International Journal of Architecture and Urbanism Vol. 07, No. 01 (2023) 158 – 172

International Journal of Architecture and Urbanism

Journal homepage: https://talenta.usu.ac.id/ijau

An Appraisal of Double Skin Facade in Building Design: Architectural Intervention and Sustainability

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ARTICLE INFO

Article history:
Received 12-12-2023
Revised 20-01-2023
Accepted 22-02-2023
Available online 31-03-2023

E-ISSN: 2622-1640
P-ISSN: 2622-0008

How to cite:
Nasir, O. and Kamal, M. A. An Appraisal of Double Skin Facade in Building Design: Architectural Intervention and Sustainability. International Journal of Architecture and Urbanism. 2023. 7(1):158-172.

http://doi.org/ 10.32734/ijau.v7i1.11760

ABSTRACT

One of the key issues in twentieth-century architecture is the energy problem and daily rise in environmental pollution brought on by the creation of greenhouse gases, particularly in the construction industry. The purpose of the research that follows is to investigate how well buildings heat up while also updating double-skinned facades to ensure thermal comfort for the residents while using the least amount of energy possible. The thoughtful design of a building's exterior is one of the most crucial ways to conserve energy in that structure. The finest choice for controlling the interplay between the interior and exterior spaces is a 'double-skin facade'. Double-skin facades have been used more frequently recently to increase transparency in both building renovations and new construction. Although glare issues may worsen, double-skin facades improve lighting levels and the outside view. When comparing a typical glass facade to one with an additional layer of glazing, it is possible to reduce heat loss and outside noise. A very critical concern appears to be the protection of external solar shading devices against wind and deterioration. This paper reviews and discusses the earlier research on double-skin building facade systems. The evaluation of a double-skin facade system for long-term building envelope or infrastructure development is the main theme of the paper.

Keywords: architecture, climatic, double-skin facade, energy, sustainability

1 Introduction

The need for better methods and tactics to improve building energy efficiency is growing quickly as energy consumption reduction emerges as a major national concern. The building industry is renowned for being a significant energy consumer. Electricity produced from fossil fuels is frequently used to supply their operational energy needs. According to studies, nearly one-third of the final energy used globally is consumed by buildings [1]. This amounted to approximately a quarter of all CO_2 emissions worldwide. These issues have a big impact on how an architect approaches their profession and lead to the growing acceptance of sustainable architecture principles [2]. Creating modern structures that adhere to strict energy efficiency criteria has become difficult for architects, forcing them to consult experts in various branches of engineering and science. Today, a building's spatial form, visual character, and architectural detail are more frequently shaped by its ventilation system, the lighting it offers for users, and the systems that enable it to achieve the highest level of energy efficiency.

Traditional building skin facades are well known to have several issues, including thermal comfort, natural ventilation, and glare, particularly in structures with high-glazing skin that are situated in hot temperature regions. These issues motivate engineers to look for solutions and improve the issues by utilizing innovative approaches and technologies including shading devices, colored glass, and tinted glass. The use of these techniques has resulted in a decrease in natural lighting and an increase in artificial lighting, which has unavoidably increased interior heat gain in addition to the use of other electric devices and office equipment that were used to make up for the lack of penetration of external illumination. This internal heat gain is combined with the exterior heat gain from solar radiation, which is sometimes brought on by poorly shaded structures. Air conditioning is utilized to reduce the heat effect to deal with this circumstance. This causes an increase in energy usage, which raises the price [3, 4].

Due to the benefits claimed in terms of energy conservation that support sustainable development—whose fundamental goal is to meet the needs of the present without negatively affecting the capacity of future generations to meet their own needs—the level of interest in double-skin facades (DSF) has increased rapidly [5]. A double-skin facade is a three-layer design outside modern buildings that consists of an internal skin (also typically made of glass), an intermediate area, and an external skin [6]. Building facades with high glazing fractions can perform more efficiently in terms of thermal energy with the usage of double-skin facades (DFS). It is constructed from external glazing that is spaced apart from internal glazing that is built into a curtain wall (Figure 1). The space between the two glazing systems frequently has a programmable shade system [7, 8]. Due to its ability to decrease solar heat gain or loss in buildings, it has been quite popular in recent years [9, 10, 11]. Particularly in regions with cool climates, it has become a highly prominent global modern building practice. The primary architectural benefit of DSF lies in its transparency qualities, which allow for direct interaction with the building's surroundings and allow for a significant amount of glare-free daylight to penetrate the structure. Finally, it has a desirable aesthetic value that architects, developers, and owners highly value [12, 13]. However, employing DFS has several drawbacks, one of which is the investment cost, which is significantly greater than a conventional single facade. Additionally, there is a risk of overheating on hot, sunny days, which could increase the need for cooling [14, 15]. Decisions about the geometric dimensions of the glass, ventilation plan, shading, daylighting, aesthetics, wind loads, and anticipated maintenance and cleaning costs are made when designing the DSF.

