balance between daylight and thermal metrics. Stage one sets up the daylight controls and in stage two the energy consumption is calculated based on the controls in stage one. Another example from Sabry et al. (2014) demonstrated a three-stage process to balance the thermal and daylighting performance in a desert climate. Firstly, the daylighting performance is optimized, next, the glare presence is taken into consideration, and lastly, the energy consumption is analysed to find a balanced performance.

Parameter Combination

Thermal-daylighting balance can also be achieved when the factors are combined into a single metric or research objective. According to Yu et al. (2020), this method is usually used when the energy factor is centred in achieving the optimum balance. The total energy demand and also energy consumption is widely used as the main objective throughout the research of certain authors, compared to other parameters. For example, Chi et al., (2017) investigated the ratio of the daylit area to the shading coefficient to find the balance between solar shading and daylighting performance. The results show that a lower shading coefficient shows better annual solar shading performance, while a higher actual daylit area value is indicated as better daylight performance. With reference to Xiong and Tzempelikos (2016), the shading and lighting control operation is investigated to minimize lighting energy usage and at the same time maintain required daylight levels and sustain the visual comfort of office space. The Daylight Glare Probability approximation, vertical and work plan illuminance is used throughout the experiment of real-time shading control, using simple sensors as inputs to analyse and operate the shade operation without sacrificing visual comfort. Atzeri et al. (2018) performed an analysis on both the thermal and daylighting metrics together but it was presented in several charts to form a large combining diagram to compare daylighting, visual comfort and energy performance. Katsifaraki, Bueno and Kuhn (2017) studied both the visual comfort and energy efficiency together and they introduced an algorithm whereby it depends on the room occupancy to prioritize a certain parameter.

Multi-objective Optimization

A multi-criteria design approach provides an optimal combination of framework analysis and a suitable trade-off through a set of design parameters to improve the performance of a building and relatively find the thermal-daylighting balance. This method allows several parameters to be used in the research alone and allows control of the preferred parameters too, while also reduce the number of simulations required compared to the normal method of research. This approach has been used by several authors due to the computational approach, which allows fast and accurate results.

De Almeida Rocha et al. (2020) used this approach by using a pixel counting technique; the Pareto optimality and dominance concepts and physical programming to discuss various perforated shading device designs and result in a few designs, which is location-specific to balance energy consumption and daylighting (Figure 1). Zani et al (2017) performed an optimization process by using a general algorithm and lighting and energy simulations for a concrete shading device system. This allowed the geometry of the shading device to be optimized in terms of design and configuration, calculation for solar radiation and maintaining outdoor visibility. Manzan and Clarich (2017) introduced the FAST algorithm for their research of movable indoor blinds with fixed external shading panel. The algorithm allows an efficient number of simulations to be conducted in the optimization process of energy and daylighting parameters.

This method is considered as the most complex out of the three balance methods. This is due to the usage of multiple research factors and parameters. However, it is effective in showing the balance between the aspects of daylighting and thermal performance.

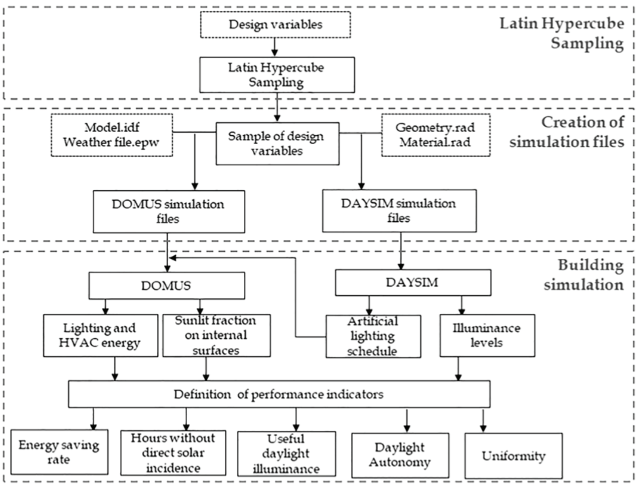

Figure 1. A Simulation Methodology Introduced by de Almeida Rocha et al. (2020) in a Study Conducted for a Pixel Counting Based Method

