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USING MULTI-LAYER FACADE SYSTEMS TO INCREASE THE ENERGY EFFICIENCY OF BUILDING: A SYSTEMATIC REVIEW OF THE FACTORS AFFECTING THERMAL PERFORMANCE, DAYLIGHTING, AND VENTILATION.

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ABSTRACT

The increasing use of energy has been the main driver of renewed interest in building techniques that increase the energy efficiency of buildings. Multilayer facades (MSF) are facades that structurally consist of two or more layers with one or more cavities between them. MSF layers contain elements that can be controlled to respond to external environmental conditions in a manner consistent with ensuring the energy efficiency of buildings. The aim of this review is to study the effect of factors related to the performance of multi-layer facades (thermal performance, daylighting, and ventilation) on increasing the energy efficiency of buildings. The review focuses on studying the factors related to the design of MSF facades in particular, as the study of their impact on the energy efficiency of buildings was not addressed in previous reviews. This was done by conducting a review of more than 50 research papers that dealt with studying the performance of various types of MSF facades. Through a review of previous literature, it was found that MSF facades are an effective building technology for increasing the building's functional performance (thermal performance, daylighting, and ventilation) and then increasing its energy efficiency. When comparing the MSF to single facades, it was found that it has the ability to achieve the required balance between the conflicting functional requirements of the building while ensuring an increase in its energy efficiency. In addition, the final results concluded that the types of MSF can be summarized into three main types, and when they are well designed, it is possible to ensure that the energy efficiency of the building is increased. However, the studies did not cover the possibility of comparing them in the early stages, designed to choose the most appropriate with regard to the issue of energy efficiency.

KEYWORDS: Multi-layer facade(MSF)؛ Energy efficiency؛ Thermal performance؛Ventilation ؛Daylighting ؛Double facadevdfh .

استخدام أنظمة الواجهات متعددة الطبقات لرفع كفاءة الطاقة في المباني: مراجعة منهجية للعوامل المؤثرة على الأداءالحراري والإضاءة والتهوية

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الملخص

ان الاستخدام المتزايد للطاقة كان المحرك الرئيسى لتجديد الاهتمام بتقنيات البناء التى من شانها زيادة كفاءة الطاقة للمبنى. الواجهات المتعددة الطبقات MSF هى واجهات تتكون هيكليا من طبقتين او اكثر بينهما تجويف او اكثر. تحتوى طبقات ال MSFعلى عناصر يمكن التحكم بها لتستجيب لظروف البيئة الخارجية بما يتناسب مع ضمان كفاءة الطاقة للمبانى . الهدف من هذة المراجعة هو دراسة تاثير العوامل المتعلقة باداء الواجهات المتعددة الطبقات (الاداء الحرارى - الاضاءة النهارية - التهوية) على زيادة كفاءة الطاقة للمبانى. وتركز المراجعة على دراسة العوامل المتعلقة بتصميم الواجهات ال MSFبشكل خاص حيث لم يتم التطرق الي دراسة تاثيرها على كفاءة الطاقة للمبانى فى المراجعات السابقة. وذالك من خلال عمل مراجعة لاكثرمن ٥٠ بحث تناول دراسة الاداء للواجهات MSF بانواعها المختلفة . من خلال مراجعة الادبيات السابقة وجد ان الواجهات MSF تقنية بناء فعالة فى رفع اداء المبنى وظيفيا(اداء حرارى - اضاءة نهارية - تهوية) ومن ثم زيادة كفاءتة طاقيا . فعند مقارنة ال MSFبالواجهات المفردة وجد ان لديها القدرة على تحقيق التوازن المطلوب بين المتطلبات الوظيفية المتضاربة للمبنى مع ضمان رفع كفاءتة طاقيا. علاوة على ذالك خلصت النتائج النهائية الى انة يمكن اجمال انواع ال MSFفى ثلاث انواع رئيسية ،وعند التصميم الجيد لهم يمكن ضمان رفع كفاءة الطاقة للمبنى. الا ان الدراسات لم تغطى امكانية المقارنة بينهم فى المرحلة المبكرة التصميمة لاختيار الانسب فيما يتعلق بمسالة كفاءة الطاقة.

الكلمات المفتاحية : الواجهات المتعددة الطبقات، كفاءة الطاقة، المبانى المستدامة، جودة البيئة الداخلية، التهوية، ضوء النهار، الواجهات المزدوجة.

1. Introduction

Today, the world is facing a major crisis due to the increasing demand for energy, and this is evident in the increase in the percentage of global energy consumption to 50% from 2018 to 2050 [1]. Therefore, we find a lot of global effort being made by companies, sectors, and various countries to bear responsibility for their increasing energy consumption. Basically, the building sector, especially the built environment, is the largest contributor to energy consumption, as consumption may reach about 30%–40%. This is considered the building sector to be the second highest energy-consuming sector after the industrial sector [2].

Consequently, the current global trend has increasingly been towards designing buildings with high energy efficiency, with the aim of providing comfortable living conditions inside them with the least possible amount of energy consumption, which means increasing their efficiency. However, the use of traditional systems inside the building for heating and cooling, or for lighting, as well as for ventilation, significantly increases the building's energy consumption, thus reducing its efficiency [3]. For example, research has indicated that the use of fans represents 25% of the total energy consumption of a building, and the consumption of a building that relies on HVAC systems for heating, cooling, and air conditioning may reach 70% of the total consumption [4]. Therefore, it is necessary to consider redesigning these traditional systems or replacing them with natural building techniques that contribute to these buildings achieving high rates of good thermal performance and ensuring appropriate levels of daylighting in addition to the availability of natural ventilation inside them, which contributes to achieving energy efficiency strategies for buildings [5].