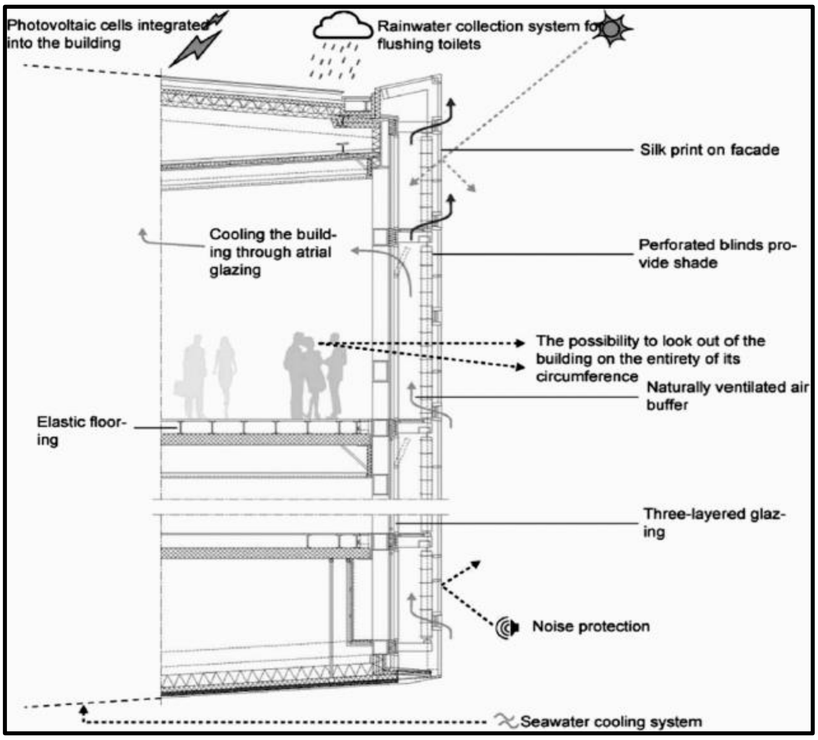

Figure 1 Cross-section of the double-skin façade

By eliminating the solar radiation that has been collected by the glass envelope, the DSF idea improves ventilation inside the building. Reducing the amount of energy required for both cooling and heating as a result [16]. However, due to the complexity of the thermal and airflow phenomena in its behavior as well as the adaptation of these solutions to climatic circumstances of different geographic places, its implementation is accompanied by considerable hurdles [17]. As a result, eco-friendly concepts and practices have become more sophisticated, and the construction design now includes considerations for environmental preservation [18].

2 Literature Review

There are various definitions of the DSF System. Safer et al. 2005 [19] stated that "A double-skin facade is a unique kind of envelope in which a transparent glazed second skin is positioned in front of a standard building exterior. The channel - the empty area between—can be quite significant (up to 0.8–1.0 m). The channel is typically vented (naturally, mechanically, or through a hybrid system) to reduce summertime overheating issues and aid in wintertime energy savings". Oesterle et al. [20] stated that it "Gave the most thorough explanation of DSF. A double-skin facade, according to the author, comprises a multi-layered facade envelope with an external and internal layer that includes a buffer gap for sun protection and regulated ventilation". According to Ding et al. "An interior facade, an intermediary space, and an outward facade make up a double-skin facade. The glazing on the exterior facade layer offers weather resistance and increased acoustic insulation against outside noise. Kim and Song [22], and Wong [23] supported that "Double-skin facades are constructed with numerous skin layers that include an inner skin, an intermediate space, and an external skin. Float glass or safety glass panes with a single glaze or a double glaze could be used for the external and internal skins. For temperature regulation, an adjustable sunshade device is typically installed in the middle space. The double-skin buildings can generally be divided into four categories: multi-story facades, corridor facades, box window facades". Baldinelli indicated that in contrast to a single-skin facade, a DSF consists of exterior and internal glazing that is incorporated into a curtain wall, frequently with a programmable shading system situated in the space between the two glazing systems [24]. Chan et al. contended that a double-skin facade is a building facade that has multiple glass skins covering one or more storeys. The skins can be artificially or naturally ventilated or airtight. The outer skin is often fully glazed, toughened single glazing. In most uses, the inner skin is not entirely glazed and can be double-glazed to provide insulation. The air space between the two skins might be anywhere from 200 mm to more than 2 m wide. An air-tightened double-skin facade can boost the building's thermal insulation and lessen heat loss during the winter [25].

The Essence of Double-Skin Facade

Due to their attractiveness, low weight, and potential for natural light, glass facades are frequently employed in contemporary architectural projects, especially commercial structures. Despite their widespread use, single-layer glass facades have common flaws that should limit (or at the very least prevent) their use in specific situations, such as inadequate heat insulation and a low sound reduction index [26]. It is commonly acknowledged that using DSFs to solve these issues presents an important opportunity to lower energy usage and hence enhance the sustainability of buildings. The first DSF to be used in a structure was discovered in a factory designed by Richard Steiffin Giengen in Germany in 1903 to enhance daylighting and take into account the area's chilly climate and high winds [27]. Despite being primarily employed in the European region, DSFs have recently become more and more common throughout North America and Asia [28]. According to the study methodologies, studies about DSF performance may be divided into analytical and lumped models [29], dimensional analysis [30], network and zonal models [31], and airflow networks coupled with energy simulation [32]. Additionally, computational fluid dynamics (CFD) models have been used to examine the effectiveness of mechanically and naturally ventilated facades. Multiple skins have been used to describe DSFs [30]. Although their use in hot climates has been frequently mentioned, they were created as an efficient improvement to conventional facades for colder climates [34].

Table 1 Identified environmental and economic benefits of DSFs.

No.	Main Identified Benefits	
1	Environmental benefits	Energy consumption reduction, ventilation, airflow and thermal comfort enhancement, daylighting and glare control, sound insulation, noise reduction and acoustic enhancement visual and aesthetic quality enhancement.
2	Economic benefits	Reduced long-term cost

The goal of the study is to examine the many advantages of DSFs, such as "energy consumption reduction," "ventilation, air-flow and thermal comfort enhancement," "daylighting and glare control," "sound insulation, noise reduction and acoustic enhancement," and "visual and aesthetic quality enhancement." As summarized in Table 1, the study also looks into the potential drawbacks of DSFs, their high investment, excessive heat gain caused by their high U-values, overheating, and asymmetric thermal radiation and its associated discomfort [35].

