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Integration of Daylight Use and Analysis in Double Skin Facades: A Literature Review

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Highlights

- Effective use of daylight provides energy efficiency, health and comfort.
- Double skin facades (DSF) save energy reducing the heat losses in buildings.
- DSF can get benefit from daylight more efficiently
- DSF can be an effective solution to reach sustainability targets.

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Abstract

Double skin facades (DSF) aim to save energy reducing the heat losses in buildings. They are visually appeal while allowing to use daylight efficiently. Such facade systems can reduce glare and distribute daylight evenly in the interior when compared to conventional facade systems. That is a result of cavities between two glass facades and locating sun shading elements in them, although this system provides a high level of transparency. As their primary purpose of application is to ensure thermal performance and ventilation, most studies in literature have focused on these. This study started with the hypothesis that studies examining daylight performance in DSFs are more limited than studies examining thermal performance and that daylight optimization methods are not used sufficiently in DSFs. In this context, the study aims to analyze studies focusing on daylight performance of DSFs. The review targets results of such current studies to guide future ones providing feedback knowledge. This may help to better technical developments in such facades and make them prevail in constructions or in retrofitting So, it contributes to literature in this sense. Recent studies are shown in tabulated form and interpreted in detail with graphics. considering their methodologies, daylight parameters and findings. Results show that the daylight parameter is one of the most important issues that architects or designers should consider from the moment they start the design, and they should make their designs based on the optimum penetration of daylight into the building. Consequently, this review presents that the use of daylight optimization has started to be used in recent studies dealing with DSFs. A DSF design can optimally get daylight into the interior can be made by using this method more frequently.

1. INTRODUCTION

Following the principles of sustainable development in the built environment let us design more sufficient building envelopes which maintains energy saving more efficiently [1]. Facades controlling the interaction between the indoor and outdoor environment, are one of the basic components of the building envelope. Traditional ones and the ones with less amount of window area may cause insufficiency in natural ventilation, thermal discomfort, lacking use of daylight and high energy consumption. The highly glazed façades as a result of contemporary architecture, cause glare and overheating, relatively increase in cooling loads and energy consumption [2]. Innovative facade systems have been designed and used for better thermal comfort and visual quality with the developing technology in recent years [3]. Double skin façades (DSF), consisting of two transparent surfaces with a naturally or mechanically ventilated air gap, covering one or more floors, is one of the façades that provides improved thermal and visual comfort. They efficiently control indoor and outdoor interactions [4]. DSF prevent glare and offer enhanced visual comfort, since they allow opportunity to use sunlight in a controlled manner throughout the year [5]. Shading elements in

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the air gap acts as a barrier to take daylight in a controlled way and be against the undesirable effects of microclimatic conditions between the two facade layers where air flow is provided [6]. Their appearance is somehow appealing and improve acoustical quality of the interiors against noise pollution [7].

Literature cites studies mostly about their thermal energy performance, ventilation capabilities, and reviews in context of these concerns and abilities (Table 1). Daylight performance of these systems has remained one step behind these researches, although a holistic point of view is necessary in building performance when a new building system is introduced as being efficient. One study about daylight performance focused in office buildings with DSF in 12 countries. Results showed no glare problem in any of the DSF systems examined [8]. Another study presented that the best daylight performance and optimum ventilation of DSF is achieved in autumn regarding seasonal conditions [9, 10]. Review studies about DSF present a comprehensive researches on DSF compelling previous ones. One review study focused on environmental issues and basic strategies of DSF in general terms. Energy performance remains to be the basic domain, the ventilation and daylighting benefits follow the energy strategies. There happens the perception that DSF provide energy saving, heat loss is less than completely glass facades, better daylight performance. However, there may be overheating problems in hot climates when compared to cold climates [11]. Another review examined existing DSF systems' structural and constructional attributes mainly in Finland and Germany. Specifically, DSF in Finland are mostly at floor height or space in height of the building, while four types of (box window, shaft-box, corridor and multi-store DSF) are frequently constructed in Germany [12]. One review article presented previous studies of DSF in terms of their important aspects, namely, ventilation, daylighting, performance, simulation, shading, solar photovoltaics, glass, smoke, cavity, wind [6]. The other study indicated disadvantages and advantages of DSF in designing energy efficient buildings [13]. The integration of DSF in HVAC systems becomes the main topic in a review study, including classifications, technical aspects and advantages/disadvantages of DSFs. Simulations can create energy efficient and aesthetic structures of these systems [14]. A similar one reports benefits of DSF in terms of energy efficiency and thermal performance. Environmental benefits and technical aspects are the other key concerns in the article [1]. The comparative analysis of energy benefits of DSF and responsive facades become the matter in another review article. The potentials of these façade solutions, reducing energy consumptions and CO2 emissions, are deeply investigated to achieve building retrofits [15]. Three review articles about daylighting in general are noteworthy to read and understand the wide perspective in daylighting analysis and design. One depicts the historical development in daylight prediction strategies and tools, explaining sky models, data sets, building geometry, calculation parameters/tools and simulation tools [16]. A review about daylighting design explains general aspects about daylight, its use in buildings, new daylighting strategies and calculation methods [17]. Another similar review focuses on fundamental physical quantities about daylighting, and its relation to lighting control systems and energy efficiency [16] Connections of the theory of daylighting to other relevant topics are significant in terms of underlining possible and further research areas. One is about applications and generalization potentials of machine learning tools in daylighting design and control [18], while a link is constructed between daylighting control systems and user preferences and user behavior in another review [19]. Thermal and energy performance are integrated as a basic matter in research [20], or applications of innovative daylight strategy, fiber optics, are clarified through previous studies [17]. Additionally, a critical review scans previous surveys about users' responses on window view and daylighting [21]. In view of these ongoing studies, a possible link between daylighting design and DSF in a holistic way becomes necessary for further research possibilities by marking existing knowledge gaps.

This comprehensive literature review examines the use of daylight, its relationship with energy and health, performance parameters and the technical characteristics of DSF, interior comfort parameters and its relationship with design, and ultimately its effects in terms of daylight performance and visual comfort (Table 1). The aim is to outline potentials of features required for the effective use of daylight of DSF for further research developments although their prevailing application purpose remains to be thermal performance. This study differs from other studies in the literature in examining the daylight performance of DSFs in detail, and it is important in paving the way for new studies on this subject.

2. METHODOLOGY

A systematic literature review was conducted on three main concepts, namely, daylight, double-skin facades and daylight performance in DSF, to guide the study in May 2022. Databases were Sciencedirect, Scopus, ResearchGate, and Google Scholar to let us search in different sources. Items evaluated during the literature review have become the limitations of the previous studies under these headings, the methods used, and the tools. Limitations were also brought to the topics covered by the main headings we defined at the beginning of the study, not to have any difficulties in terms of which resources to use during the literature review. Researches on daylight include i) definition of daylight, ii) daylight performance, iii) daylight - energy relationship, iv) daylight - human health relationship and v) studies examining daylight optimization; while studies on DSFs involve i) the definition of DSs, their technical properties and ii) the thermal performance of DSF were examined, and finally, studies on daylight performance of buildings with this facade system examine under the concept of daylight performance in DSF by limiting them to the combination of two terms. Despite their importance, this research aims to overcome such limitations of previous studies by presenting a deep understanding of the effects of daylight on energy consumption and human health, the properties and thermal performance of DSF, as well as daylight performance. In order for the research to achieve its purpose, the methodological procedure was carried out in several steps as shown in Figure 1. Keywords of daylight, DSFs, energy efficiency, building envelope and health are combined with operators such as AND, NOT and OR to obtain relevant results, to achieve the targeted coverage. Due to the scope of the study area, the emerging literature is analyzed analytically, its purpose and scope are determined and the relevant candidate articles are distinguished within the scope of this review. Thus, the exclusion criteria were: i) out-of-scope articles, ii) articles on artificial lighting, iii) studies on other indoor parameters, ie multi-site studies. In the refined scientific literature, articles cited or cited by other articles are filtered again using the same criteria. Those that pass the filter are also identified as candidate articles; all are then categorized according to the topical and chronological nature of the entire review. According to the methods of the studies examined, they were classified in 4 groups as i) literature review, ii) measurement, iii) simulation, iv) optimization. Unlike previous studies, the tools used were also discussed and the percentage of use of these tools was evaluated.

