Double Skin Façade Adoption Influencing Ventilation Performance in Educational Buildings

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Abstract

Double skin façades are adaptive envelopes that aim to improve building energy consumption and comfort performance. Their adaptive principle relies on the dynamic management of the cavity's ventilation flow and the shading devices, which can integrate with the environmental systems. This research demonstrates the possibility of modifying existing buildings to study unconventional building envelope solutions. Scenarios A and B show insignificantly decreasing measures in air velocity, relative humidity, and air temperature; however, Scenario C shows the most significant changes, the average air velocity increases by 45%, the air temperature drops between 5 to 8%, and the relative humidity drops between 5 to 8%. The utilization of DSF can be used to reduce solar heat gain, enhance natural ventilation, and mitigate the inefficiencies of mechanical ventilation in educational buildings. The Double Skin Façade is effective in improving parameters that are in accordance with thermal comfort.

Keywords: *Double Skin Façade; Natural Ventilation; Hot-Arid climate; Thermal Comfort; Building Energy Simulation*

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1. INTRODUCTION

Double skin façade (DSF) is a multi-sided skin that was specifically created for cold climates in European nations. In order to prevent any indoor climate issues in daily life, they began discussing the prospect of implementing this technology after it was successful. After reviewing the findings of earlier studies, particular variables, such as the location and the local microclimate, must be taken into account in order to determine the parameters that will be employed (e.g., the ratio between the floor level and the height of the screen, the orientation, and the cavity depth) (Abtar, 2021, p. 96). In addition, it is necessary to recognize that mechanical ventilation is crucial for DSF in hot weather to maintain its interior temperature and cool (Kilaire & Stacey, 2017). The dynamic integration between a ventilated façade and the HVAC system could also play a significant role in enhancing the adaptive behavior of a façade, yet this feature has been rarely investigated so far (Lucchino et al., 2022).

DSF is gradually becoming a standard architectural component in commercial, academic, and residential structures. DSF design has a challenge in establishing a balance between the aesthetic, acoustic insulation, and visual considerations that enhance the building's performance from an energy standpoint (Yagoub et al., 2010). Due to the success of the application in the European region, a number of nations with various temperatures are beginning to consider the dissertation of DSF into consideration in order to begin adapting it to other climates in order to obtain adequate comfort and save energy.

The opportunities and challenges of simulating a double-skin façade system using software application for building energy simulation are presented in this paper. The study demonstrates how to enhance the indoor environmental quality of existing educational buildings and how they can be altered to satisfy the modelling specifications for building envelope systems (Lucchino et al., 2019). The objectives of this study can be concluded as:

- Take into consideration the implications of DSF geometrical factors and window/room designs;
- Employ a comprehensive guideline for the design and deployment of DSFs in buildings;
- Emphasize on the effects of the double skin presence, by utilizing different DSFs designs.

2. CLASSIFICATION OF DOUBLE SKIN FAÇADE SYSTEMS

DSF consists of two glass panels separated by an air gap or other insulation gas. This area acts as a barrier against the intense heat, frequent wind changes, and noise. Always placed in between two layers are sun protection devices. Both solid and transparent membranes are used in the various arrangements of the components. Due to the significant variances across the DSF construction types (Saad & Araji, 2020).