(Source: adapted from de Almeida Rocha et al. (2020) https://doi.org/10.1016/j.apenergy.2020.114497)

Table 2. Summarization of the Balance Method Applied according to Reviewed Papers

Balance Method	Citations
Parameter Relation	Wankanapon & Mistrick (2011); Sabry et al. (2014); Wagdy et al. (2015); Choi et al. (2017); Al-Obaidi et al. (2017); Evola, Gullo & Marletta (2017)
Parameter Combination	Koo, Yeo & Kim (2010); Mandalaki et al. (2012); Xiong and Tzempelikos (2016); Katsifaraki, Bueno and Kuhn (2017); Chi et al., (2017); Ricci et al. (2018); Atzeri et al. (2018); Gutierrez et al. (2019); Srisamranrungruang & Hiyama (2020)
Multi-objective Optimization	Zani et al (2017); Manzan and Clarich (2017); Jayathissa et al. (2017); Kirimtat et al. (2019); De Almeida Rocha et al. (2020)

(Source: Author, 2021)

BUILDING SHADING DEVICES

Shading devices are equally important as a passive system to a building design (Kirimtat et al., 2019). It is also said that shading devices are building components that deal with overheating problems, minimizing building energy consumption and at the same time preserving renewable resources. Shading should be considered as an integral part of fenestration system design for commercial and office buildings to balance daylighting requirements versus the need to reduce solar gains. In addition, buildings without shading devices may induce too much daylight illuminance, while buildings with wrong shading systems may reduce too much daylight intake (Evola, Gullo & Marletta, 2017; de Alemida Rocha et al., 2020). There are various kinds of building shading devices in the market, but according to de Almeida Rocha et al. (2020), designers would try to carry out building performance analyses before choosing the type and position of the devices. The papers reviewed formerly were further discussed in terms of the building shading devices introduced as a method to control and balance thermal and daylighting in their respective studies in Table 3.

Table 3: The Analysis and Finding on the Methods in Shading Devices to Adopt Thermal-daylighting Balance

No	Author	Application	Description	Finding
1	Srisamran-rungruang T., Hiyama K. (2020)	Double-skin perforated façade system	The study investigated the performance of the integration of a double-skin façade and perforated screen through simulation to optimize energy saving and improve daylight and natural ventilation	Screens, on the south orientation, with a perforated percentage of minimum 40% to achieve daylighting without glaring, while 50% is the optimum rate (in Spring season, Japan) and 30% throughout the year to balance natural ventilation and daylighting
2	de Almeida Rocha A. P., Reynosa-Meza G., Oliveira R. C. L.F., Mendes N. (2020)	Simple geometry perforated shading device	The study investigated the design of simple geometrical perforated shading through a multi-criteria approach to balance daylighting and energy performance in a sunny climatic condition	By using the method, different device configurations were evaluated in a two-step process. The pixel counting technique is proven to be an accurate and fast computing analysis method for better decision making of the best solution for each location and preferences.
3	Gutiérrez R. U., Du J., Ferreira N., Ferrero A., Sharples S. (2019)	Fixed louvre screens (specular aluminium, and two types of ceramic finishes)	Annual performance simulations for a full-scale room (Daysim) were conducted to assess the effects of the three material systems on indoor daylighting levels and distributions using both the traditional Daylight Factor and climate-based daylighting metrics	Aluminium Venetian blinds provided the best performance in terms of artificial lighting energy reduction (30%) and optimal daylighting. Ceramics is proven to be a promising alternative louvre material that tackles visual and thermal comfort, and energy optimisation, minimising the potential glare from traditional aluminium louvre system, besides also improving the ecological impact.
4	Kirimtat A., Krejcar O., Ekici B., Tasgetiren M. F. (2019)	Amorphous shading device	Proposal of a novel design amorphous shading device system that is energy-saving through parametric modelling and performance evaluation-based optimization was produced	By using a geometric amorphous design on the shading devices integrated on glazed facades provide a higher energy saving (14%) and achieve daylight illuminance of above 50% to the office space compared to non-amorphous types. Design can be adapted to different climatic conditions