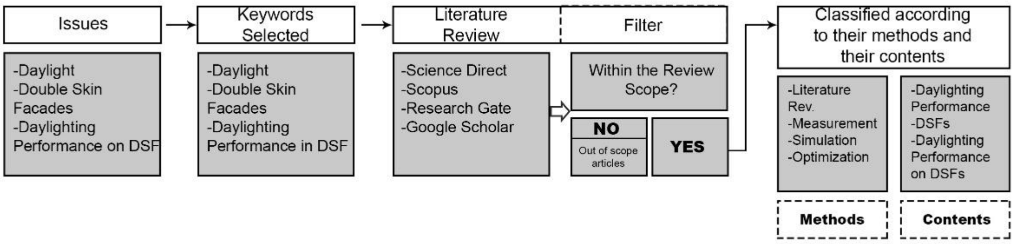

Figure 1. *Work Flow*

3. DAYLIGHT PERFORMANCE

3.1. Definition of Daylight and Differences from Artificial Lighting

The source of daylight is the sun. Sunlight is transmitted to the earth directly or diffusely by the atmosphere [17]. The sunlight emitted in the atmosphere is called skylight, and as a result of the combination of sunlight and skylight, daylight emerges. Sunlight is often the main source of indoor lighting in hot and dry climates. Since the cloudiness of the sky is low in these regions, sunlight is less scattered, overheating problems and visual discomfort may occur. To avoid these problems, sunlight is not taken indoors directly in these climates. In cloudy climates, diffuse sky light from the sky can be taken indoors with large windows [22]. Geographical latitude, season of the year, time of day, local weather, sky conditions and building geometry all affect the quality and intensity of daylight, and in a country with low sunshine such as the United Kingdom, it may not be sufficient to illuminate indoor environments with daylight [23]. When daylight lighting alone is not enough, it is used with artificial lighting systems. Although artificial lighting systems are frequently used today, the use of these systems causes CO_2 emissions that cause global warming. In the study conducted by Alrubaih et al. was stated that 223 million tons of CO_2 emissions could be reduced by the effective use of daylight [20]. Using sunlight has an important place in protecting human health and curing diseases, as well as in terms of energy [24]. In addition, the use of daylight can reduce the psychological distress associated with seasonal affective disorder [25, 26]. In addition, since sunlight contains different spectra, it provides positive physiological and biological results as it provides vitamin D and hormone production in the human body [26, 27].

3.2. Relationship Between Daylight and Energy

There is an increase in carbon emissions as a result of the use of artificial lighting. This causes global warming. The efficient use of energy is of great importance for a sustainable future, and buildings consume 40% of the total energy produced in Europe. About 19% of this energy is consumed for lighting, and the electricity consumption per square meter in buildings varies between 20 and 50 kWh/m^2 [28]. It has been determined that 20-30% of the total energy use in commercial buildings and 35% of the total energy used in office buildings is taken by lighting energy [29, 27]. By taking natural light, which is the most important element of modern architecture, into the interior through façade openings, it reduces the need for artificial lighting and contributes to reducing building energy consumption and increasing visual comfort [30, 31]. In the studies, it was concluded that 223 million tons of CO_2 emission and 24,000 MW energy demand can be reduced by using daylight, while excessive daylight exposure causes thermal discomfort due to glare and overheating in building users [32, 18]. In Xue's study, the results of the survey concluded that the visual performance of the building occupants was affected by the quality of daylight [33]. When visual needs and comfort criteria are carefully considered, it is possible to see the benefits of daylighting [34]. Also, according to Krarti, electric artificial lighting increased the annual energy consumption of a building by 40% [35]. Daylight alone does not provide savings in a building, and when sufficient daylight level is reached in an environment, photosensors that control artificial lighting should be integrated [17]. In addition, the use of manual or automatic timed lighting control systems should be considered. The Building Research Institute (BRE) and CIBSE have studied different lighting control systems [36, 37]. In the study conducted by Ihm, it was concluded that artificial lighting energy can be reduced in buildings with lighting controls [38]. Today, in parallel with the developing technology, it is aimed to reduce the electricity consumption used for lighting to less than 10 kWh/m^2 per square meter with the use of high efficiency light sources, the use of lighting control systems and efficient use of daylight. Daylight is effective in the energy flow in the building and especially the glazed area of the facade is effective in this energy flow. More than optimum level of daylight causes overheating problems in the indoor environment, which causes an increase in the amount of energy required for cooling. Shades can be used to control daylight in the sections where glass surfaces are dominant, thus preventing both glare and overheating problems [39].

Table 1. *A comprehensive literature review*

Daylight Performance in Buildings									
Year of Study	**Region &Period**	**Latitude**	**Analysis /Parameter**	**Examined system**	**Aim**	**Method**	**Tool**	**Type of Examined Building**	**Main Findings & Results**
1998, [30]	Freiburg, Almanya	47° (N)	W/m^2 Lm/m^2	Room	To examine daylight characteristics and thermal performance of buildings.	Sim.	Radiance	Modern buildings	Lighting and thermal behavior of room are interrelated.
2001, [40]	Saudi Arabia	24^0 (N)	Lux	Rowshan shading system	Analyzing the state of paralel shading device systems.	Sim.	Fortan 77	Modern Buildings	The passage of light from natural sources through parallel shading devices cannot be modeled with conventional methods.
2003, [29]	Hong Kong	22° (N)	kWh	Room	To find the element that consumes the most electricity in the office structure.	Measure.	-	Office	While the HVAC system consumes the most electricity in the office structure, it is followed by electric lighting.
2005, [35]	Denver,	39° (N)	Lux	Glass type	To save energy in the use of electric lighting by using different glass types.	Sim.	DOE-2	Modern Buildings	Window permeability and window area significantly affect the daylight taken into the interior as well as the electrical energy required for artificial lighting.
2005, [31]	North Carolina	35° (N)	Lux	Classroom	To investigate the performance of daylight systems at 4 schools in North Carolina.	Measure.	Daylight sensors	Educational Buildings	In classrooms, it is necessary to provide the same illuminance near the window and at the farthest points from the window.
2009, [38]	ABD and 12 European Countries	-	Lux	Room	To investigate the effect of location, building geometry, window size and glass type on daylight performance.	Simulation	DOE-2	Office	Significant energy savings can be achieved by using daylight control where natural light can be appropriately brought indoors.
2013, [19]	Bangi, Malaysia	03° (N)	Daylight literature	-	To examine the key features of daylight and lighting control strategies, including daylight factor, illuminance and glare index.	Rev.	-	-	The correct design and selection of daylight lighting systems not only reduces the need for artificial lighting, but also reduces the amount of energy required for cooling.
2013, [25]	Rome, Italy	41° (N)	W/m^2	Infra-red PV	Efficient use of daylight by using Infra-red PV.	Sim.	MATLAB	Modern Buildings	Daylight increases user satisfaction and learning performance. Direct sunlight should be preferred in areas such as classrooms, libraries and laboratories.
2014, [33]	Hong Kong	22° (N)	P value	Room	To investigate the effect of daylight performance on occupant comfort in residences in Hong Kong.	Survey Statistics	SPSS 19	Housing	Although there is no statistical difference between gender in light preferences, older people are more satisfied with bright environments.
2014, [41]	Singapore	1° (N)	DA	Room	Evaluating daylight performance for tropical office buildings with a parametric approach.	Sim.	DAYSIM	Office	Passive design strategies such as internal surface reflection, glass visual transmittance and shading control have significant effects on DAcon and DAmax.
2015, [24]	Bratislava, Slovakia	48° (N)	Lm/W	Spectral filters	To reveal the chronobiological aspects of daylight in the built environment and to create an architectural environment suitable for human health, which receives daylight indoors.	Exp.	-	Modern Buildings	Spectral filters examined in daylight systems caused a decrease in the circadian stimulus.
2016, [42]	Alexandria, Egypt	31° (N)	DA	Windows	To examine the effect of glass in mosques on indoor lighting.	Sim.	DIVA	Mosque	Window opening principle significantly affects daylight and thus user comfort.
2017, [43]	Delhi, India	28° (N)	Lux	Atrium	To study daylight performance on the inner surface of the atrium.	Measure.	Lux meter	Modern Buildings	The highest daylight illumination was found in the area of the wall extending vertically from the upper edge of the courtyard.
2017, [44]	Naples, Italy	40° (N)	Lux	Room	To measure brightness and illuminance at three offices in Naples.	Measure.	Lux meter	Office	Although the interior features of the 3 different offices measured were different, each of them received good daylight .
2017, [17]	Glasgow, UK	55° (N)	Daylight literature	-	To prepare a detailed literature review about daylight.	Review	-	-	Although daylight has positive effects for building users, it causes problems such as heating problems, so daylight control systems should be used.
2018, [45]	China	39° (N)	DA	STPV facades	To minimize the negative effects of STPV facades against daylight performance.	Sim.	DAYSIM	Modern Buildings	To maximize the energy potential of STPV facades, a south-oriented optimum design has been proposed for buildings located in cold climate zones.