It is clear from the above that ensuring high levels of building performance, whether with regard to thermal performance, daylighting, or natural ventilation, affects increasing the energy efficiency of the building in general. The research paper aims to shed light on one of the building techniques known as multi-layer facades, which would enhance the building's performance (thermal, daylighting, and natural ventilation) and then increase its energy efficiency, as will be discussed late. It is also worth noting that the façade of the building is geometrically, the protective barrier that separates what is inside the building from what is outside. Its design usually aims to protect the internal environment of the building or completely isolate it from the conditions of the external environment. Over time, this concept developed until it became the filter that allowed some external environmental conditions to enter the building to benefit from the comfort of the building's occupants [6]. With the emergence of the term highly energy efficient buildings, various goals emerged for the design of the facades of these buildings, including taking advantage of a moderate portion of the external environmental conditions (heat, lighting, and ventilation) not only for the comfort of the occupants but also to the extent that contributes fundamentally to ensuring the energy efficiency of the building [7].

As a result, many previous reviews focused on studying different building technologies that help increase the energy efficiency of buildings. Some of them studied in this regard different types of modern facades, such as smart facades (IFs), opaque ventilated facades (OVf), or ventilated facades (VDFs) [8-10]. While some previous review studies addressed the issue of increasing the energy efficiency of buildings using multi-layer facade technology (or double-layer, which is considered a form of multi-layer facade), only with regard to its thermal and ventilation performance [11]. Other studies have also focused on studying the factors that influence increasing the energy efficiency of multi-layer facades, but these are related to the environment surrounding the building or related to the building only [12]. As a result, this research paper will focus on studying the possibility of increasing the energy efficiency of buildings using multi-layer facades, as it was easy to identify the current research gap from reviewing all previous review studies. As follows: It focuses on studying the effect of other factors, especially those related to the design of multi-layer facades (such as the orientation and type of the facade, the type and characteristics of the materials used in it, and the depth of the cavity between its layers), on increasing the energy efficiency of buildings with regard to the three main functions: thermal performance, daylighting, and ventilation.

Multi-layer facades (MSF) differ from traditional (single) facades structurally in that they consist of two layers (also known as double facades) or more, containing one or more cavities between their layers, and the thickness of one cavity ranges from 20 cm (the small cavity) to several meters (the large cavity) according to the design need. The MSF also structurally contains in its layer design elements that respond to the conditions of the external environment (such as mechanical openings, automatic shading devices, or light shelves) with the ability to intelligently control those conditions to ensure the energy efficiency of the building. Therefore, the MSF is functionally distinct from the traditional facade, as it works to achieve communication with the external environment of the building, in addition to providing the required balance between conflicting functional requirements, such as providing an appropriate amount of heating or cooling, the availability of daylight, and natural ventilation, while avoiding high heat or glare, pollution, dust, and so on [13,14]. It can be said that the multi-layer facade system combines between its different layers passive design strategies for heat, daylighting, and natural ventilation. This is after clarifying the requirements for highly energy efficient buildings and the high levels of performance that multi-layer facades can provide with regard to the three main issues under study are shown in **Fig. 1**. The objective of the research review can be formulated as follows: study the effect of factors related to the performance of multi-layer facades (thermal performance - daylighting - ventilation) on increasing the energy efficiency of buildings.

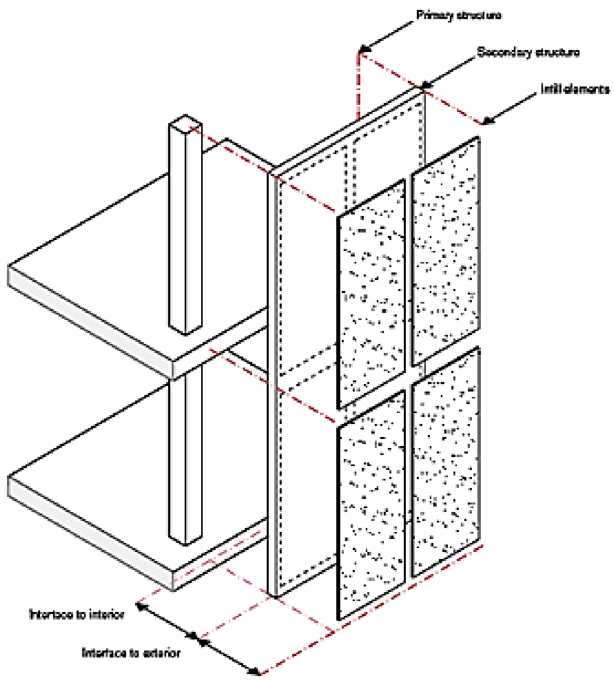


Figure.1. Schematic representation of the multi-layer façade construction: functional requirements can be combined into this layer [7].

2. Review methodology

To achieve the goal of the research paper, previous literature was reviewed related to three main issues of multi-layer facades: thermal performance, daylighting, and ventilation. The previous research was selected according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) are shown in **Fig. 2**.

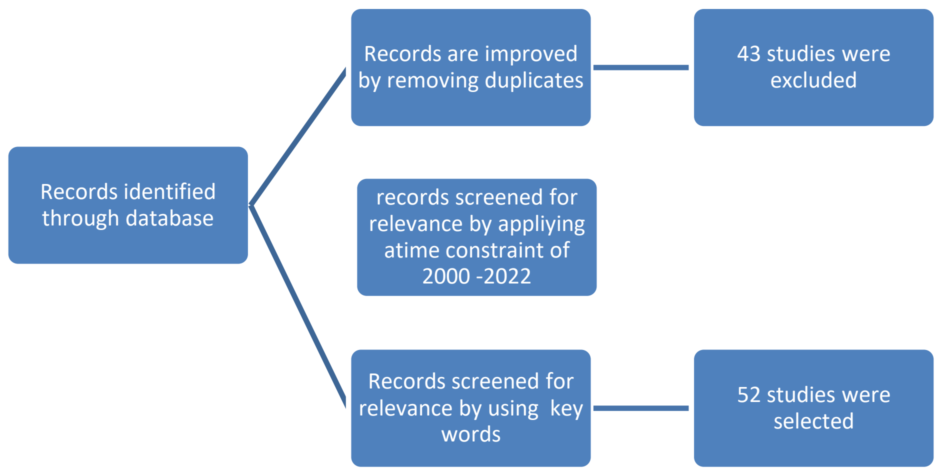


Figure.2. Diagram of the PRISMA method**.**

The procedures followed are as follows:

Using the following databases : Google Scholar-Springer-Elsevier.