5	Ricci, A., Ponzio, C., Gaspari, J., & Naboni, E. (2018)	Climatic adaptive building shell through dynamic horizontal louvres	A simulation was conducted on a dynamic façade system that uses aluminium horizontal louvres. The adaptive system used an actuator that uses thermo-active resin, which absorbed solar energy to expand, and allowed the louvre movement mechanism.	The method allowed parameter monitoring of light and temperature to keep track of the indoor comfort level of the case study. Lux level was kept at a comfort range of an office building at all times (500-2000 lux). This solution also allowed uniform daylighting across the indoor space. The mechanism itself also omitted the supply of energy
6	Atzeri A. M., Gasparella A., Cappelletti F., Tzempelikos A. (2018)	Three roller shade control strategies on different glazing systems	The paper conducts three control approaches on roller shades (standard operation, intermediate shade positions, and shade position including work plane illuminance) to evaluate visual and thermal comfort with energy usage through simulations	The overall performance of each control strategy showed that control 3 is the best option, while control 2 (intermediate shade positions) is least favourable in terms of solar gains and result in higher cooling requirements and lowest overall visual comfort performance compared to the other two. The outcomes portray advanced shading controls that may provide a more comfortable indoor environment and energy consumption reduction.
7	Al-Obaidi K. M., Munaaim M. A. C., Ismail M. A., Abdul Rahman A. M. (2017)	Integrated daylighting system through 3 components	The paper studied deep-plan spaces in low-rise buildings in the Malaysian context through a roof light, dynamic shading, and fibre optic daylighting system, carried out by actual room experiment through a 2-stage process	The integrated daylight system successfully delivered a uniform illuminance. Dynamic shading system on the skylights achieved below 2000 lux, with an average of 350 lux, with functionality between 46% and 56% under intermediate sky condition and solar irradiance above 500 W/m2
8	Zani A., Andaloro M., Deblasio L, Ruttico P., Mainini A. G., (2017)	Innovative concrete shading device system	The paper studied through a computational analysis of static shading system using concrete as a material, by optimization process (simulations and generic algorithms)	The optimised solution showed a slight decrease in overall energy demand and showed improvement in daylighting performance. The illuminance level was between 100-2000 lux and reduced over lit hours (70-80%) and glare hours

9	Katsifaraki a., Bueno B., Kuhn T. E., (2017)	Venetian blind control system	The study conducted a new simulation-based controller on Venetian blinds in office spaces through a Three-phase method and bi-directional scattering distribution functions, to analyse the visual comfort and energy demand of the space	The study innovates the conventional systems which operate on numerous illuminance sensors in a single space and substitute it for real-time daylight simulations to decide optimal shade configuration. Total energy demands of the building were successfully lowered by 10%, cooling energy demand by 30% compared to two other controls, which show promising development
10	Jayathissa P., Luzzatto M., Schmidli J., Hofer J., Nagy Z., Schluter A., (2017)	Dynamic Building Integrated Photovoltaic (BIPV) shading	The study conducted a comparison between static shading devices and dynamic adaptive photovoltaic system, through multi-objective optimization and simulations of dynamic configurations at hourly time step	The adaptive shading system controlled solar heat gains, allowed daylighting, and also generated electricity. The total energy saving was in the range of 20-80%, compared to conventional static systems, which allowed compensation for the building's entire heating/ cooling/lighting load, while compensating energy demand by 61% with PV supply
11	Chi D., Moreno D., Navarro J. (2017)	Perforated solar screens (PSS) on fully glazed building façades	The study applied an integrated simultaneous analysis of daylighting and energy consumption of spaces with PSS during the design stage, through daylight analysis (DIVA), and thermal analysis (EnergyPlus)	A balanced PSS solution was achieved by controlling its perforation percentage, matrix and shape by using the orthogonal arrays (DOA) statistical method. In comparison to a non-optimised façade located in Seville, Spain, the predicted optimal PSS achieved a 50% increase in the actual daylit area and a 55% reduction in the total energy demand
12	Manzan M., Clarich A. (2017)	Fixed external inclined shading panel with internal Venetian blinds	This paper analysed external fixed and movable internal shading devices simultaneously, by using the optimization of energy and daylighting (FAST algorithm and simulations)	The algorithm performance of FAST proved to reduce the number of simulations conducted. The optimal solution in terms of design reduced the primary energy consumption to about 26% for both triple and double glazing.