2019, [46]	Madrid, Spain	40° (N)	UDI and DA	Louvre System	To compare 3 different materials used in the Louvre system.	Sim.	DAYSIM	-	The proposed ceramic louvers performed better than other systems in providing a more even lighting distribution. In terms of artificial lighting energy saving, aluminum blinds provided the best performance.
2019, [47]	China	30° (N)	kWh/m²*year	CdTe PV glazing	To investigate the energy and daylight performance of offices located in 5 different climate zones of China with PV windows with different facade designs.	Sim.	Radiance EnergyPlus	-	The results showed that PV window application can result in energy savings in large window to wall ratio..
2019, [48]	Lebanon (Coastal Area)	43° (N)	Lux	-	To examine energy and sunlight performance in educational buildings.	Sim.	DesignBuilder Climate Consultant	Educational Buildings	The Sda indicator is the most important parameter to reach the minimum illumination level of 300 Lux, and all directions except the north direction from the samples provided this value.
2019, [49]	Tabriz, Iran	38° (N)	UDI	-	Increasing the energy and visual performance in the best way by taking the daylight indoors in the optimum way.	Sim. Opt.	Grasshopper Octopus	Office	Designers can make effective decisions in the design process with these tools.
2019, [50]	South Korea	37° (N)	Lux	Polymer dispersed liquid crystal (PDLC)	To investigate the effect of PDLC dispersed liquid crystal films on energy and daylight performance.	Sim.	EnergyPlus	Historical Buildings	It has been shown to be effective in reducing heating and cooling energy and improving daylight performance by using PDLC films.
2020, [51]	Shantou (China), Pittsburgh (USA) and Calgary (Canada)	23°(N)/ 40°(N)/ 51° (N)	Lux Kelvin	TiO2@W-VO2 thermochromic glass	To investigate the effect of TiO2@W-VO2 thermochromic glass on indoor daylight performance of a typical office room.	Measure.Sim.	Spectrophotometer Radiance EnergyPlus	Office	The examined brownish TC glass showed 18.6% solar modulation ability and 56% apparent transmittance. The effect of TC glass on the UDI varies depending on the distance from the window, and in areas far from the window, the window glass adversely affects the UDI.
2020, [52]	Malaysia	3° (N)	Lux	Light Shelf System	To increase the usability of daylight by integrating a light shelf system into the completely glass facade with the optimization method.	Sim. Opt.	Grasshopper GA	Office	Comparing the Optimal Design Options results with reference models has shown great potential in increasing useful daylight levels in all watches.
2020, [53]	Jordan	31° (N)	Lux	Advanced daylight technologies	Achieving visual standard levels of daylight performance in different seasons and minimizing the possibility of glare.	Sim.	IESVE	Educational Buildings	The anabolic system, the light shelf, the upper windows in the corridor and the translucent material can increase the daylight level by more than 100%, especially in the rear.
2020, [54]	Lahore, Pakistan	31°(N)	Lux	Light shelves	To examine the effects of different light racks on daylight performance.	Sim.	EnergyPlus Radiance	Educational Buildings	Limited success has been achieved when using a light rack in closed sky conditions, with the light outer rack at a 20 degree angle found to be the most appropriate choice.
2020, [55]	Konya, Turkey	37° (N)	Lux	Interior of Mosque	To examine indoor daylight performance in mosque structures.	Measure.Sim.	DesignBuilder	Mosque	The indoor light level has increased with the development of construction techniques and design criteria.
2020, [56]	South Korea	37° (N)	Lux	Light Shelves	To investigate the effects of different shading devices on illuminance levels and annual cooling energies.	Sim.	Sketchup	Housing	Proper use of shading devices has the potential to save energy by reducing cooling and artificial lighting loads in a building.
2020, [57]	Tehran, Iran	35° (N)	Lux	Room	To provide optimum office layout in Tehran.	Sim.	Grasshopper	Office	The highest daylight and lowest annual energy demand in all directions and shading modes are related to parallel arrangements and minimum height of bays.
2020, [58]	Egypt	30° (N)	ADI and sDA		Improving the daylight in Ommor Tosson Palace, redesigning the skylight in an optimal way affecting the psychological state of the user and the light dispersion.	Sim. Opt.	Grasshopper Octopus	Palace	Despite the difficult large skylight opening in a warm and clear sky climate, a 42% improvement in daylight performance was achieved.
2020, [59]	12 European Countries	-	P value	Classroom	To investigate the effect of daylight on learning performance.	SINPHONIE (Schools Indoor Pollution and Heath)çalışması	-	Educational Buildings	Data collected in the SINPHONIE study in 12 European countries showed that daylight parameters were related to the performance of students at school in their lessons.

2021, [60]	Beijing, China	30° (N)	Lux	Room	To evaluate users' opinions on daylight performance in a nursing home in Beijing with a survey.	Survey Sim.	IESVE	Nursing Home	Satisfaction can reach the highest level in cases where daylight illumination varies between 6000 lux and 10000 lux in toilets and between 400 lux and 600 lux in bedrooms.
2021, [61]	Mazandaran,Iran	36° (N)	Lux, PMV and PPD	Room	To investigate how the variation of different parameters in the building envelope examines thermal satisfaction and daylight performance.	Sim.	Grasshopper Radiance Honeybee	Housing	The insulation layer of the roof and walls is the most critical element in the energy performance, and the WWR shading properties and glass types significantly affect the energy, daylight and thermal comfort performance.
2021, [62]	Beijing, China	30° (N)	Lux	Room	To propose a daylight simulation for general floor plans based on CNN and GAN.	Sim. Opt.	Sketchup Grasshopper/ machine learning	-	The estimation of static daylight metrics outperformed the estimation of annual metrics in the same dataset and model structure.
2021, [63]	London, Stockholm, Rome, Singapore	51°(N)/ 59°(N)/ 41°(N)/ 1° (N)	Lux	Room	To examine the effect of using thermotropic materials on lighting and energy performance.	Sim.	Radiance EnergyPlus	Office	Both the optical properties and transition temperature of the thermotropic material layer affect the final energy efficiency and daylight performance.
2021, [64]	Xi'an, C-Si, Beijing, Guangzhou, Harbin, Chongqing (China)	30° (N)	Lux	Semi-transparent photovoltaic	To propose solutions to the problems that occur as a result of the use of SIPV technology in skylights.	Sim.	DAYSIM	-	Cities with sufficient sunlight such as Beijing need a relatively higher optimal ARPM range, while cities with limited sunlight conditions such as Harbin and Chongqing need a lower ARPM range.
2021, [65]	Cairo, Egypt	30° (N)	Lux	Tubular daylight guidance system	It is aimed to popularize the use of TDGS.	Measure.		Modern Buildings	Where solar radiation is abundant, sand and dust sources are abundant, resulting in a decrease in TDGS efficiency. The highest luminous transmittance magnitude and ratio was observed at midday when GHI and solar altitude were highest.
2021, [66]	California, USA	34° (N)	Lux	Daylight guidance systems	To investigate the effect of daylight guidance systems on daylight performance.	Sim.	Radiance	-	The solar directing system provides significant energy savings compared to the traditional shading system.
2021, [67]	Granada, Spain	37° (N)	Lux	Park	To increase the visual performance of pedestrians in urban gardens.	Measure.	Luxmeter	Urban Environment (City Gardens)	Plants not only have the benefits of CO2 absorption, but also modulate daylight. The tree species to be selected according to the climate should be different.
2022, [68]	Kitakyushu, Japan	33° (N)	Lux	Metal Shading Element	To investigate the effect of metal shading elements on daylight performance.	Sim.	Grasshopper	-	Through this work, metal shading improves daylight performance and the metal mesh is recognized by USGBC LEED.
2022, [69]	Tehran, Iran Sari, Iran	35° (N)	Lux		To investigate the effect of sky cloudiness on optimum light shelf characteristics defined for classrooms.	Sim. Opt.	Grasshopper OpenStudio	Educational Buildings	In Tehran, the UDI and ASE values between the base states and the optimized light shelf states are higher than the values measured in Sari in all cases. Daylight performance of south-optimized cases is acceptable in three scenarios in Tehran and in two scenarios in Sari.
Double Skin Facade Buildings									
2001, [12]	Finland, Germany	60° (N) 52° (N)	-	-	To examine the existing double skin façade systems.	Rev.	-	-	DSFs in Finland are mostly at floor height or space in height of the building, while there are four different types of them in Germany.
2002, [70]	Berlin, Germany	52° (N)	W/m^2	Room	To examine the temperature behavior of double skin facades.	Model	Mathematical Model	Modern Buildings	There is a risk of incorrect results when using the resistance factor z to analyze the flow characteristics of buoyant ventilation.
2004, [71]	Dusseldorf, Germany	51° (N)	^{0}C	Room	To examine the energy performance of 3 buildings with double skin facades.	Measure.	Datalogger	Office	Wind protection, sound insulation, evening ventilation are the advantages of double skin facades, while high air temperatures near the window and high cleaning costs are disadvantages.