Essential Concepts of Double-skin Facades

The early 1900s saw the introduction of the DSF, but until the 1990s, little progress was made [36]. DSF's past is not well known, and little is still known about the underlying physical mechanisms. Although its usage is more widespread in regions with stricter building energy efficiency laws, the lack of uniform criteria in the majority of nations might be a barrier to the implementation of DSF [37]. An ordinary facade, an air hollow, and an additional exterior skin, typically constructed of glass, make up a DSF. The major variables that promote air movement in structures with DSF, according to Gracia et al. [38], are the movement of the surrounding wind and the pressure difference brought on by the thermal buoyancy that takes place in the cavity. The density differential between the warmer air inside the cavity and the cooler air outside causes the thermal chimney phenomenon within the DSF. Solar radiation warms the air inside the cavity, which is then expelled to the outside through the cavity's top [39].

Technical Aspects of Double-skin Facades

The external facade layer, intermediate space, and internal facade layer are the three basic parts of DSFs technically. Based on external glazing offset from internal glazing, DSFs are designed [40]. To lessen the cooling demand of indoor spaces brought on by greatly concentrated solar radiation, shading devices are also inserted into the air channel [41]. Additionally, it should be highlighted that the internal and external layers of the structure both contain sufficient holes to ensure natural ventilation in the cavities and interior spaces next to the facade [42]. The three critical parameters—the facade parameter (technical attributes of the cavity and external layer), the building parameter (physical formation of the building), and the site parameter (outdoor environmental condition)—have the greatest influence on the performance of DSF.

Varying climates need different performances from DSFs. The function of DSFs in cold areas is to act as a heat exchanger, maintaining the interior skin layer's temperature near the target indoor temperature [34]. DSFs may result in a low shading coefficient in hot areas [34]. From a critical standpoint, [43] observed that although the use of DSFs in Central European weather conditions is still disputed [44], they are growing in popularity mostly because of their aesthetic value (particularly in commercial buildings). Numerous studies have regularly proven the multiple-skin facades' overall energy efficiency. According to reports [45] about the technical dimensions, the depth of the air cavity or channel is between 80 cm and 100 cm. The cavity depth is said to be related to ventilations, the impacts of a greenhouse, and energy efficiency in addition to maintenance-related difficulties [46]. The depth must also be taken into account in light of the local climate where the building is situated. Researchers observed the impact of cavity depths ranging from 8 cm to 148 cm and discovered that the cavity depth had less of an impact on energy consumption than the kind of window glass. Similar reductions in heating, as well as an increase in cooling and a 5.6% decrease in overall energy consumption, were achieved by reducing the initial cavity depth (148 cm to 78 cm) [46] suggesting the best design approaches for the cavity depth and window glazing type. Figure 2 shows the effects of changing the DSF glazing types on the energy performance of buildings [35].

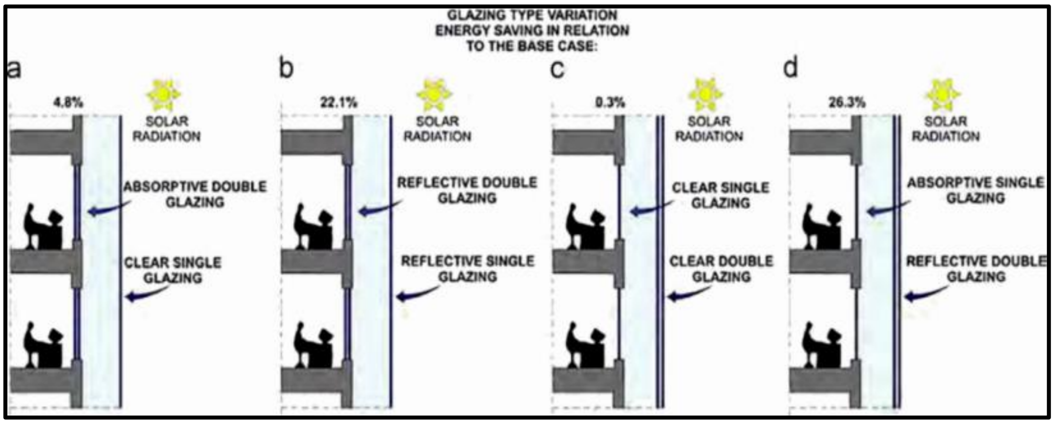

Figure 2 Performance of a building with DSF under variations of the glazing properties.

According to a recent study [46] on the types of window glazing, the most substantial changes in energy consumption were identified when the glazing type of the inner layer's outer surface was changed (from -3.4% to +18.8%). Changing the window glazing type on the inner layer's inside surface, however, resulted in the least noticeable change in energy consumption (-1.1% to +4.7%). For thermal regulation, adjustable shading devices like blinds are typically combined with DSFs and placed in the air channel [47, 48]. This is done in particular to safeguard interior spaces from rising cooling loads [49]. They serve as a pre-heater for ventilation air and reduce heat gain [50]. Other advantages of vegetation in DSF cavities include greater thermal insulation, less noise, improved air quality, oxygen production, and improved aesthetics [32]. Venetian blinds installed inside the air cavity have also been recommended that would promote ventilation and airflow [51].

Classifications of Double-skin Facades

The double-skin façade is made up of several parts, including air space, sliding device, exterior skin, and inner skin. The internal skin is often glazed, whereas the exterior skin is typically made of tempered safety glass. The width of the cavity can vary from 10 cm to more than 2 m, and the air space between the two panes may be manually ventilated, naturally vented, or supported by a fan. There are various ways to categorize double facades depending on factors like the type of construction utilized, the origin, destination, and technique of air movement through the hollow, among others. According to the geometry, the kind of air space between the two facades, and therefore the direction of airflow in it, the double facade could be categorized in a more general way. The box window type, vertical shaft type, corridor type, and multi-storey type were the classification strategies used by Lee and Saelens [52, 53]. The box window type is divided into smaller, independent boxes using horizontal and vertical partitions. For acoustical, fire safety, or ventilation, a corridor type is preferred. To ventilate an area, a multi-storey type is used joining the two facades together. A more thorough classification of the double-skin facades by the ventilation depends upon the type of ventilation i.e. natural, ventilator-aided, and/or mechanical. The direction of the airflow is internal or external, and the flow direction of the air is upward or downward (in the case of mechanical ventilation). The air cavity's width is narrow (10-20 cm), medium (0.5-1 m), and wide (over 1 m) (Figures 3) [54, 55].