- Filtering research that is duplicated or does not match the research topic
- Determine the time period for research in the last two decades.
- Determine keywords for the research, such as MSF, energy efficiency of the building, thermal performance, daylighting, and ventilation.

A total of 95 studies were obtained, and after filtering, the number of studies related to the research topic was settled at 52.

3. Factors affecting of multi-layer facades performance

The research review concluded the factors affecting the multi-layer facades performance, which can be summarized in **Fig. 3**. It is worth noting the definition of the ventilation, lighting, and thermal performance of multi-layer facades, and then mentioning the factors affecting them, respectively.

It can be said that the good daylighting performance of the facade reflects the availability of the greatest amount of daylighting within the interior depths of the building with the aim of conserving energy [27]. While good ventilation performance of the facade indicates the availability of sufficient rates of fresh air in the interior space of the multi-layer facade, which in turn helps in removing the acquired heat or recovering heat within the cavity existing between the faced layers [15]. Finally In general, what is meant by thermal performance is the ability of the built system to provide a state of satisfaction with the thermal environment for users inside the building without being affected by the surrounding external environment, so that it works to reduce the rates of heat loss during the heating season while reducing the rates of excess heat in the cooling season [16]. The following is a list of the design factors affecting the better performance of ventilation, lighting, and heat within multi-layered facades.

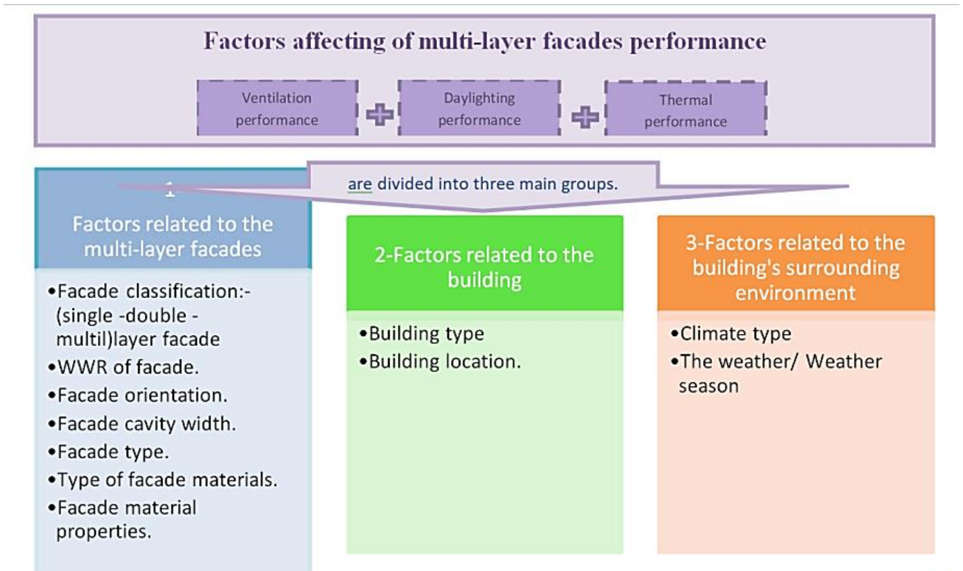


Figure. 3. A diagram showing the factors affecting energy efficiency of building**.**

3.1. Factors related to the multi-layer facades

The research review concluded several factors affecting the energy performance of multilayer facades, which are directly related to the good design of the MSF. Among them are the good orientations of the facade or its good design, choosing the best width of the facade cavity and the best materials for the facade so that they have high efficiency properties, as well as achieving the best percentage of WWR. It is worth noting that taking these factors into consideration in the early stages of designing the multi-layer facade greatly helps in achieving the highest rates of availability of natural lighting, natural ventilation, and ensuring thermal comfort inside the building.

3.1.1. Facade classification: - (single -double -multi) layer façade

Many studies (as we previously indicated in the previous systematic review) have indicated the superiority of multi-layer facades and double facades over the traditional single facade in achieving the highest performance of energy efficiency with their various elements, whether providing ventilation and natural lighting in addition to good thermal comfort and thus reducing the artificial energy used inside[17,18].

3.1.2. Wall-to-window ratio of façade

Providing the wall-to-window ratio (WWR) can easily lead to natural daylight penetrating into the building in appropriate quantities, which reduces the use of electric lighting and thus saves energy [19]. **Fig. 4** shows the importance of taking the shape, proportion, and direction of the windows into account (WWR) must be noted to ensure good levels of daylighting, in addition to ensuring a better distribution of daylight within the different spaces of the buildings [20]. The effect of determining the WWR percentage is not limited to the facade's lighting performance, but also extends to its thermal performance, because when neglecting to accurately determine the WWR percentage, this leads to the entry of daylight in large quantities, such that it becomes a source of excessive heat gain [21].

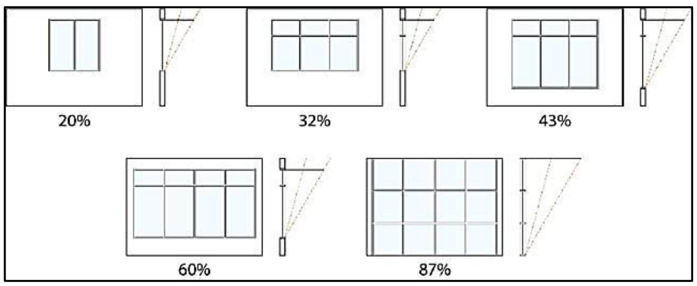


Figure. 4. WWR values for five different window positions within the façade [7]**.**

3.1.3. Facade orientation.

In general, we find that ASHRAE 90.1's interest in providing recommendations for building envelopes depends mainly on the location of the building and the climatic zone (as will be mentioned later) [22]. The orientation of the building facade generally affects the availability of natural daylight during the morning hours, as well as the availability of natural ventilation throughout the day. It also affects the amount of heat gain throughout the period of exposure to the sun are shown in **Fig. 5**[7]. Therefore, in all the research previously studied in the systematic research review, the researchers pointed out the importance of taking the orientation of the facade into account when studying the factors affecting its energy performance.

Figure. 5 The good orientation of the facades of the Arizona State University building, which won the Gold Award, contributed to raising the efficiency of the building, and then it received the Gold Award [7] .