2005, [5]	Villeurbanne, France	45° (N)	m/sn	Cavity	To evaluate the air movements of the ventilation space by creating a mathematical model of the building with a double skin facade with blinds and ventilated with natural ventilation.	Model	Mathematical Model	Modern Buildings	The distance between the louver and the outer wall has a great effect on the velocity profiles in the air duct of the DSF.
2005, [72]	Tokyo, Japan	35° (N)	h^{-1}	Room	To investigate the natural ventilation performance of a DSF.	Exp.	Scale model experiments and computational fluid dynamics	Office	In order to provide air flow from the top of the building, the opening between the outside and the atrium on each floor should not be less than $2m^2$.
2005, [73]	Delft, Netherlands	52° (N)	^0C	Room	To describe the thermal performance of DSFs with plants.	Sim.	Simulink	Office	The simulation of the building has proven that the plants will contribute to the creation of a comfortable indoor climate and energy savings.
2005, [74]	Hangzhou	30° (N)	Pa	Room	To investigate the effect of wind pressure on double skin facades.	Measure.		Office	As the wind blows across the width of the rectangular building, the negative pressure on both sides of the building, as well as on the windward side of the building, will be much greater than in a square building.
2008, [75]	Cairo, Egypy	30° (N)	KWh/year	Room	To examine the thermal performances of double skin facades in extremely hot and dry areas.	Sim.	IESVE	-	Transparent double skin facades can increase the overheating problem in office buildings in hot and arid regions compared to single-skin facades using reflective glass, thus increasing cooling loads.
2008, [76]	Singapore, Australia	1° (N)	kWh/m^2	Room	Reducing energy use in high-rise office buildings in Singapore.	Sim.	CFD	Office	It is concluded that there can be significant energy savings if natural ventilation strategies can be utilized with the use of DSF.
2008, [77]	Brussels, Belgium	50° (N)	m^3/h	Room	To analyze the thermal performance of DSFs.	Sim.	EnergyPlus	Modern Buildings	The air flow rate through the air gap, the average and the highest temperature of the air gap are developed by correlations.
2008, [78]	Trondheim, Norway	63° (N)	kWh	Room	To investigate the necessity of applying a DSF system to the east facade in order to reduce the heating demand in an office building in Norway.	Sim.	ESP-r	Office	Heating energy is 20% higher in a single skin façade system. When the U values of the windows are improved in the single skin facade system, energy efficiency close to the double skin facade system is achieved.
2009, [11]	-	-	literature	-	To present a comprehensive research on Double Skin façade systems.	Rev.	-	-	The heat loss will be less than the completely glass facades. Tt can provide better daylight performance for indoors. There may be overheating problems in hot climates.
2009, [79]	Italy	59°(N)/ 41°(N)	W/m^2	Integrated moving shading devices	Optimizing the energy performance of a building with a double skin façade with integrated movable shading devices.	Sim.	CFD	Office	The proposed model was compared with an office structure with opaque walls and glass in Italy, and the proposed facade significantly improved the building's energy performance all year round.
2009, [80]	Hong Kong	22° (N)	kWh	Room	Investigating energy performance in a double skin office building in Hong Kong.	Sim.	EnergyPlus	Office	By using a single transparent glass on the inner wall and double reflective glass on the outer wall, approximately 26% of annual cooling energy savings can be achieved compared to the traditional facade.
2010, [81]	Beijing, China	30° (N)	^0C	Room	To investigate the effect of double skin façade and shading elements on the thermal performance of the building.	Sim.	Fluent	Modern Buildings	The ventilated double skin façade system is a suitable façade system for the cold climate region of China.
2011, [6]	Bangi, Malaysia	03° (N)	literature	-	A comprehensive review of previous studies on DSF systems.	Rev.	-	-	The studies carried out so far have touched on ventilation a lot, but daylighting studies are insufficient in this facade system.
2011, [14]	Gazimagusa, North Cyprus	35° (N)	Pmv Ppd	Room	To assist architects in the design of parameters such as gap width and opening area in double skin facades.	Sim.	TAS	Office	For year-round performance of double skin facades, windows should be opened and closed according to environmental conditions.
2012, [3]	Padova, Italy	33° (N)	k-ω	Room	Performing CFD simulation of a building with a double skin façade through sensitivity analysis.	Sim.	EnergyPlus	Modern Buildings	In DSF with natural ventilation, the speed is 2-way, so the 2D CFD model gives the same or better results than the 3D model.
2012, [82]	China	30° (N)	c	Room	Investigation of wind pressure on a double skin facade of a building with experimental and numerical modeling method.	Sim.	SMPSS	Office	Through to the air gap in the double skin facades, the wind effect has less effect on the interior environment of the building.
2013, [2]	Hong Kong	22° (N)	W/m^2 ^0C	PV-DSF	To examine the effect of PV louvers positioned in the air gap on the thermal performance of double skin facades.	Measure.	Datalogger	Modern Buildings	It has been observed that when PV panels are used on a ventilated double-skin facade, it provides the lowest solar heat gain coefficient (SHGC), while heat loss is less in an unventilated double skin facade.
2014, [13]	Saint-Petersbu	59° (N)	literature	-	To classify DSFs.	Rev.	-	-	A new façade system, the DSF system, reduces the risk of overheating. In addition, from the literature study, it was concluded that the double skin