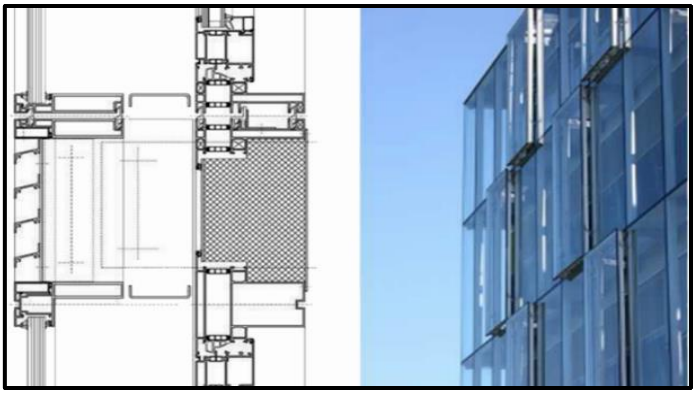

Figure 3 Double-skin façade and its sectional detail

Three design solutions for DSFs are introduced in the study by Lou et al. [56], including continuous, box, and corridor DSFs. On the other hand, as shown in Figure 5, a comparable study by Heusler and Compagno divides the DSFs into three types: window, story, and numerous tales [57].

Simulation, Modeling and Experiments of Double-skin Facades

Computer modeling and simulation are two of the newest methods available to engineers and designers [58]. To examine the DSF, experimental and numerical models were employed. Analytical and lumped models, dimensional analysis, network models, control-volume models, and computational fluid dynamics are some of the models that were utilized to forecast and analyze DSF (CFD). To simulate naturally ventilated DSF, a lumped model was utilized. Different DSF designs' energy performance was described using dimensional analysis. For a double facade with natural ventilation, Balco [59] provided a non-dimensional study involving energy and thermal attributes. Experimental and CFD simulation data were used to validate the findings of the non-dimensional analysis. The technique can be used with any type of naturally ventilated facade. Furthermore, Stec and Paassen 2005 [60] determined that the double-skin systems were competitive in terms of energy performance after comparing the performance of nine different facade systems for the Dutch environment.

Indoor Climate and Energy Aspects

When compared to standard window facades, double-skin facades have more glazing, which intensifies practically all indoor climate conditions and enhances how the indoor environment is perceived by the occupants. Compared to rooms facing a regular window facade, daylight levels are often higher in rooms facing a double-skin facade. The light-effective glazing ratio affects the daylight levels (the product of light transmittance LT and net glazing ratio Rg). Although double-skin facades will have less light transmittance than a standard window facade, their relative light-effective areas will quadruple. The amount of daylight in a space that is deeper than about 6 meters will be less affected by this, while it will initially raise the level of light close to the facade. It is evident that double-skin facades provide a greater view of the outside than a typical window facade when it comes to viewing conditions [61].

A double-skin facade is distinguished by one or more additional layers of glazing above a conventional glazed exterior, reducing heat loss. By including the thermal resistance of the additional glazing layer, it is possible to determine the decrease in heat loss. In reality, double-skin facades experience some variations of convective and radiative heat transmission. The U-value for a single layer of glass is 5.9 W/m^2K, and the U-value for double low-E glazing ranges from 1.0 to 1.5 W/m^2K. These values are used to determine the glazing's thermal resistance. U-values have been converted to the thermal resistance of the glazing layers using standard values of thermal surface resistance of 0.04 m^2K/W and 0.13 m^2K/W. In contrast to the more extreme combination of 2+2 layers of glazing, which results in a 50% reduction in U-values for the glazing in double-skin facades, the addition of an additional single layer of glazing only has a modest (20%) impact on the reduction of U-values of the glazing in double-skin facades [62].

Need for Better Envelope Performance

The 2011 Buildings Energy Data Book [63] states that buildings utilize about 40% of the country's energy, with commercial buildings using 18% of that amount annually (or 45% of the energy used in construction), a figure that is steadily rising [64]. According to Berardu, comparable trends were observed around the world, with an average of 30–40% in the US, EU, and China. Fuel type and usage, energy standards and restrictions, as well as building design types and layouts, all have an impact to varying degrees [65]. The following building characteristics have been identified as contributing to energy consumption by Charalambides and Wright [66], Oesterle et al. [67], and Silvestre et al. [68]: building type and use, aspect ratio, location and orientation, building opening, size, proportion, and temperature difference between the indoor and outdoor environments [69]. According to Incropera [70], building enclosures account for 60–70% of the structure's heat conduction even though they only occupy about 36% of the building's overall area (exterior and interior via plan and elevation) [69, 71]. According to studies by Ihm et al. [72] and Shehabi et al. [73], altering the enclosure performance from a daylighting perspective can result in an estimated 30% reduction in energy consumption.

Double-skin Facade as an Element of a Sustainable Building System

Numerous studies advocate the use of double-skin facades to reduce heat gains as an energy-efficient element for the construction of low-energy buildings [74]. DSFs are theoretically developed by combining two facade layers with a space inside (air gap - cavity). This is because it can be seen that the temperature and air ventilation are intrinsically related to the size of the cavity. However, in double-skin facades generally, there is a chance to add glaze skin to the structure, which could offer increased visual comfort, improved daylighting, and increased energy performance. The greenhouse effect is impacted by the inclusion of the interior and external facade layers in DSFs (Figure 4).