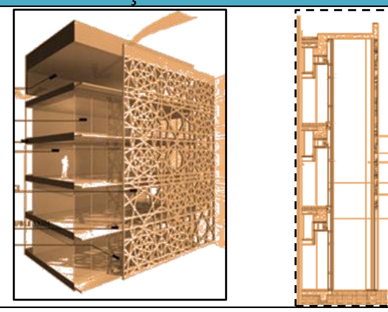
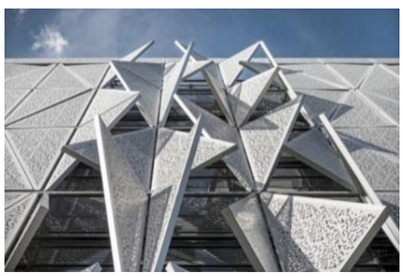
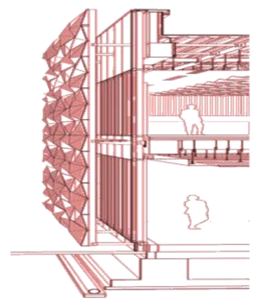
3.1.4. Facade cavity width.

Many previous studies have indicated the importance of considering the depth of the cavity in a multi-layer facade as an influential factor in increasing the energy efficiency of these facades. For example, previous research compared three types of double facades, with the cavity depth differing for each type separately more than once, with the aim of verifying the effect of this on the facade's daylight lighting levels. The research concluded that the level of daylighting and the way it is distributed within the spaces vary according to the depth of the cavity of the multi-layer facades [23]. For example, a literature review study also indicated that the depth of the cavity in a multi-layer facade has a significant impact on improving the energy efficiency of the facades. Its effect is evident in improving the rate of ventilation and temperature inside the building, as changing the cavity width ratio works to allow different flows of air to flow inside the cavity and then get different heat flows as well [24]. Many researchers have also pointed out the necessity of reaching the correct cavity width ratio to obtain air and heat flows appropriate to the conditions of each individual facade [25-27].

3.1.5. Facade type.

It should be noted that the references specialized in studying building facades from an architectural and structural perspective classify the types of building facades into two basic types: opaque building facades and glass building facades [7]. However, this research review concluded another classification that follows the geometric configuration of facades emerging from the first main classification of other types of double or multi-layer building facades. As shown in the previous research review tables, the new classification of facade types includes facades with perforated panels, facades with shading devices, facades with light shelves, and finally glass facades [28-30]. Whatever the type of building facade, it can be said that the structural layers that make up the multi-layered facade clearly affect the provision of ventilation within the spaces, whether natural or mechanical. These layers also help in allowing daylighting inside the building, in addition to improving the thermal performance of the facade [2,31]. This effect occurs regardless of the geometric design of the multi-layered facades, whether it is with a perforated panels, with shading devices (louvers) , or with light shelves. Three new types of facades are shown in **Table 1**

Table1. The three main types of MSF facades. 1 - MSF with perforated panels. 2- MSF with shading devices. 3- MSF with light shelves.

The type	Façade picture	Façade sketch
MSF with perforated panels.		
MSF with shading devices.		
MSF with light shelves.		

3.1.6. Facade material type and properties

It is worth noting that important references (books that include a detailed study of building facades) have indicated that the importance of good selection of the type of materials and their characteristics is not limited only to achieving the aesthetic element of the building. Rather, it also includes raising the energy efficiency of the building with what is known as sustainable facades or high-performance facades. These references included case studies of buildings with high-performance double or multi-layer facades, and one of the strategies for achieving this was the good selection of the materials and characteristics of those facades[6,7,32]. Most of the previous research discussed in the research review indicated the importance of making a good choice of the type of materials that make up the multi-layer facade, in addition to comparing their properties, and demonstrating the impact of this on raising the energy efficiency of these facades.

For example, we found a group of previously mentioned studies that confirmed that a good choice of the type of glass used in double or multi-layered facades and its properties have a great impact on increasing the thermal, optical, and energy efficiency of the facades [24,32,34] . One of these studies also compared 12 types of glass used for double facades, with their different characteristics, to choose the best one, which achieves the best thermal and visual performance for the facade and thus leads to energy savings for the building [25]. Likewise, the previously mentioned research that dealt with multi-layered perforated facades indicated the necessity of choosing the type of perforated panels and determining their characteristics in a way that is appropriate for raising the performance of the facade in terms of thermal performance and providing both daylighting and natural ventilation [29,35]. The matter was no different with regard to research related to facades with shading devices or integrated with light shelves, as it emphasized the necessity of good design and selection of the materials composing the devices or light shelves, while ensuring the efficiency of their characteristics to raise the performance of the facade. Many materials were chosen to make these shelves or louvers for the shading devices in this research, such as ceramic, glass, and expanded metal [28,36-39]. As previously noted in the research review, there is some research focused on studying modern materials with innovative and good properties that help raise the performance of the interface in addition to achieving an advanced technological aesthetic appearance [40]. It is worth noting the necessity of increasing such research in the future.

3.1.7. Previous studies for review

Table 2 summarizes previous studies related to multi-layer facades, and some factors were noted that may effect on the highly efficient performance of the building. These factors determine the influence of (the type of facade, its orientation, the good choice of the constituent materials and their characteristics, and a good WWR ratio) on the facade’s energy performance.