	rg, Russia								facade system is dependent on external conditions and greatly affects the indoor climate.
2014, [83]	-	-	literature	-	To present a comprehensive research on Double Skin façade systems.	Rev.	-	-	DSF can be applied not only in cold climates but also in hot climates. There are advantages such as high transparency rate, providing heat and sound insulation, and preventing glare problems in DSF. The disadvantage is the overheating problems in the air duct.
2014, [84]	Seoul, Korea	37° (N)	kWh	Cavity	To quantitatively analyze the effect of DSF design on energy consumption of adjacent conditioned zones in relation to window glass type and cavity depth.	Sim.	EnergyPlus	Office	The greatest variation in energy consumption occurred when the type of window glass on the outer surface of the inner layer was changed.
2014, [85]	Puigverd de Lleida, Spain	41° (N)		Cavity	To investigate the thermal satisfaction in the air gap of DSFs containing PCM.	Measure.	Datalogger	Modern Buildings	In systems using PCM, the payback of the active system is lower than in other buildings.
2015, [86]	Lisbon, Portugal	38° (N)	Cp	Cavity	Measuring air flows in a naturally ventilated double skin facade.	Measure.	Tracer gas test	Modern Buildings	Estimating natural ventilation flow rates is very important for DSF design.
2015, [87]	Gazimagusa, North Cyprus	35° (N)	literature	-	To examine the energy consumption in the ventilation systems of double skin facades.	Rev.	-	-	When DSF is used in an integrated way with the HVAC system, the building provides energy efficiency. By creating models from the designs of designers, both energy efficient and aesthetic structures can be created.
2016, [1]	Auckland, New Zealand	35° (N)	Literature	-	To present a comprehensive research on Double Skin façade systems.	Rev.	-	-	In the areas of "reduction of energy consumption", "improvement of ventilation, air flow and thermal comfort", "daylighting and glare control", "sound insulation, noise reduction and acoustic improvement" and "visual and aesthetic quality improvement", DSF systems offer positive effects.
2021, [15]	Napoli, Italy	40° (N)	literature	-	To reduce energy consumption and CO_2 emissions.	Rev.	-	-	The existing building stock worldwide is thermally and energy-inefficient and requires renovation. A reactive façade design that can produce energy can be put at the service of the society. It contributes to the creation of renewable energy communities by reducing heating consumption.
Daylight Performance in Double Skin Facade Buildings									
2007, [79]	United Arab Emirates	25° (N)	Lux	Daylight sensitive dimming control systems	To investigate the effects of daylight sensitive photosensitizers in different weather conditions.	Sim.	Radiance	Office	The location of the photosensors did not significantly affect the daylight performance.
2013, [8]	Chile, Colombia, Malaysia, Turkey, USA, India, Germany, UK, China	33° (S)	Lux	Room	To investigate the glare problem in DSF systems.	Sim.	IESVE	Office	There is no glare problem in office entrances with no DSF facades. The best examples of DSF designs have been found in subtropical regions.
2013, [88]	Egypt	30° (N)	kWh/year	Mashrabiya facade	To examine the effect of various perforated outer claddings on light quality for non-sealed double skin façades in a prototypical office space using parametric design.	Sim.	Grasshopper	Office	Based on the simulation results, the potential use of daylight can be increased with an effective design of the west façade. The modules developed from the Maşrabiya façade, which are traditionally used in Egypt, increased the illumination level from 54% to 78%.
2017, [10]	Benha, Egypt	30° (N)	Lux	Classroom	Studying daylight performance in classrooms with double skin façades at Benha University, Egypt.	Measure.	-	Educational Buildings	According to the measurement results, better daylight performance can be achieved in classrooms with DSF compared to single-skin facades. In DSF, daylight spreads more homogeneously in the interior.
2019, [89]	Izmir, Turkey	38° (N)	Lux	Room	To examine the effect of system variables of double skin facades on daylight performance.	Sim.	Relux	Educational Buildings	With some interventions that can be made during the design phase of double skin facades, optimal use of daylight can be achieved.
2019, [90]	Kano, Nigeria	12° (N)	Lux	Room	To examine the daylight and energy performance of the building with a double skin facade system.	Sim.	Grasshopper Ladybug Honeybee	Office	The performance-based design approach is inherently not very suitable for energy use, but it has been concluded that there is a fundamental deficiency

									in the conceptual design of energy use for the Nigerian region to exploit the full potential of the approach.
2019, [47]	China	30° (N)	Lux	STPV windows	To investigate the effect of STPV glass in a double-walled façade system.	Sim.	Daysim	Office	In order to provide optimum daylight in the office area located in the cold region of China, a window wall ratio of 30% is required and energy consumption is minimized with STPV windows on south-facing facades.
2020, [9]	Japan	139° (N)	Lux	Room	To examine the daylight, thermal and ventilation performance of buildings with DSF system.	Sim.	DIVA DesignBuilder	-	This study indicates that the perforation level of 30% in spring and 10% in autumn and one year in open sky conditions reflects optimum values for natural ventilation and daylight performance. For cloudy skies, this value is 60%.
2021, [91]	Nottingham, UK	43° (N)	Lux	Room	To investigate the daylight performance of the ETFE layered DSF.	Sim.	Grasshopper	Office	The light was more evenly distributed throughout the room. Using BSDF data for weather-based daylight simulations may suggest new ways to analyze daylight performance of adaptive ETFE facades more comprehensively.
2022, [92]	Japan	139° (N)	Lux	Room	To investigate the thermal and daylight performance of double skin facades.	Sim.	DesignBuilder Ecotec	Modern Buildings	Adding PDSF + SC and PDSF to lab modules increases the space with UDI levels ranging from 100 to 2000 lux and improves the daylight quality of the overall lab module.
2022, [93]	Depok, Indonesia	69° (S)	Lux	Room	To investigate the effect of window/wall ratio on daylight performance in a double skin educational structure.	Sim.	DiaLux	Educational Buildings	In a DSF, SC 0.42 and 40% WWR and SC 0.95 and 60% WWR were obtained for the north and south façades, respectively.

3.3. Relationship Between Daylight and Human Health

Lighting has an important relationship with human life as a result of its direct or indirect effects on the human body as well as energy efficiency. When the studies are examined, it has been seen that natural lighting has positive effects on human health compared to artificial lighting [94]. Although the effect of light on humans is not fully known yet, besides providing visual performance, it also has non-visual effects such as increasing attention, as well as affecting the biological clock in providing sleep patterns [95]. The orders in the nervous system and the biological system affected by the hormones secreted as a result of these orders are affected by the reaction of the hormone and nervous system with light, and it has been understood that the quantity and quality of the light coming into the eye are effective on the circadian rhythm, biological clock, biological system, perception mechanism and psychological state. In addition, the light created by artificial lighting sources used as an alternative to daylight indoors cannot meet the needs of human metabolism. Because the parameters such as brightness and color temperature of the light produced by artificial lighting sources are the same throughout the day, it is not compatible with the structure of dynamic daylight, and for this reason, the circadian cycle, which is the cycle of repetitive biological events such as digestion, sleep, hormone secretion and body temperature, repeated in a 24-hour cycle in users. may cause rhythm disturbances. After the light reaches the retina of the eye, it is transmitted through the nervous system to the area called the suprachiasmatic nucleus (SCN) in the hypothalamus. By controlling the biological clock of the body, the light regulates the circadian rhythm, so that activities such as hormone secretions, cortex work, body temperature, sleep-wake cycles in the human body are provided at certain periods. In addition, light is effective in the secretion of the hormone melatonin, which regulates the circadian rhythm in the body, and bright blue light suppresses the secretion of this hormone, while darkness increases it. In addition, sunlight is more effective than artificial light in the secretion of the hormone melatonin. The light in the morning triggers the body's biological clock, and the body releases hormones such as serotonin, cortisol and adrenaline to this stimulus, and also increases the metabolic rate and body temperature. The metabolic rate reaches its highest level after noon and with the sunset in the evening, the biological clock stimulates the pineal gland. As a result of this stimulation, the pineal gland converts the serotonin hormone it secretes into the melatonin hormone. Thus, the body temperature also decreases. In the morning, the secretion of the hormone melatonin is stopped. This cycle continues in this way for 24 hours. As a result of the studies, ipRGC cells (intrinsically photosensitive retinal ganglion cells - photosensitive retinal ganglion cells) were discovered in addition to the photoreceptors known as rod and cone cells that enable vision in the retinas of mammalian species. they have been associated with the circadian rhythm due to their response to the length (~460 – 480nm). During the day, ipRGC cells send signals to our brain to produce or inhibit hormones and neurotransmitters, and the discovery of these cells revealed that light has non-visual effects [96]. Changes in daylight have an effect on the human circadian rhythm, and the human circadian rhythm and its associated biological clock are synchronized with the world's light-dark cycle. There are studies showing that the use of daylight in buildings can reduce the psychological distress of users related to seasonal mood [25]. In addition, sunlight is necessary for the production of some hormones and vitamin D in the human body under the influence of sunlight [32, 27].

3.4. Measuring Daylight Performance

Methods have been developed since the 1900s to evaluate daylight performance indoors, and these methods are divided into two as static and climate-based dynamic methods, as seen in Table 2.