13	Choi S. J., Lee D. S., Jo J. H. (2017)	External moving shading devices control	This study introduced a shading control algorithm by conducting 3 control modes of experiments of the shading device through simulations and mock-up study to evaluate the energy and environmental performances	All three modes (Mode 1 – energy consumption; Mode 2 – energy consumption and glare protection; Mode 3 - glare protection, energy consumption and illuminance satisfaction) reduce the total amount of energy consumption by 48% compared to the no shading, while maintaining a uniform indoor illuminance (around 300 lux)
14	Evola G., Gullo F., Marletta L. (2017)	Three types of shading devices – external roller blind, solar control film and internal Venetian blind	This research evaluated the visual and thermal comfort of an existing office building in Italy through a series of shading devices applied. Energy usage was also analysed to further confirm the result of the experiment	Both the external blind and solar film showcase about the same result with a reduction of 10ºC of internal temperature and minimum illuminance was kept around 1000 lux. External shading blind reduced energy usage by 47.7%, while solar file with about 59.8%. The internal Venetian blind was stated to be not effective as compared to the other shading devices due to non-uniform daylight distribution and the risk of glare.
15	Xiong J., Tzempelikos A. (2016)	Model-based internal shading device control	This paper investigated the implementation of a model-based control algorithm for shading and lighting operation in an office space test model.	Aiming at reducing the lighting energy usage and controlling glare probability was proven successful through the usage of simple sensor reading input, which can identify daylight glare probability, work plane and vertical illuminance as visual comfort criteria in the experiment

16	Wagdy A. Elghazi Y., Abdalwahab S., Hassan A. (2015)	Kaleido-cycle rings building skin	The kaleidocycle rings were investigated to develop a specific façade configuration based on origami, through two phases using genetic algorithm and simulation on the South-orientated façade of an office room.	The first phase simulated daylighting for façade optimization influencing the second phase to reach the balance point between daylight and thermal performance. The kaleidocycle rings of 26cm in size and 64º rotation angle exceed the LEED V4 daylighting requirements and achieve a remarkable energy saving of 23% in comparison to a non-optimized configuration
17	Sabry H., Sherif A., Gadelhak M., Aly M. (2014)	Solar screens	This paper investigated the capability of solar screens in achieving visual comfort and energy consumption reduction through exploring the design and configuration in a three-stage process	The solar screens were proven to enhance daylighting and visual comfort by providing 66-79% daylit areas in the tested space and significantly reduced energy consumption by 25% compared to a window with no screen. However, combining two solar screen design parameters did not result in a better outcome.
18	Mandalaki M., Zervas K., Tsoutsos T., Vazakas A. (2012)	Fixed shading devices with integrated Photo-voltaic (PV) Panels	This study analysed the balance between the energy needs for heating and cooling the space that the shading device was used for and the energy that was used for lighting the same space and the energy that 14 different shading devices of different forms can produce	All shading devices with integrated south-facing PV can efficiently produce electricity. Shading devices such as Surrounding shading, Brise–Soleil full façade and Canopy inclined double work efficiently against thermal and cooling loads and may be used to produce sufficient electricity and control daylight.

19	Wankanapon P., Mistrick R. G., (2011)	Roller shades and automatic lighting control	The study analysed roller shades operated with different solar radiation setpoint control strategies in an attempt to minimize total energy consumption, using simulation (EnergyPlus)	A simple solar control strategy can provide a significant reduction in terms of heating, cooling and lighting energy consumption (in offices) especially in hot climates. The best lighting saving is by a white shade with 76-83% savings and 14% total energy savings, at a high solar setpoint of 400 W/m2 in a heating-dominated region, also provide good results in a cooling-dominated region with 26% total energy savings
20	Koo S. Y., Yeo M. S, Kim K. W. (2010)	Auto-mated Venetian blinds control method	This paper evaluated the automated blinds to be deployed by control preferences and also controlled hourly by the outdoor solar conditions to maximize daylighting in terms of energy consumption and occupant visual comfort.	The new control method was introduced to allow protection from direct solar glare as well as prevent undesirable blockage of daylight, according to specific user-defined zones and time of the day, as disregarded by manually operated blinds. Energy consumption is to be further evaluated in future research.