Table 2. Summary of studies on design factors related to MSF design affecting the energy efficiency of buildings

REF	Function of facade	Factors related to the multi-layer facades									Study findings
		Façade classification	Façade WWR	Facade orientation	Cavity width	Facade type			Material type	Material properties	
						Perforated	Device	Shelve			
[35]	Daylight	DSF	30%	South	1.2 m	Perforated			Clear glass -PV cell	U-value - SHGC	The study concluded that both the wall ratio of the windows, the orientation of the facade, and the ratio of photovoltaic cells to the outer surface of the facade are effective factors for improving the quality of daylighting.
[34]	Thermal	MSF	-	South	-	Perforated			TT PS-TIMs	T-R-AB-TT	The study concluded that the selection of elements and their properties is an important factor for the effective sensitivity of thermal performance
[41]	Daylight	MSF	-	South	-	Reflective automated blind			-	U-value - SHGC	The results indicatethe good orientation of the facade in addition to the use of shading devices are an important factor.
[36]	Daylight	MSF	-	North	-	light shelf			Glass Shelf	R	The study concluded that light shelf design features such as (external length, angle, and height) are effective in terms of daylight efficiency for facades.
[42]	Daylight	DSF	26.5 %	East	-	Upper window			Low-E double glazing	U-value - SHGC	The study concluded that it is necessary to take standards such as (WWR, providing upper windows in the facade) into consideration when designing mosques .
[43]	Daylight	MSF	-	North	-	Shading systems			Low-E double glazing	U-value - SHGC	The study concluded that good design of the elements of the facade shading device, such as (length, angle, and height), ensures the efficiency of daylighting.
[44]	Daylight	PDSF	-	East	-	Plants as shading devices			Low-E double glazing	U-value - SHGC	The study indicated that the use of PDSF double-stranded productive facades improves the efficiency of daylighting
[18]	Daylight	DSF -	-	South	.6 mm	(Box window type)			Low-E double glazing	U-value - SHGC	The study concluded that the use of double facades is effective in reducing the intensity of daylight lighting, and ensuring the quality of lighting.
[45]	Daylight	DSF	-	North	-	Anabolic system, upper windows, and the light shelf			Translucent material	U-value - SHGC	The study confirms that the use of the anabolic system, upper windows and the light shelf and their good design guarantee the quality of daylight and visual comfort
[25]	Daylight	DFS	30%	South	1-1.40m	(Box window type)			Low-E double glazing	T = 0.76	The best quality of daylighting based on the depth of the cavity, the type of glass, its properties, and the optimal WWR ratio.
[46]	Thermal	MSF	50%	South	-	The middle automated blind system			Double reflected glazing	-U-value -SHGC -Slat Conductivity	The study concluded that the use of a double facade with no ventilation in the cavity and a good design of the shading device located between its layers helps reduce light energy consumption and reduce thermal loads.
[28]	Thermal	DSF	30%	South	-	External shading device			Low-E double glazing	U-value - SHGC	The study concluded that a good choice of the type of glass, a good design of the shading system (by determining the number of slats, their depth, and the angle of deviation) and a good WWR ratio are factors affecting energy on thermal comfort.
[37]	Daylight	MSF	-	South	-	External ceramic louvre system			Ceramic	R - T	The research evaluated three different shading systems on the exterior surface of the facade, and the ceramic system proved superior in good distribution of daylight and reducing glare.
[29]	Daylight	MSF	100%.	South	.5m	Perforated facade (PSS)			Solar screens - double glazed	T - (SHGC) - (U-value) -PSS : R	The study concluded that using facades with perforated solar screens increases the percentage of daylight by 50% and reduces energy consumption by 55%.

[38]	Daylight	MSF -	65%	South	1 m	External shading device	Single clear glass	Glass: VT Louvers: R	The study concluded that good design by specifying the number of slats, their depth, and the angle of deviation of the facade shading device greatly affects the provision of daylighting for the building.
[33]	Daylight	DSF	-	East	1.50 m	The middle shading device	Low-E double glazing	U-value - SHGC	The study concluded that choosing the type of glass for the facade and the depth of the cavity , in addition to determining the time period for the experiment and using a shading device in the cavity, are important factors to ensure the availability of daylighting for the double facade.
[23]	Daylight	DSF	-	North	0.6 m	(Box window type)	Low-E double glazing	U-value - SHGC	The study concluded that the type of facade, the depth of the cavity between its layers, the type of climate, and the good orientation of the facade are influential factors in ensuring the availability of daylight for the building.
[47]	Daylight	DSF	90%	South	-	The EggCrate shading device	Low-E double glazing	T of glass Shadings (R)	The study compared 4 different types of shading devices for the facade of a double residential building, and concluded that the Egg-Crate system succeeded in effectively improving the quality of daylight.
[39]	Daylight	DSF	-	East	-	Expanded-metal shading device	Expanded metal	Glass T Shading R	The study concluded that using expanded metal shading system is the most efficient in terms of ensuring the availability of daylight inside buildings in Japan through parametric design.
[40]	Daylight	DSF	60 %-	South	-	ETFE cushions	Standard double glazing	T of ETFE	The results of the research study showed that the use of double facades with ETFE cushions can improve daylight lighting for the office spaces in the building, after simulating five types of materials and three different climates.
[48]	Daylight	DSF	30% - 40%	South	-	light-shelves	Low-E double glazing	Light-shelf : R	The study concluded that both spatial location and precise shading characteristics, in addition to the WWR ratio, are influential factors in improving daylighting within educational classrooms.
[30]	Daylight	DSF	90&	South	-	light-shelves	Low-E double glazing	Light-shelf: R Glass :T	The study indicates that the optimal design of light-shelves (external and internal length, deviation angle, and height) helps improve the quality of daylighting of the spaces.
[24]	Ventilati n	DSF	-	East	The width of cavity	Shading device	Type of glass	Properties of glass	The study concluded by indicating the necessity of taking some factors into consideration to ensure the energy efficiency , such as the depth of the cavity, good design of shading devices, and good selection of the type of glass and its characteristics.
[19]	Daylight	DSF	40% - 60%	South	-	(Box window type)	Low-E double glazing	U-value - SHGC	The study concluded that both the window-to-wall ratio (WWR) and the shading coefficient (SC) are important factors in improving the quality of daylight entering from double facades within educational spaces in Indonesia.
[31]	Thermal	DSF	-	East	.6m	Multi-storey DSF	Low-E double glazing	U-values	The study concluded that there are fundamental factors affecting their performance, such as climate type, cavity depth, orientation, and facade type.

Keyword of table: –T: Transmittance value. -R: Reflectance value. -AB: Absorptance value.
– TT: Transition temperature. PDSF: Productive double skin façade. - U-value: Thermal transmittance.
-SHGC: Solar Heat Gain Coefficient.