Table 2. *Methods for assessing daylight performance indoors*

Static Daylight Assessment Methods	**Dynamic Daylight Assessment Methods**
Daylight Factor (DF)	Daylight Autonomy (DA)
Average Daylight Factor (ADF)	Continuous Daylight Autonomy (DAcon)
Illuminance at a Point (SPT)	Maximum Daylight Autonomy (DAmax)
Average Luminous Level Amount (Em)	Useful Daylight Illuminance (UDI)
Vertical Illuminance - Horizontal Illuminance Level	Spatial Daylight Autonomy (sDA)
Level Ratio (VH)	Annual Sunlight Intake (ASE)

Daylight Factor; According to CIE standards, it is the ratio of the illuminance level of a point located in the indoor working plane to the outdoor illuminance level under the conditions of closed sky, and it is obtained as a percentage [97].

Average Daylight Factor; The average daylight factor, on the other hand, is expressed as the ratio of the daylight flux falling on the considered plane to the plane area, to the outdoor illuminance level under unobstructed clear sky conditions, and no additional artificial lighting is required when the average daylight factor is 5% or more [98, 99].

Average Illuminance Level; The average illuminance level in the horizontal working plane is an indicator of daylight efficiency in a place illuminated by natural lighting, and the average illuminance level in the horizontal working plane lower than the desired level negatively affects the visual performance and prevents vision [100].

Daylight Autonomy; The ratio of the hours in which the minimum illumination level required for the space is met only by daylight, to the total usage hours of the space during a year is defined as daylight autonomy. Although the values are usually taken annually, seasonal, monthly or daily values can also be taken [46].

Useful daylight illuminance, on the other hand, is a range that is considered useful by users rather than a threshold level of illumination in indoor daylight assessments, and low (<100 lx) and very high (2000, 2500 lx) illuminance levels that will cause visual impairment are not taken into account [97].

Spatial Daylight Autonomy; In the spatial daylight autonomy method introduced by IES in 2012, 300 lx. The target illuminance level has been determined and this value should be provided for half of the usage area of the space examined during the usage hours of 08.00-18.00 [101].

3.5. Optimization

Technology that enables to achieve certain goals such as increasing the efficiency of existing resources in a system is defined as optimization [102]. Modeling and analysis are two important components in optimization optimization, and modeling is the mathematical expression of the problem encountered in real life. Analysis, on the other hand, involves obtaining the best solution that provides this model. In optimization studies, researchers primarily focused on modeling, and the first studies in this area were the publications by Leontief to model the foreign trade and economic structure of the United States [103, 104]. Optimization technology, which accelerates decision-making processes and increases decision quality, is used in the correct and real-time solution of problems [105]. Optimization is also frequently used in studies related to daylight. In the study conducted by Khidmat in Japan, metal shading element designs were examined, simulation was made in the Grasshopper program, and daylight performance optimization was achieved with the use of parametrics and MOO [106]. Daylight optimization was also performed in the study by Ziwei, and the estimation of static daylight metrics outperformed the estimation of annual metrics in the same dataset and model structure [107]. In a study by Ziaee on daylight optimization in educational buildings in Tehran and Sari, Iran, it was concluded that when WWR is more than 20% in both cities, daylight in north-facing classrooms is satisfactory. The UDI and ASE values between are higher than the values measured in Sari in all cases. Daylight performance of south-optimized cases is acceptable in three scenarios in Tehran and in two scenarios in Sari. The differences between the UDI values in the two cities reveal that the light shelf application in Tehran, where the sky is less cloudy, is more effective than Sari, when the WWR is greater. In any case, the annual thermal comfort rate in Sari is higher than in Tehran [108].

4. DOUBLE SKIN FACADES

4.1. Definition and Classification of DSFs

The effects of ventilation, effective use of daylight and thermal conditions on user comfort and energy consumption in buildings are undeniably important. The facades, which are the building envelope elements that form the distinction between indoor and outdoor space and protect the interior from external influences, affect these comfort conditions. Traditional facades may not be sufficient to provide optimum comfort conditions [3]. Among the façades developed in recent years to improve thermal comfort and ventilation conditions, especially indoors, there are also double-skin façades in which a second mostly transparent shell is placed in front of the building façade [75]. The double-skin facade system, which is a European architectural trend, also fulfills aesthetic demands through increased transparency [83]. Uutu defined the double-skin façade as layers of glass separated by an air corridor and mentioned the advantages of the air space to provide insulation against extreme temperatures, sound and wind [12]. These facade systems consist of the inner layer, the outer layer and an air gap between the layers, which insulates against the undesirable effects of microclimate conditions, provides thermal comfort as well as insulation against wind and sound. The width of the air space between the two layers varies between 20 and 200 cm [13]. Especially in the summer period, since the sun's rays are too much and steep, the ventilation in this space must be done very well, and the ventilation of the space can be done by natural or mechanical means. In addition, the air flow direction in this ventilation gap can be changed in order to increase the energy performance in summer and winter periods, and different air flow directions can be applied [106]. Typologies of double-skin façades, which are generally divided into "ventilated" that reduces heat gain in summer or "airtight" that provides thermal insulation in winter, are classified according to the ventilation strategies in the cavity [107, 109]. In addition, they can be examined in five groups as box windows, shaft box window system, corridor type, multi-storey and multi-story double-skin facades with louvers [106]. Figure 2 shows the DSF types.

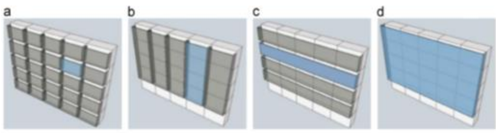

Figure 2. *Categorization of DSFs according to Ghaffarianhoseini: (a) Box window, (b) shaft-box, (c) corridor and (d) multi-storey DSF [1]*

4.2. Technical Specifications of DSFs

Cavity: In double-skin facades, the air exchange between the air gap between the two facade layers depends on the wind pressure conditions in the building envelope, the chimney effect and the discharge coefficient of the openings. The vents in this facade system can be designed as passive systems that are always left open, as well as passive systems that can be opened manually or by machine [107]. Oesterle et al. In his study, it was stated that when the gap between the facade layers is less than 40 cm, significant pressure losses may occur, otherwise the interspace will not show great resistance to air flow [84]. The width of the air space between the two layers in double-walled facade systems varies between 20 and 200 cm, and it is stated that the width should be taken into account according to the climatic conditions of the region where the building is located [13]. When the studies on the maintenance of double-skin facades are examined, they draw attention to the ventilation of the air space, the greenhouse effect and its effect on energy performance, and they concluded that the depth changes according to the climatic conditions of the region where the building is located. Also, in the study conducted by Joe et al., the decrease in the depth of the cavity from 148 cm to 78 cm resulted in a decrease in the heating energy and an increase in the cooling energy, while reducing the total energy consumption by 5.6% [84]. In addition, adjustable shading elements can be placed in this air gap to reduce the increased cooling loads indoors. Indoor cooling loads can thus be reduced [72, 110, 111]. While shading elements that reduce heat gain and act as a preheater provide an advantage in cold regions, they have disadvantages in hot regions, and in order to overcome these disadvantages, vegetation that provides improved thermal insulation, noise reduction and improved air quality can be done [79].

Glass Types in DSFs: Glass coating of building facades is especially desired in commercial buildings. Studies show that glass facades can be beneficial in reducing the costs of lighting and heating by making maximum use of daylight, especially in the winter months when there is heating [111, 79]. Double-skin facades usually include exterior and interior layers, and both layers are made of single or double glazing [79, 76]. In the outer layer, usually single toughened glass can be used and even this layer can be completely covered with glass, while the inner layer is mostly double-glazed and has a lower glass/wall ratio compared to the outer layer [112]. For this reason, it can be concluded that the glass used in the inner wall of double-skin facades is more insulating [80]. It has been stated in the studies that solar-controlled glass and transparent low-emission (low-e) layer can be integrated into the design of the double-skin facade, and it has been concluded that the type of glass affects the energy performance of the building in both single-layer facades and double-skin facades [108, 84]. Recently, many studies have proposed PV-DSFs obtained by incorporating PV glass into double-skin façades. In study conducted by Pappas, simulation using EnergyPlus showed a 23% and 16.4% reduction in total energy use for a PV window with 50% window-to-wall ratio compared to single-glazed and double-glazed windows, respectively [77].