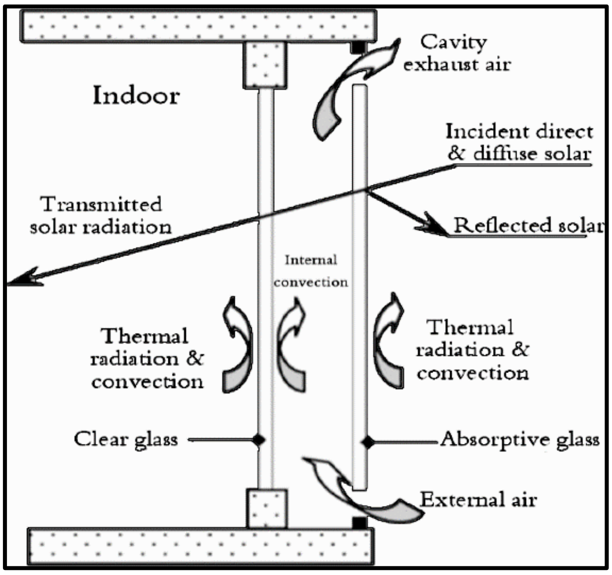

Figure 4 The heat transfer and air movement in DSFs

Yilmaz and Cetintas highlight other benefits of double-skin facades, such as sound insulation and improved visual elements in addition to their sustainable energy performances. On the other hand, some studies have demonstrated how successful DSFs are at lowering energy consumption, particularly regarding cooling requirements. Thus, it is implied that additional investigation, verification, and potential reinforcement of these facades are still required for improved building energy performances. The research by Yilmaz and Cetintas suggest that the main effect of double-skin facades in summer is the decrease of solar heat gain, whereas, in winter, double-skin facades aid to reduce heat loss and improve the u-values [16]. Simulations support the finding that the use of DSFs lowers the demand for heating energy in buildings. Ding et al. [21] propose adding thermal storage as a solar chimney above the double-skin layers to improve the ventilation to increase the effectiveness of DSFs compared to traditional DSFs.

3 Research Methodology

In this paper, the qualitative research method has been used. The systematic literature review explores the basic concepts of double-skin facade through books, internet and secondary data from relevant published academic literature from journal's research papers. The data collected in the qualitative research is the data that comes from several case studies and examples that are described descriptively and are supported by illustrations and photographs to reinforce the arguments put forward. This study offers a framework to evaluate the constructed facilities concerning energy efficiency and double-skin facades. The purpose of this paper is to analyze the future built environment's sustainability by highlighting similarities and disclosing discrepancies reflected in existing Double-skin facade works. To further clarify the concept of built environment sustainability, a list of criteria that can be used as a starting point for future research and implementation is provided in the conclusion of the paper.

4 Analysis and Discussion

During the construction phase, pertinent information on the double-skin facade system design parameters and constraints is thoroughly examined. This metric has a direct impact on both the general design and building procedure. The essential criteria include the type and design of the facade, its cavity shape, air consumption, HVAC system, shading, glazing, and lighting mechanisms, materials used, and the arrangement of shading devices [75]. From the aforementioned factors taken into account and a thorough examination of the double-skin facade system's performance, good technical management of the system in terms of sustainability is created. As a result, this will produce the primary goals and targeted outcomes that are necessary for the design and construction of the double-skin facade. Energy use during the construction stage (typically 10 to 20% of the total energy use) and the occupation stage (typically 80 to 90% of the total energy use) are also factors to be taken into account. Indoor climate considerations also include thermal and visual comfort, air quality, and acoustical concerns. To achieve an overall strategy and for professionals to be more accurate in their design process predictions that will prevent unpleasant flaws and issues that will increase the construction or operational costs of the double-skin facade, design constraints should be taken into account at an early stage of decision makings, such as climate, location and impediments, use of the structure, operational times, occupant duties, and rules governing construction and design.

Solution for Reducing Heat Loss

Utilizing insulators is one approach to lessen heat loss. Bulk insulators, which operate as weak thermal conductors, include materials like glass wool, mineral wool, cellulose fibers, and foam boards (polyurethane), and are categorized separately from reflecting insulators. These materials are used in the building sector. Reflective insulators require an air space to limit heat transfer through the walls by reflecting the majority of radiation or inhibiting heat transfer by radiation in the walls of this air space. This type of insulation is good at reducing the heat that is absorbed in the summer (heat from the Sun) but has little impact on heat loss in the winter (when conduction and convection account for the majority of losses). Since still air makes a great insulator, insulators either include tiny air pockets, like foam boards, or they absorb air onto their surface, like fiber insulators. Insulators have a very low conduction coefficient as a result. Insulators made of glass wool and mineral wool create substantial air-contact surfaces, which allow air molecules to adhere to them and generate layers of still air [76].

Future Prospects of Double-skin Facades

The most typical kind of energy-efficient facade, according to studies in the literature, is a double-skin facade system. The conventional facade appeared to symbolize a system that can be found in older, more traditional models but that has since been altered. It continues to be the least "complex" from a building standpoint and is applied when simple environmental buffering is necessary. The Double-skin Facade is more sophisticated mechanically than the conventional method and is preferred since it does not allow for natural ventilation. The Double-skin Facade system is currently popular due to its many design options, unique status as the only base system actively utilizing natural ventilation techniques, and inclusion of some type of movable windows. Even though the study is still in its early phases, preliminary findings suggest that double-skin facade systems do not triumph when judged using a strictly "hard" grading method that is based on economics and statistics. When evaluated using some "softer" environmental factors that are more challenging to measure, some of the systems do better. Daylighting, sun control, access to and management of natural ventilation, as well as the resulting employee satisfaction and productivity, would be some of these. It would be necessary to establish a solid "base case" building or wall type upon which to base an extensive set of statistical comparisons to carry out this inquiry in a more scientific manner [77].