3.2. Factors related to the building

The previous research review concluded that several factors related to the building effectively influence the design of multi-layered, highly energy efficient facades. As noted, some of these factors can be controlled by designers, such as good design of the building, proper orientation, and good selection of the type of use of the building in a way that is appropriate for increasing its efficiency. As for other factors related to the building that are outside the designer's control they are summarized in the location in which the building is built.

3.2.1. Building type

ASHRAE 90.1 establishes recommendations for the design of building envelopes that consider design requirements for high-performance buildings based on the basic function of the building and occupancy. In many research studies, researchers have explained how the type of building affects the control of energy performance [11]. In one of the published studies, the researcher redesigned an abandoned building that was previously used as a silk factory by adding a double facade. This researcher discovered that the presence of chimney stacks that were already present on the roof of the building since it was used as a factory contributed to the flow of air into the building, which increased its performance efficiency. Which means that the type of building contributed to increasing the building's performance by approximately 12% [49]. Likewise, another researcher conducted a similar experiment with a textile factory building using a double facade as well [50]. These experiments and research mentioned in the previous research review indicated that the type of building greatly affects the provision of natural ventilation, daylighting, and heat as well.

3.2.2. Building location

Researchers emphasize the importance of the effect of the building location on the performance of the building facade. For example, we found some of them who pointed out the effect of the building location in China on the performance of the double facade with regard to air flow inside it [51]. While the building's location in Hong Kong helped the double facade perform well visually in terms of daylight availability [52]. Other research also reported the spread of the problem of the high degree of cavitation of the double facades located in Tel Aviv and Salta, Argentina, during periods of cooling [53].

3.3. Factors related to the building's surrounding environment

3.3.1. Climate type

In general, the term climate refers to the behavior of the atmosphere, including rain, winds, and air pressure, in addition to temperature and humidity, over a relatively long period of time, which may extend from years to hundreds of years. The design strategies for facades vary depending on the climatic zone of the building's location, such as determining the characteristics of the materials that make up the facades (such as thickness, conductivity, reflection, light absorption, and heat transfer), in addition to determining the number of layers [7].

3.3.2. The weather

The term weather refers to the behavior of the atmosphere during a short period of time, starting with an hour and extending over a week. Daily and historical weather data helps in modeling the energy performance of buildings, as this data (wind speed, relative humidity, temperatures, etc.) is analyzed statistically to predict the building's heating and cooling loads [7].

3.3.3. Previous studies for review

Based on approximately 26 previous research papers, the most common climate for using multi-layer facades is a distinct climate, followed by dry and tropical climates, which means that hot and cold climates are considered a current research gap. **Table 3** summarizes previous studies related to multi-layer facades, and some factors were noted that may affect the highly efficient performance of buildings. These factors include building type, building location, climate type, and weather.

Table 3. Summary of studies on design factors related to (the building and surrounding environment) affecting the energy efficiency of buildings.

REF	Function of facade	Façade classification	Factors related to (the building and surrounding environment)				Study findings
			Building type	Building Location	Climate type	The weather	
[54]	Ventilation	DSF	Office	Belgium	Cfb, Moderate Sea	Summer	The study concluded that it is possible to facilitate the cooling process in summer if the width of the cavity is greater than 7 cm
[55]	Ventilation	DSF	Office	Belgium	Cfb, Moderate Sea	Summer	This study concluded that the color and position of blinds affect cooling in summer for double facades
[56]	Ventilation	DSF	Office	Trondheim, Norway	Dfc, Continental Subarctic	Winter	The results indicate that the use of improved windows in DSF leads to providing 20% better natural ventilation than single facades.
[57]	Ventilation	DSF	Office	Lyon, France	Cfb, Marine West Coast	Summer	The difference in the angle of the shading device in the double facades affects the amounts of air flow flowing inside the building.
[58]	Thermal	DSF	Office	Tehran, Iran	Csa, Mediterranean	Summer and winter	Double facades are a technology that increases the energy performance of buildings
[59]	Daylight	Obstructed DSF	Residential	Cairo-Egypt	BWh hot desert climate	Summer and winter	The research concluded that the obstructed double facade is the best in improving daylighting .
[37]	Daylight	MSF	Residential	Madrid	Csa, Mediterranean	Summer	The research evaluated three different shading systems on the exterior surface of the facade, and the ceramic system proved superior in good distribution of daylight and reducing glare.
[29]	Daylight	MSF	Commercial	Seville, Spain	Csa, Mediterranean	Summer and winter	The study concluded that using facades with perforated solar screens increases the percentage of daylight by 50% and reduces energy consumption by 55%.
[38]	Daylight	MSF	-	Cairo, Egypt	BWh hot desert climate	Summer	The study concluded that good design by specifying the number of slats, their depth, and the angle of deviation of the facade shading device greatly affects the provision of daylighting for the building.
[33]	Daylight	DSF	Residential	KANO, NIGERIA-	(BWh) warm desert climate	Summer and winter	The study concluded that choosing the type of glass for the facade and the depth of the cavity , in addition to determining the time period for the experiment and using a shading device in the cavity, are important factors to ensure the availability of daylighting for the double facade.