4.3. Evaluation of Daylight Performance in DSFs

Natural daylight illumination values of 5000 lx in dense cloudy sky and over 40,000 lx under direct sunlight are obtained, and these values are quite high, 500 lx, which is the maximum required for indoor lighting [71]. If the daylight is not taken into the interior in a controlled and homogeneous way, glare problems occur especially in the areas close to the windows, and dark areas begin to form as you move away from the window. In double-skin facade systems designed to reduce energy consumption and at the same time increase user comfort, daylight receives less attention than ventilation systems [8]. However, these facade systems can take the daylight into the indoor environment in a more controlled manner. The fact that it has a more transparent surface compared to the traditional facade allows more homogeneous daylight to be taken into the interior and glare problems in the sections close to the window are prevented with the help of sun shading elements in the air gap, which is one of its layers. In the study conducted by Ghonimi, daylight illuminance measurements were made in double-skin and single-skin classrooms at Benha University in Egypt, and as a result of the study, it was concluded that daylight is more homogeneously distributed in buildings with double-skin facade systems. Through this system, high illumination level problems near windows can be solved [10]. Study by O. J. Hendriksen, he stated that the double-skin façade system provides outside visibility and higher daylight levels compared to traditional façades, and also concluded that measures should be taken in the air gap to prevent glare problems as the glass area increases [89]. In the study carried out in offices with double-skin facade system in the cold regions of China, it was concluded that a 30% window-wall ratio is required in order to provide optimum daylight [90]. In a study conducted by T. Srisamranrungruang et al., they analyzed the daylight performance of a double-skin façade system in Japan using the DIVA program and determined the natural ventilation and daylight performance of 30% perforation level in spring, autumn and 10% during one year in open sky conditions. He concluded that it reflects the optimum values for [9]. Study of O. Etman et al. conducted by in Egypt, the traditional façade type of Egypt and similar to the double-skin façade system, the siding façades were discussed and an office building with this façade system was simulated in the Grasshopper program and more effective use of daylight was investigated through this façade. While the illumination level of the existing office, which has a Mashrabiya façade, was 54%, the illumination level was increased to 78% as a result of the study [113]. In the study conducted by Ergin in 2019, an educational structure in İzmir was considered as a field study and the effects of system variables of double-skin facades on daylight performance were examined. In the study, both measurements were taken and simulations were made in the Relux program and the results were compared and analyzed. The glass types in double-skin facades, the inner-outer layers and the air gap between the 2 layers are variable elements in double-skin facades. As a result of the study, some interventions that can be made during the design phase of double-skin facades can provide optimum benefit from daylight [40]. In Nigeria, 22 different façade options, varying in glass type and cavity depth, were examined and it was aimed to provide the energy and daylight performance of the building efficiently by using the appropriate shading devices of the air gap in the double-skin façade. Low-E Argon in the inner layer, air gap 50 cm. proposal showed the best energy performance in August. When we examine it in terms of daylight, the system with single glass on the inner wall, 150 cm air gap and double glass on the outer wall showed the best values again in August [41].

5. CLIMATIC AND ORIENTATIONAL COMPATIBILITY

The double-skin façade system has been used mostly in the north of Europe and North America until today, as it reduces the use of heating energy during the winter months, which is the heating period, and can absorb the daylight homogeneously. It is thought that the double-skin façade system can reduce the use of cooling energy despite the homogeneity of daylight and increased transparency. For this reason, DSF has started to be used in buildings in warmer climates such as the Middle East and Asia [11]. In addition, it can be said that there are differences between the double-skin facade system applied in cold and hot climates. In hot climates, instead of allowing direct sunlight to enter the interior, the use of shading elements in the air gap can prevent both the glare problem and the overheating problem by preventing excess light from being taken indoors. In addition, in hot climates, unlike the design in cold climates, it should be noted that there are more gaps to provide ventilation on the facade. Because the air gap between the two layers acts as an insulator, and poor ventilation of the air gap in hot regions causes overheating problems. In addition, it can be said that the use of DSF system is more common in cold climates [11]. In addition, the best performance for reducing external heat loads for buildings with HVAC systems was shown by the Buffer DSF analysis, which was performed on a double-skin building located in Hong Kong [42]. Another study examined the suitability of using DSF in office buildings in India and was based on building energy simulation of theoretical buildings in Hyderabad and New Delhi. As a result of the study, he states that the system that provides the best performance can be achieved by reducing the window/wall ratio to approximately 50% [40]. Also, according to the results of M. A. Shameri's study, the best examples of DSF system designs were found in subtropical regions [8].

6. DISCUSSION ON FREQUENCY OF STUDIES

Reviewed studies were classified in three groups according to main research areas as daylighting, DSF and daylight performance in DSF (Table 1). Online databases become main way to find studies with the help of these keywords, daylight, DSF, energy efficiency, building envelope and sustainability. The significant and most related ones were analysed in terms of research area, publication years, region, latitude/longitude, analysed parameter, examined building system, analysis tools, building type, and results. These criteria are followed to structure this section. Regarding research area, a total of 40 studies focused on daylight performance in general; while 30 studies included general characteristics, thermal behavior and ventilation capabilities of DSF, only 11 studies' research domain, which was relatively low, was on their daylight performance. The classification of studies examining daylight performance in daylight performance, DSFs and daylight performance in DSFs according to years is shown in Figure 3. Despite a rising trend in daylighting performance based published articles in recent years (2019-2022), a flat trendline is obvious in daylighting performance of DSF and the amount of research on the latter is almost one-eighth of the former. While a cluster of articles is dominated in around 2005-2009 in DSF, there is a gap from 2016 to 2021 about these building systems.

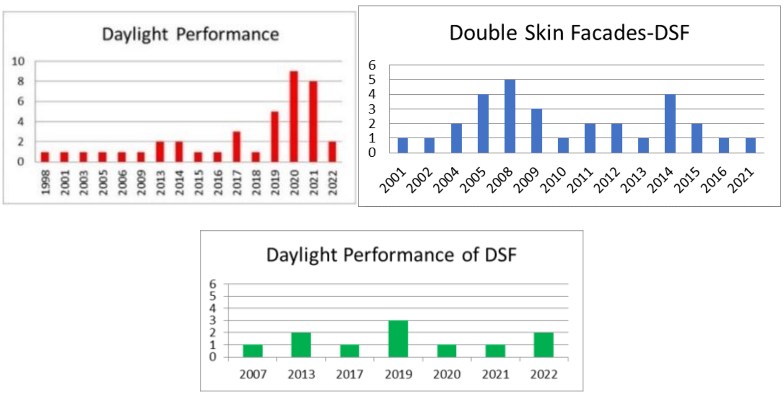

Figure 3. *Classification of the reviewed studies by years*

The studies are classified according to location of case buildings corresponding to latitudes and countries (Figure 4). Daylighting performance studies examined case buildings in the Northern Hemisphere. A total of 29 of them are in east longitude, while only 10 buildings are in west longitude. 70 % of them are in the region from 30 0N - 400N, while the rest is either in the above and below this location on earth. Daylighting has caused popular research problems within these countries. On the other hand, 40 % of cases about DSF take place in that region. 50 % of them are in the region from 40 0N and above. Since, getting more efficiency in thermal performance of DSF gains importance in those countries. Daylight performance of DSF is studied in countries at 30 ^{0}N – 40 ^{0}N with a 66% rate. These ratios are striking in understanding the effect of research area on studies' country. Since thermal and ventilating performance of DSF have been research problems in northern countries, while even the implementation of daylight performance analysis in these systems have been argued mostly in middle regions as daylighting stands out. The aim of controlling side daylighting is significant, and of proposing better or innovative solutions, may be the reason for that.