5 Conclusions

The double-skin facade (DSF) is very significant and valuable in modern building developments, in conclusion. The cost of the double-skin facade is claimed to be higher than the conventional single-glass facade, which is the only drawback. Many experts concur, nevertheless, that double-skin facades (DSF) are more economical in the long run. Numerous aspects of the indoor environment and to some extent energy use are impacted by double-skin facades. When double-skin facades are used instead of conventional window facades, transparency, views to the outside, and daylight levels are increased. In open-plan offices where disability glare may develop in the depth of the rooms, an increased glazing area will also increase glare issues. Ventilation is essential in the summer to keep adjacent rooms from overheating. Double-skin facades can be employed as a component of a mechanical and natural ventilation strategy, however, ventilation is more complicated than it is with a free facade. It also offers additional advantages not possible with a single glass facade. One of them is that the double-skin facade contributes to the creation of a cozier and environmentally friendly workplace setting, which in turn lowers maintenance costs by conserving the building's energy resources. Compared to standard double glazing, glazing with double-skin facades gives a greater noise reduction, especially at low frequencies. Fire is a significant hazard with double-skin facades that needs to be properly considered in each situation.

In a double-skin facade construction, adding a single layer of glazing results in a small (20%) reduction in heat loss compared to adding two layers of low-E glazing. The addition of additional double low-E glazing will cut heat loss by about 50%. Due to the lower heat loss through non-transparent elements of a conventional facade, it is evident that it provides better conditions for heat loss than a full glass or double-skin facade. In a variety of study fields, DSF devices have a huge potential to reduce energy use. The characteristics of interior climate factors include interaction and, in some situations, opposing relationships, which makes determining which factors, should come first more challenging. Therefore, it's crucial to take a comprehensive or holistic approach to come up with good design ideas for double-skin facades. For the various design processes, it is equally important to have the right tools for analyzing the performance of double-skin facades. The challenge for the design teams is to provide a comfortable indoor climate with fair energy usage, yet it appears feasible. Thus, the authors of this paper suggest that research be done on DSF designs, difficulties with DSF designs and how they affect the environment, comfort, ergonomics, and human psychology in buildings. Due to its low cost and high energy efficiency, DSF applications in buildings should be given great consideration as a means of tackling climatic changes and environmental threats.

REFERENCES

[1] G. B. Hanna, "Green energy and green buildings in Egypt," *International Journal of Engineering Research.*, vol. 3, no. 4, 466–470, 2013.

[2] W. Celadyn, "Energia w architekturze," *Internet publication* [Online]. Available: yadda.icm.edu.pl/.../httpwww_kaiu_pan_plimagesstories3_2012w_celadyn [Accessed: January, 2,2022].

[3] P. C. Wang, "Natural Ventilation in Double-Skin Facade for Office Buildings in Hot and Humid Climate", Ph.D. Thesis, University of New South Wales, Australia, 2008.

[4] A. L. S. Chan, T. T. Chow, K. F. Fong, Z. Lin, "Investigation on the energy performance of double-skin facade in Hong Kong," *Energy and Buildings*, 2009;41:1135–42.

[5] N. Safer, M. Woloszyn, J. J. Roux, and F. Kuznik, "Modeling of the double-skin facades for building energy simulations: Radiative and convective heat transfer," *Building Simul*., 1067–1074, 2005.

[6] J. Zhou and Y. Chen, "A review on applying ventilated double-skin facade to buildings in hot-summer and cold-winter zone in China," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 4, 1321–1328, 2010.

[7] M. Fernando Marques da Silva, G.Gomes., "Gap inner pressures in multi-storey double-skin facades," *Energy and Buildings*, 2008; 40: 1553–9.

[8] K. Roth, T. Lawrence, J. Brodrick, "Double-skin facade," *ASHRAE Journal* 2007;49(10):70–3.

[9] G. Elisabeth, A. De Herde, "Are energy consumptions decreased with the addition of a double-skin?" *Energy and Buildings*, 2007; 39: 605–19.

[10] C. Balocco., "A non-dimensional analysis of a ventilated double facade energy performance," *Energy and Buildings*, 2004; 36: 35–40.

[11] G. Ballestini, M. De Carli, N. Masiero, G. Tombola., "Possibilities and limitations of natural ventilation in restored industrial archaeology buildings with a double-skin facade in Mediterranean climates," *Building and Environment*, 2005; 40: 983–95.

[12] E. Gratia, A. De Herde., "Greenhouse effect in double-skin facade," *Energy and Buildings*, 2007; 39: 199–211.

[13] W. W. Braham, "Double-skin facades ds: typological and Historical account of active glass walls," *Construction Specifier*, 2006; 59(6): 73–9.

[14] E. Gratia, A. De Herde, "Natural cooling strategies efficiency in an office building with a double-skin facade," *Energy and Buildings*, 2004; 36: 1139–52.

[15] W. Ding, Y. Hasemi, T. Yamada, "Natural ventilation performance of a double-skin facade with a solar chimney," *Energy and Buildings*, 2005; 37: 411–8.

[16] Z. Yılmaz and F. Cetintaş, "Double-skin facade's effects on heat losses of office buildings in Istanbul," *Energy Build*., vol. 37, no. 7, pp. 691–697, Jul. 2005.

[17] M. A. Shameri, M. A. Alghoul, K. Sopian, M. F. M. Zain, and O. Elayeb, "Perspectives of double-skin facade systems in buildings and energy saving," *Renew. Sustain. Energy Rev*., vol. 15, no. 3, pp. 1468–1475, Apr. 2011.

[18] Y. Pan, Z. Huang, G. Wu, "Calibrated building energy simulation and its application in a high-rise commercial building in Shanghai", *Energy and Buildings*, 2007; 39:651–7.

[19] D. Sinclair, V. Mezhibovski, "Ventilationg facades," *ASHRAE Journal*; April 2009.