[23]	Daylight	DSF - 0.6 m	Educational	Miami	Am, Tropical Monsoon	Winter	The study concluded that the type of facade, the depth of the cavity between its layers, the type of climate, and the good orientation of the facade are influential factors in ensuring the availability of daylight for the building.
[47]	Daylight	DSF	Office	Seoul in Korea -	Dfa, Hot Humid Continental	Summer and winter	The study compared 4 different types of shading devices for the facade of a double residential building, and concluded that the Egg-Crate system succeeded in effectively improving the quality of daylight.
[39]	Daylight	DSF	Commercia l	Fukuoka, Japan	Cfa, Humid Subtropical	Summer and winter	The study concluded that using expanded metal shading system is the most efficient in terms of ensuring the availability of daylight inside buildings in Japan through parametric design.
[40]	Daylight	DSF	Office	Spain	Csa Hot-Summer Mediterran ean	Summer and winter	The results of the research study showed that the use of double facades with ETFE cushions can improve daylight lighting for the office spaces in the building..
[48]	Daylight	DSF	Educational	Tehran	Csa, Mediterran ean	Summer	The study concluded that both spatial location and precise shading characteristics, in addition to the WWR ratio, are influential factors in improving daylighting within educational classrooms.
[30]	Daylight	DSF	-	Malaysia	Af: Tropica l rainforest climate	Summer and winter	The study indicates that the optimal design of light-shelves (external and internal length, deviation angle, and height) helps improve the quality of daylighting of the spaces.
[60]	Ventilation	DSF	Residential	Florence, Italy	Cfb, Marine West Coast	Summer and winter	It is possible to facilitate the cooling process in summer if the width of the cavity is greater than 7 cm.
[19]	Daylight	DSF	Educational	Depok, Indonesia.	Af: Tropica l rainforest climate	Summer and winter	The study concluded that both the window-to-wall ratio (WWR) and the shading coefficient (SC) are important factors in improving the quality of daylight entering from double facades within educational spaces in Indonesia.
[31]	Thermal	DSF	Office	Chicago	Dfa humid continental	Winter	The study concluded that there are fundamental factors affecting their performance, such as climate type, cavity depth, orientation, and facade type.
[61]	Ventilation	DSF	Office	Belgrade, Serbia	Cfa, Humid Subtropical	Summer and winter	The energy simulation result of the double facades showed an increase in the air flow of the building
[62]	Thermal	DSF	Residential	Serbia	Cfa, Humid Subtropical	Winter, Summer, and Transition	The results indicate that using DSF does not always reduce energy consumption
[63]	Thermal	DSF	Educational	Hong Kong	Cfa, Humid Subtropical	-	The use of a double facade leads to better thermal performance, but it is economically expensive
[64]	Ventilation	DSF		Delft, Netherlands	Cfb, Warm and Temperate	Summer and winter	Using DSF with an external shading device is better in terms of ventilation performance than a single facade with HVCA.
[65]	Thermal	DSF	Residential	Kitakyushu , Japan	Cfa, Humid Subtropical	Summer and winter	Using DSF saves 10-15% of the cooling energy in the summer and about 20-30% of the energy used for heating in the winter.
[66]	Thermal	MSF	Office	Salta City, Argentina	Cfb, Humid Subtropical	Spring and Summer	The use of MSF with an externally perforated layer reduces cooling energy in summer in hot climates
[67]	Thermal	DSF	Office	Atlanta, Georgia	Cfa, Warm and Temperate	Spring	The use of an internal shading device in the double facade cavity improves the visual and thermal performance

4. Results and discussion

The factors affecting the performance of multi-layer facades (MSF) were presented in Tables 2 and 3, after dividing them into 3 main groups: 1.Factors related to multi-layer facades. 2. Factors related to the building. 3. Factors related to the surrounding environment.

Table 2 displays a general outline of previous studies that dealt with parameters related to multi-layer facades, in addition to presenting the results of previous studies. The parameters mentioned in the literature include façade classification, WWR, façade orientation, cavity width, façade type, and material type and properties. As noted, the most evaluated parameters in the study are the facade classification, as studies have proven that MSF facades are an effective building technology in raising the building's performance compared to a single facade if designed well.

The parameters most evaluated in previous studies were those related to the type of MSF facades and the type of materials and their properties. As for the type of MSF facade, the study concluded by identifying four basic types: facades integrated with perforated panels, facades integrated with shading devices, facades integrated with light shelves, or glass facades are shown in **Fig. 6**. (It was referred to in detail in the type of facade in the review literature.) The type most discussed in previous studies was MSF facades with shading devices, where some of their design parameters that are important to ensure raising the performance of the facade were mentioned. These parameters are summarized in the number of slices (N), the angle of deviation (A), their depth (D), the type of materials, and their characteristics, in addition to their location (externally - internally in the cavity). The performance of the facade shading device is good in providing improved daylighting when the number of slats and depth are large and the angle of deviation is downward [24,28,38]. The previous study also tested the integration of the shading device into the external surface of the MSF facade, which led to reducing heat and lighting loads and thus increasing the energy efficiency of the building, in contrast to placing blinds inside the cavity [46]. Other studies have highlighted the importance of a good selection of the materials from which the louvers are made, as each has a significant impact on improving daylight lighting. Among them is a study that compared three types of shading devices using different materials to manufacture the louvers for the MSF facade with the aim of reducing the environmental impact, and the use of ceramic led to achieving satisfactory levels of daylight inside the room [37]. Another study in Japan used expanded metal, which also proved its effectiveness [39].

The study also revealed the effect of integrating light external shelves into MSF facades on ensuring air flow and natural light for the building. This is achieved through good design of the following shelving parameters: external length(Lx), internal length (Ln), deviation angle (A), and height (H), in addition to good orientation [48,60]. A previous study compared different types of shelves depending on their position, angle of deviation, and height, and it was proven that the model with a height of 7 inches and an angle of 20 degrees and placed externally on the facade is the most effective. It worked to raise the level of daylight to about 11.5% on June 21 and about 10.6% on December 21 in Pakistan in weather with cloudy skies [42]. While a study indicated the success of a model of light shelves (among 12 other models with different parameters) on a southern MSF facade in Malaysia, with a height of 1.8 m, a deviation angle of 10, and an internal and external length = 0.5 m in improving daylighting inside the spaces [30].

Previous research related to evaluating the integration of perforated panels into MSF facades identified important design parameters: shape(S), matrix (M), and perforation percentage (PP) [33, 35]. A previous study concluded that improving the percentage of PP (not to exceed 37%) and using perforated panels behind the southern glass facades improves the energy efficiency of the building. It leads to finding the required balance between reducing energy consumption (by a total of 55%) for heating and cooling (86% - 58%, respectively) and saving daylight (by about 50%) [29].