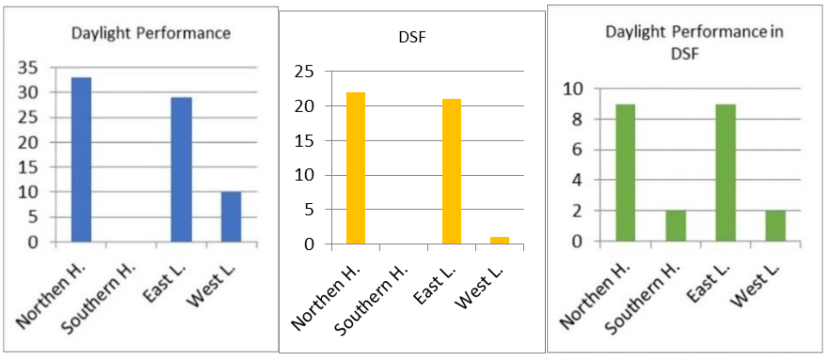

Figure 4. *Classification of the studied structures according to their location*

The strength and accuracy of performance studies and their generalizations depend on parameters, methodology (simulation, measurements, review) and system/building type (Figure 5). Among the reviewed articles, 60% of them used simulations, 17% applied measurements, 11 % of studies involved reviews, 6 % included optimizations, the rest include survey, statistics and experiments.

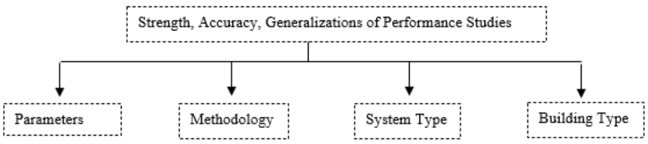

Figure 5. *The factors affecting performance studies*

UDI has been the most preferred daylight metric. Lux was the secondly preferred parameter in the studies. UDI was used in 14 studies on daylight, followed by 6 studies using the lumen. Studies on thermal issues, 0C was the most analysed output (Figure 6). Studies are classified in Figure 5 according to the types of buildings examined. Office buildings have become the most frequently dealth in 27 studies, and modern buildings were among the most studied buildings in 15 studies. Figure 6 shows the tools used in the studies. Grasshopper and EnergyPlus in 10 studies and Radiance in 9 studies were the most used simulation programs. Grasshopper was used in 8 studies on daylight and Radiance was used in 7 studies, and they were the most used analysis programs. Although the Radiance program was used even in the oldest of the studies examined, the Grasshopper program has been widely used in recent years. EnergyPlus has become the most preperred thermal performance simulation tool in 6 studies on daylight and 4 studies on the thermal performance of DSFs. The most used programs were Grasshopper in 3 studies and DesignBuilder in 2 studies examining the daylight performance of double-skin facades.

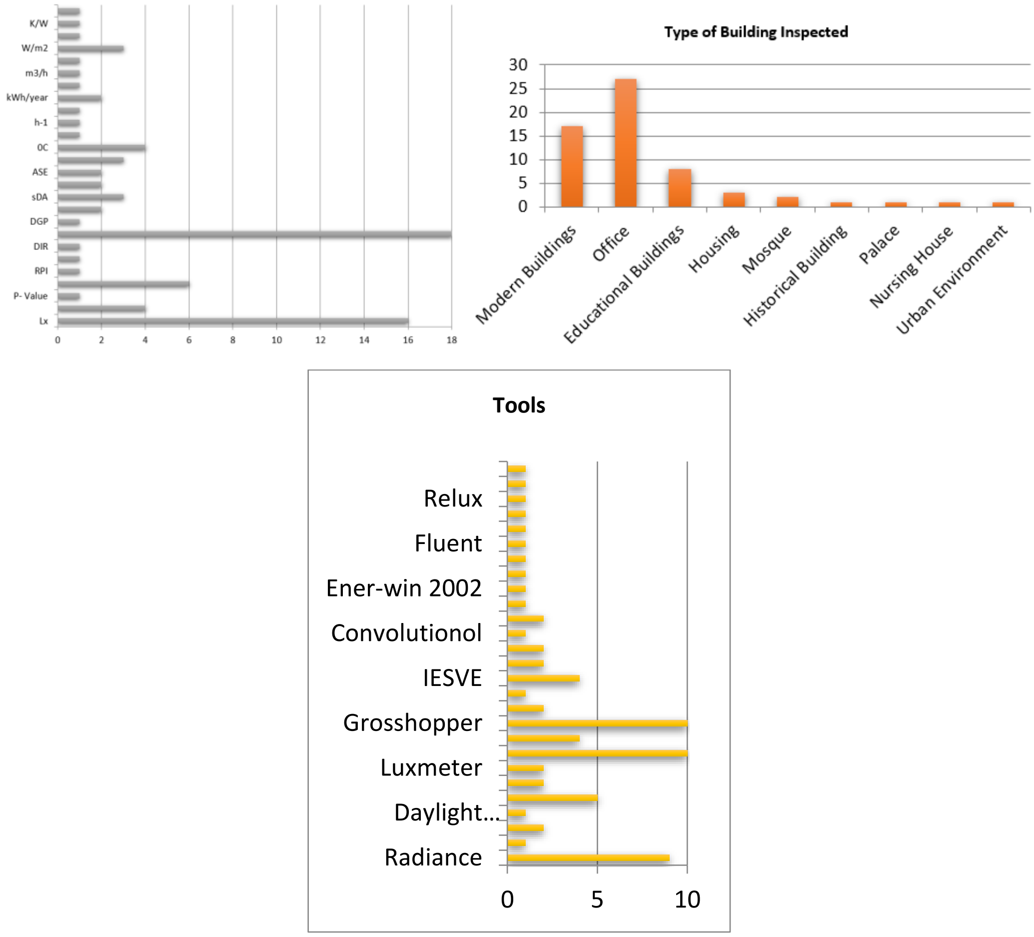

Figure 6. *Types of buildings examined in the studies, Classification of the reviewed studies according to their parameters and tools for analyses*

7. CONCLUSION

The daylight parameter, which significantly affects user comfort, can be one of the prior considerations in the initial steps of architectural design. The way how daylight penetrates into the building and how it is distributes and how it contributes to the efficiency of the building are basic questions to be askes. Taking excessive or insufficient daylight into the indoor environment affects user comfort and eye health negatively. Generally, the amount of daylight is very high near the window in traditional facades, and dark areas occur as they move away from the window. Glare problems are frequently observed on modern facades containing a large amount of glass, when the sun cannot be controlled. DSFs can be a good solution to overcome these problems. Facades must be adequately studied from the earliest stage of design in order to design energy efficient systems. Since traditional facades may not be sufficient to provide optimum comfort conditions, DSFs can be developed to improve thermal comfort and ventilation conditions, in parallel with the developing technology in recent years.

As review studies showed us that researchers have targets to develop these systems using a variety of simulation techniques and daylight parameters. That may show us that studies are getting more and more accurate findings to correspond to the actual physical environments. Finally, optimization techniques have been observed in studies to combine multi objective situations all together. All these attempts in research may find the best technical façade solutions and application to reach may find the best technical façade solutions and application to reach sustainability and energy efficiency targets in general. And DSFs have such a potential in this sense.

Although their potential on improving thermal and ventilation conditions have been focused in studies until recent years, they can be accepted as a globally widespread façade system which is attractive and stylish to satisfy both daylight and thermal performance of buildings, comfort, sustainability and economy. Further studies may continue in this holistic research approach.

This paper examines studies focusing on daylight performance of DSFs extensively. Reviews on these studies show that daylight is distributed homogeneously in the spaces in DSFs and there is no glare problem with the increasing transparency rate. Conclusions present the absence of glare problems in buildings with this facade system, and DSFs do not adversely affect the visual comfort and eye health of the user, on the contrary, the visual performance remains at an optimum level. The prevention of glare problems can be provided by sun shading in the air gap in the structure of double-skin facade systems. On the other hand, it has been observed that DSFs have disadvantages in the reviewed literature. Overheating problems can be seen in DSFs in hot seasons and climates. In order to prevent this, different optimizations of thermal management of DSFs should be made. In this study, it was understood that the thermal performance of the structures with DSF was investigated extensively, unlike daylight performance. In addition, daylight optimization is not used abundantly in DSFs applications. Although the cavity space, glass type and sun shading elements DSF parameters in DSFs were optimized using simulation programs in literature, detailed studies are needed to make more generalizations. So, technical details of these system can be improved and produced by the companies according to comfort needs. Working on the optimization of daylight performance in DSFs, architectural design parameters, such as, window to wall ratios can be proposed at optimized levels, so, design norms depending on this façade or orientation or climate can be developed for architects.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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