[20] W. Oesterle, E. Lieb, R-D. Lutz, and M. Heusler, "Double-skin facades – Integrated planning," Prestel Verlag Munich, Ger., 2001.

[21] W. Ding, Y. Hasemi, and T. Yamada, "Natural ventilation performance of a double-skin facade with a solar chimney," *Energy and Buildings*, vol. 37, no. 4, 2005.

[22] S. Y. Kim and K. D. Song, "Determining photosensor conditions of a daylight dimming control system using different double-skin envelope configurations," Indoor Built Environ., vol. 16, no. 5, 411–425, 2007.

[23] P. Wong, "Natural ventilation in double-skin facade design for office buildings in a hot and humid climate," University of New South Wales, Australia, 2008.

[24] G. Baldinelli, "Double-skin facades for warm climate regions: Analysis of a solution with an integrated movable shading system," *Building and Environment*, vol. 44, no. 6, 1107–1118, 2009.

[25] A. L. S. Chan, T. T. Chow, K. F. Fong, and Z. Lin, "Investigation on the energy performance of double-skin facade in Hong Kong," *Energy and Buildings*, vol. 41, no. 11, 1135–1142, 2009.

[26] T. E. Jiru, TaoY-X, F. Haghighat, "Airflow and heat transfer in double-skin facades," *Energy and Buildings,* 2011; 43: 2760–6.

[27] O. Kalyanova, "Double-skin facade: modeling and experimental investigations of thermal performance," Aalborg: Dept. of Civil Engineering, Alborg University; 2008.

[28] V. Yellamraju, "Evaluation and design of double-skin facades for office buildings in hot climates," Texas, United States: Texas AandM University; 2004.

[29] C. S. Park, G. Augenbroe, T. Messadi, M. Thitisawat, N. Sadegh, "Calibration of a lumped simulation model for double-skin facade systems," *Energy and Buildings,* 2004; 36: 1117–30.

[30] C. Balocco, "A non-dimensional analysis of a ventilated double facade energy performance," *Energy and Buildings,* 2004; 36: 35–40.

[31] T. E. Jiru, F. Haghighat, "Modeling ventilated double-skin facade—A zonal approach," *Energy and Buildings,* 2008; 40: 1567–76.

[32] W. Stec, A. Van Paassen, "Symbiosis of the double-skin Facade with the HVAC system," *Energy and Buildings,* 2005; 37: 461–9.

[33] W. Ding, Y. Hasemi, T. Yamada, "Natural ventilation performance of a double-skin facade with a solar chimney," *Energy and Buildings,* 2005; 37: 411–8.

[34] J. Zhou, Y. Chen, "Are view on applying ventilated double-skin facade to buildings in hot-summer and cold-winter zone in China," *Renewable and Sustainable Energy Review,* 2010; 14: 1321–8.

[35] S. Barbosa, K. Ip, "Perspectives of double-skin facades for naturally ventilated buildings: are view," *Renewable and Sustainable Energy Reviews,* 2014; 40: 1019–29.

[36] P. D. Pomponi et al., "Assessment of double-skin facade technologies for office refurbishments in the United Kingdom," Sustain. Build. – Constr. Prod. Technol. Graz, 2013.

[37] J. H. W. Choi, J. Joe, and Y. Kwak, "Operation and control strategies for multi-storey double-skin facades during the heating season," *Energy and Buildings,* vol. 49, 2012.

[38] A. De Gracia, A. Castell, L. Navarro, E. Oró, and L. F. Cabeza, "Numerical modeling of ventilated facades: A review," *Renewable and Sustainable Energy Reviews*, vol. 22, pp. 539–549, Jun. 2013.

[39] H. Radhi, S. Sharples, and F. Fikiry, "Will multi-facade systems reduce cooling energy in fully glazed buildings? A scoping study of UAE buildings," *Energy and Buildings*, vol. 56, pp. 179–188, Jan. 2013.

[40] C.S. Park, G. Augenbroe, "Local vs integrated control strategies for double-skin systems," Autom Constr 2013; 30: 50–6.

[41] A. Ghaffarianhoseini, A. Ghaffarianhoseini, U. Berardi, J. Tookey, D. Hin Wa Li, S. Kariminia., "Exploring the advantages and challenges of double-skin facades (DSFs)," *Renewable and Sustainable Energy Reviews,* 60, 2016.

[42] N. Mingotti, T. Chenvidyakarn, A. W. Woods, "The fluid mechanics of the natural ventilation of a narrow-cavity double-skin Facade," Building and Environment, 2011; 46: 807–23.

[43] H. Manz, T. Frank, "Thermal simulation of buildings with double-skin facades," *Energy and Buildings,* 2005; 37: 1114–21.

[44] K. Gertis, "New facade developments—do they make sense from a building physics point of view? Part 2: glass double facades" Bauphysik 1999; 2: 54–66.

[45] N. Safer, M. Woloszyn, J. J. Roux, "Three-dimensional simulation with a CFD tool of the airflow phenomena in single floor double-skin facade equipped with a Venetian blind," Sol Energy 2005; 79: 193–203.

[46] J. Joe, W. Choi, Y. Kwak, Huh J-H., "Optimal design of a multi-story double-skin Facade," *Energy and Buildings,* 2014; 76: 143–50.

[47] S. Kim, K. Song, "Determining photo sensor conditions of a daylight dimming control system using different double-skin envelope configurations," *Indoor Built Environ* 2007; 16: 411–25.