(Source: Author, 2021)

It is proven that shading devices do play a big role in the approach of finding the balance between thermal and daylighting performance of a building or space. Control strategies in operating the shading devices (Koo, Yeo & Kim, 2010; Wankanapon & Mistrick, 2011; Xiong & Tzempelikos, 2016; Katsifaraki Bueno, & Kuhn, 2017; Choi, Lee & Jo, 2017; and Atzeri et al. 2018) are widely studied. Based on this, reviews found in the through occupancy-based control or climatic-based control, mainly show a variety of result to enhance or overwrite previous claims made by other authors. There were also studies that approached multiple types of shading devices in a single research, often for both the external and internal shading devices. For example, Evola, Gullo and Marletta (2017) evaluated three different shading devices, which are external roller shades, solar control film and internal Venetian blinds to investigate the balance between visual and thermal comfort. On the other hand, Manzan and Clarich (2017) conducted research on the external inclined shading panel with internal Venetian blinds through optimization of visual and energy performance. Besides that, a building-integrated photovoltaic panel (BIPV) was also introduced as a proven effective shading device that can maintain a balance in both the thermal and daylighting performance, and at the same time produce energy (Manadalaki et al., 2012; Jayathissa et al., 2017). It is also brought to light on several studies that introduced innovative shading device materials, which are not normally found in the market. Wagdy et al. (2015) applied the kaleidocycle rings method, while Zani et al. (2017) explored concrete as a promising material, and Gutierrez et al. (2019) introduced ceramic to louvre shading panels as a potential material in terms of an ecological impact besides its thermal effect and reduction of glare.

CONCLUSION

Highlighting the issue of achieving thermal-daylighting balance, this systematic literature review first studied to define the concept of the balance through the factors affecting the aspect of daylighting and thermal performance and analysing the keyword parameters that are researched throughout. The factors are categorized into three major factors which are energy, comfort and perception or view. Each factor is then further discussed through their research keyword parameters in which are studied in various papers by their respective authors. Therefore, to understand how to reach the thermal-daylighting balance, the method to balance was categorized into three which are parameter relation, parameter combination and multi-objective optimization. A vital design solution in achieving the balance in a building performance is through building shading devices installed. This observation agrees with Yu et al. (2020) and Kirimtat et al. (2019) who concluded that the number of studies on shading devices has increased. The major findings derived from the study are as follows:

- The most common combination of performance factor parameter is the energy and comfort factor due to its wider scope of research parameter and this allows for the different combination of parameters. The most frequent keyword parameter used is the energy consumption parameter, followed by the visual comfort parameter.
- The parameter relation balance method is applied to understand and evaluate one parameter first and proceeding with another or multiple other parameters, while relating the results with the former. This

research method can be a little more time consuming compared to the other two balance methods.

- Parameter combination and multi-objective optimization are balance methods that are applied in more recent studies in the span of 10 years. Generally, the multi-objective optimization method is faster and more accurate way of analysing the balance between the thermal and daylighting performance research due to the optimization of multiple parameters and the usage of simulation tools and newly introduced algorithms to support the research method, though it is comparatively more complex.
- The paper is only dedicated to analyse the balance through various building shading devices, which are considered as an integral part of the design of a building. The control mechanism or strategies applied to movable shading devices are recommended due to their flexibility and effectiveness in the daylighting performance and reduction of energy consumption, while also considering occupant-based controls. However, other types of design solutions can affect the thermal and daylighting performance that was not the focus in this paper, for example building location and orientation, space functionality, glazing systems, opening areas, building material and interior decorations.

For future investigations, the concept of thermal-daylighting balance may be further discussed in terms of the sustainability or long-term aspect of high-performance buildings. Moreover, the balance method of multi-objective optimization can be further developed through better algorithms to support a more instant result and analysis. The application of better technology like artificial intelligence and big data may clarify and improve the method better. The innovation and production of new building materials can also be taken into consideration for the type of daylighting control design solutions in the future.

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