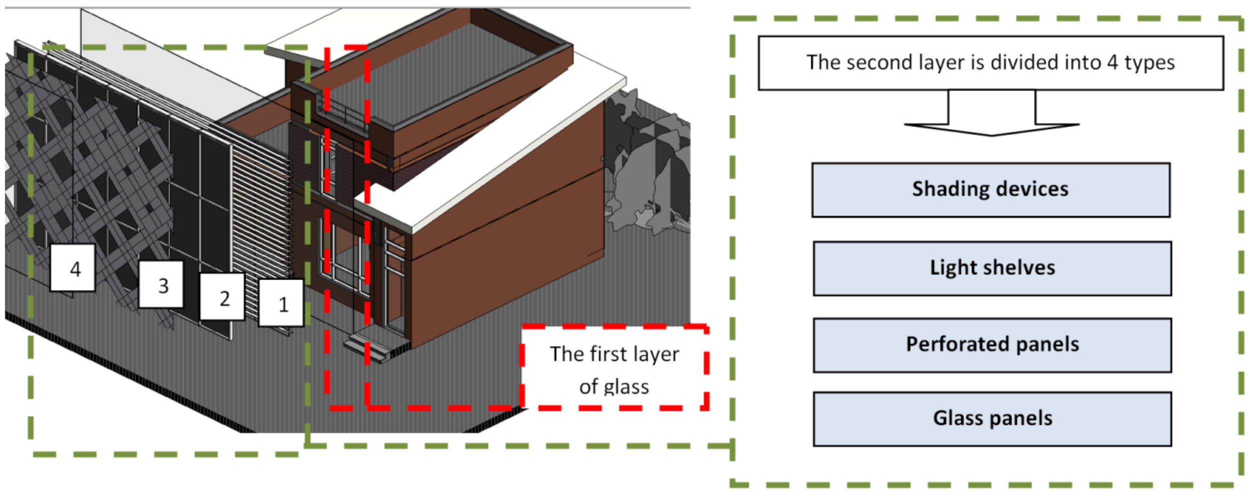


Figure . 6 . A sketch showing the four possibilities for designing multi-layered facades.

As for the type of materials used in MSF facades and their characteristics, what was mentioned in previous literature can be summarized as follows: First: consider both the U-value - transmittance (TT) - SHGC values in the transparent materials of the facade. [29, 31, 41, 42] Second: Considering the transmittance (T) – reflectance (R) - absorptance (AB) values in the opaque materials of the façade [29,37,40].

Some literature has indicated that choosing the depth of the cavity for the MSF facade is to achieve the highest rates of internal air flow and thus increase the energy efficiency of the building [31]. The literature differed in determining the depth of the cavity, with values ranging between .5 - .6 - 1.2 - 1.4 - 1.5 - 1.6 depending on the difference in other parameters such as climate, use of the building, and its location, in addition to whether or not a shading device is placed inside it[18, 23, 25, 29, 33, 38] . One study changed the depth of the cavity according to the height 1:15 - 2:5 to obtain the best depth to achieve the highest air flow rates [24].

Table 3 outlines previous studies that addressed parameters related to the building and surrounding environment and presents the results of previous studies. Parameters mentioned in the literature include building type, orientation, climate type, and weather. We find that most of the previous literature focused on determining the type of climate and weather for their role in determining the characteristics of the MSF façade. This in turn helps in ensuring control and raising the energy efficiency of the building [54, 55, 66]. We find that temperate climate is the most widespread in previous literature, followed by tropical and continental climate, and that most studies were conducted in the summer and winter seasons.

While a limited amount of literature has focused on the effect of building type on increasing its energy efficiency, MSF facade treatments can vary depending on the type of building [40, 48]. The type of building mentioned in previous literature that was most studied was office, followed by residential, then educational, followed by commercial and religious.

5. Conclusions and recommended studies

A review of previous literature was conducted to determine the factors related to the performance of multi-layer MSF facades (with regard to thermal performance - daylighting - ventilation) and those affecting increasing the energy efficiency of the building. The factors were divided into three main groups, and each group included a number of parameters that were explained in Tables 2 and 3.

- Factors related to MSF facades

Among the parameters related to MSF facades, the facade classification, type, materials and properties have been extensively studied by previous researchers. Previous studies have indicated the role of these parameters in increasing the performance of MSF facades and thus increasing the energy efficiency of buildings.

- Regarding the type of facades, we find that:

Previous literature on studying the performance of an MSF facade with a shading device integrated was the most widespread, followed by that which studied the performance of facades with built-in light shelves. While the literature related to studying the performance of MSF facades embedded with perforated panels is limited. Therefore, the researcher recommends increasing future studies interested in studying the possibility of increasing energy efficiency in buildings by using perforated panels in MSF facades. It is also recommended to conduct studies to compare different types of MSF facades and develop a tool that helps designers make a good choice among these types during the early design phase of the facade.

Some design parameters were also extracted (shading devices - light shelves - perforated panels), which must be taken into account when designing facades to increase their performance. They are as follows, respectively:

- Shading devices: the number of slices (N), the angle of deviation (A), their depth (D)

- Light shelves: external length (Lx), internal length (Ln), deviation angle (A), and height (H),

-Perforated panels: shape(S), matrix(M), perforation percentage (PP)

The researcher also recommends in the future study the necessity of taking into account the previous design parameters for designing multi-layer MSF facades of various types to avoid any defects in them.

- Regarding the type of materials and their specification:

It is possible to extract some of the properties that must be available in facades materials as follows (U-value-Visible Transmittance-SHGC) in transparent materials, (Transmittance T - Reflection R - Absorption A B) in opaque materials. Through good selection of appropriate values for these material properties, it is possible to increase their functional performance and thus increase the energy efficiency of the building.

The rest of the parameters were studied, such as the depth of the cavity and its function in increasing the flow rates of natural air inside the building was clarified, while determining its value depends on its purpose, function and other parameters. Explaining the effect of a good choice of the facade's WWR ratio in ensuring control over the quality of natural light and the availability of air inside, while its value varies depending on the orientation and its purpose.

- Factors related to the building and surrounding environment

Most previous researchers focused their efforts on studying the effect of the type of climate, weather, and building location on increasing the energy efficiency of the building. We find that temperate climate is the most widespread in previous literature, followed by tropical and continental, and that most studies were conducted in the summer and winter seasons. Which means that cold and hot climates still need further study and research into the possibility of using MSF facades in them and proving their effectiveness to increase the energy efficiency of buildings.

In general, there are few studies related to clarifying the effect of the type of building, depending on the type of activity inside it, on increasing the energy efficiency of the building. The type of buildings mentioned in previous literature that was most studied was office, followed by residential, then educational, followed by commercial and religious.

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