[48] P. Wong, "Natural ventilation in double-skin Facade design for office buildings in a hot and humid climate," Australia: University of New South Wales; 2008.
[49] G. Baldinelli, "Double-skin facades for warm climate regions: analysis of a solution with an integrated movable shading system," *Building and Environment*, 2009; 44.
[50] W. Stec, A. Van Paassen, A. Maziarz, "Modelling the double-skin facade with plants," *Energy Build* 2005; 37: 419–27.
[51] Ji Y, Cook MJ, Hanby V, Infield DG, Loveday DL, MeiL., "CFD modelling of naturally ventilated double-skin facades with Venetian blinds," Journsl of Build Performance and Simulation, 2008;1:185–96.
[52] D. Saelens, "Energy Performance Assessments of Single Storey Multiple-Skin Facades," Ph.D. thesis, Catholic University of Leuven Belgium, 2002.
[53] T. Tee, S. Selkowitz, V. Bazjanac, V. Inkarojrit., "High-Performance Commercial Building Facades", Building Technologies Program, University of California. Berkeley. 2002.
[54] Wicon, "Double-skin Facade" [Online]. Available: http://www.wicon.ch/de/Produkte/Tussaden'lg [Accessed: December 30th, 2022].
[55] Fuochi, "Double-skin Facade System" [Online], Available on http://en fuochi.it/systems/facciate-a-doppia-pelle
[56] W. Lou, M. Huang, M. Zhang, and N. Lin, "Experimental and zonal modeling for wind pressures on double-skin facades of a tall building," *Energy and Buildings*, vol. 54, pp. 179–191, Nov. 2012.
[57] C. A. Heusler, "Multiple-skin facades," Fassade Facade, vol. 1, pp. 15–21, 1998.
[58] M. Bartak, F. Drkal, J. Hensen, and M. Lain, "ESP-r : Integrated simulation tool for design example 1: A modern office building in Prague," in Proc. Int. Workshop of Integrated Build. Simulation, pp. 108–116, 2003.
[59] C. Balocco, "A non-dimensional analysis of a ventilated double facade energy performance," *Energy and Buildings*, vol. 36, no. 1, pp. 35–40, Jan. 2004.
[60] W. J. Stec and A. H. C. Van Paassen, "Symbiosis of the double-skin facade with the HVAC system," *Energy and Buildings*, vol. 37, no. 5, pp. 461–469, May 2005.
[61] Christoffersen J., Petersen E., Johnsen K., Valbjørn O., Hygge S., "Vinduer og dagslys – en feltundersøgelse i kontorbygninger," Statens Byggeforskningsinstitut, København, 1999, p. 9. SBI-Rapport, 318, (in Danish)
[62] H. E. Hansen, P. Kjerulf-Jensen, O. B. Stampe, "Varme- og Klimateknik Grundbog," Danvak ApS, København, 1997, 2nd edn. p. 487. (in Danish)
[63] DOE, "Buildings Energy Data Book," Energy Efficiency and Renewable Energy Dept., 2011 [Online]. Available: http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2010_BEDB.pdf
[64] D. B. Crawley, J. W. Hand, M. Kummert, B. T. Griffith, "Contrasting the capabilities of building energy performance simulation programs," Building and Environment 2008, 43, 661–673.
[65] U. Berardi, "A cross-country comparison of the building energy consumptions and their trends," *Resour. Conserv. Recycle.* 2017, 123, 230–241.
[66] J. Charalambides, J. Wright, "Effect of early solar energy gain according to building size, building openings, aspect ratio, solar azimuth, and latitude," Journal of Architectural Engineering. 2013, 19, 209–216.
[67] E. Oesterle, R. D. Oesterle, L. M. Lutz, W. Heusler, Double-skin Facades—Integrated Planning; Prestel Verlag: Munich, Germany, 2001.
[68] J. D. Silvestre, J. de Brito, M. D. Pinheiro, "Building's external walls in life-cycle assessment (LCA) research studies. In Proceedings of the SB10–Sustainable Building Affordable to All," iiSBE–Portugal: Vilamoura, Portugal, 2010.
[69] M. Saleem, G. Chhipi-Shrestha, T. Barbosa Andrade, R. Dyck, R. Ruparathna, K. Hewage, R. Sadiq, "Life cycle thinking–based selection of building facades," J. Archit. Eng. 2018, 24, 04018029.
[70] F. P. Incropera, "Introduction to Heat Transfer," John Wiley and Sons: New York, USA, 2011.
[71] S. Selkowitz, "Energy efficiency perspectives: Intelligent networks and the challenge of zero energy buildings," In Proceedings of the Presentation to Connected Urban Development Global Conf., Amsterdam, The Netherlands, 10 April 2008.
[72] P. Ihm, M. Krarti, A. Nemri, "Estimation of lighting energy savings from daylighting," Building and Environment, 2009, 44, 509–514.
[73] A. Shehabi, N. DeForest, A. McNeil, E. Masanet, J. Greenblatt, E. S. Lee, G. Masson, B. A. Helms, D. J. Milliron, "U.S. energy savings potential from dynamic daylighting control glazing," *Environ. Energy Build.* 2013, 66, 415–423.

[74] M. Arif Kamal, "Technological Interventions in Building Facade System: Energy Efficiency and Environmental Sustainability", Architecture Research, vol. 10 no. 2, 45-53, Scientific & Academic Publishing, U.S.A., 2020.

[75] M. Arif Kamal, "Recent Advances in Material Science for Facade Systems in Contemporary Architecture: An Overview", vol. 8, issue. 3, 97-104, American Journal of Civil Engineering and Architecture, USA, 2020.

[76] M. Arif Kamal,"Material Characteristics and Building Physics for Energy Efficiency', Materials and Construction Technologies for Sustainable Development", Key Engineering Materials, vol. 666, Trans Tech Publication, Switzerland, 2016.

[77] M. Arif Kamal, M. G. Abdullahi, M. Z. Kandar, L. Y. Wah, A. T. Ashiru, "Exploratory Survey of Recessed Window Facade Shading in Johor Bahru Malaysia", Chemical Engineering Transactions**,** vol. 56, 1807-1812, 2017.