To further assess and compare the advantages of the various systems, it is essential to construct a categorization system based on the "environmental success" of one building's skin as compared to another. The three primary system types are buffer systems, extract air systems, and twin systems. The three systems significantly differ with relation to ventilation technique and ability to lower overall energy consumption, as shown in Figure 1 (El Semary et al., 2017).
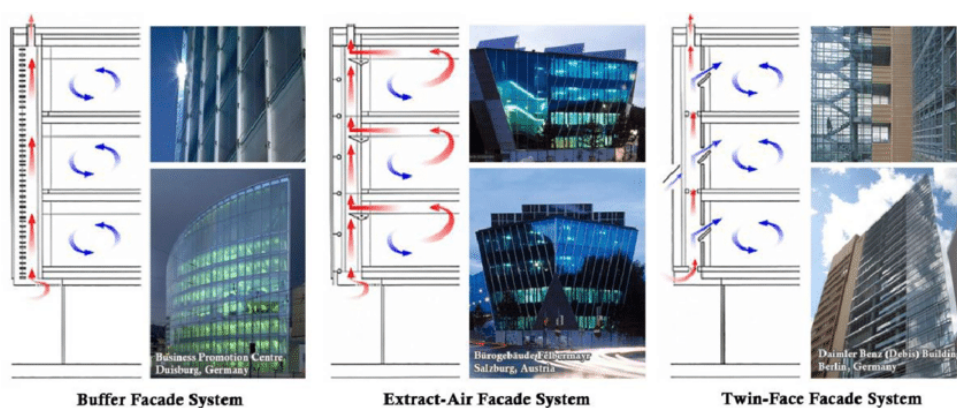

Figure 1. Examples of double façade types of buffers, extract-air, and twin face

2.1. Buffer System

The earliest façade designs originated approximately a century ago. They come before insulating glass, which was also created to absorb sound in structures. They use double laye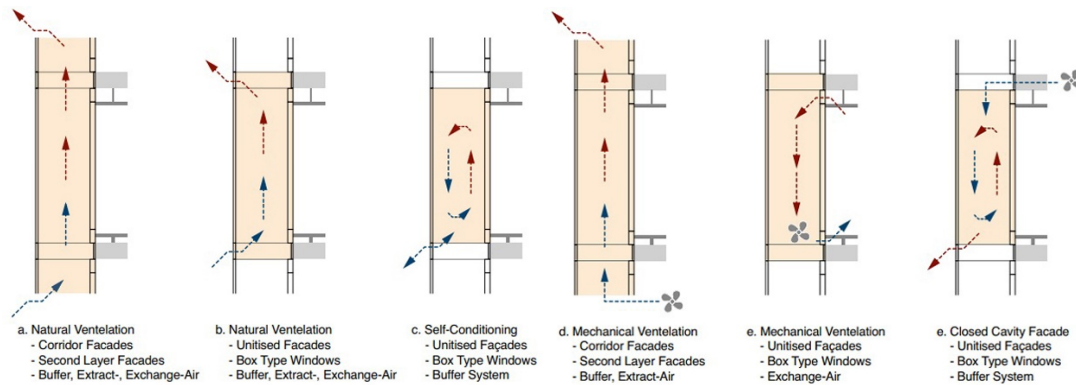r single glazing with gaps ranging from 250 mm to 900 mm and are impermeable. Additional controlled means, such as a separate HVAC system or a box type window, are used to let fresh air into the building. Depending on the purpose they are allocated, the ventilation solutions change, as shown in Figure 2 (Fabian et al., 2019).

Figure 2. Double skin façade with different ventilation concepts

2.2. Extract-Air System

These are constructed of thermal pane units, a second layer of single glazing linked to the interior of a primary façade with double glazing. The area between two panes of glass is covered by the HVAC system. The inner layer of glazing is made to be tempered while the outer layer of insulating glass minimizes heat loss by using fans to extract hot "used" air from between the glazing layers through the cavity. HVAC systems that provide fresh air limit natural ventilation. The air that is already in the system is used by the HVAC system. Because these systems require automatic fresh air changes, energy requirements are often not reduced (Boake, 2003, p. 2).

Users are not permitted to adjust the temperature in any of their private spaces. Usually, the shade apparatus is placed inside the cavity. Depending on how much space is needed to access the hollow for cleaning, the distance between the layers of glass ranges from 150 to 900 millimeters. This method is used in situations when natural ventilation is impractical, such as in environments with a lot of noise, wind, or pollutants.

2.3. Twin Face System

This design incorporates a traditional curtain wall or thermal mass wall system within a single glazed building skin. This outer glazing may be constructed from safety glass, insulating glass, or a combination of the two. Another option is to enclose the shading mechanisms. These systems should have internal spaces that are at least 500–600 mm wide to accommodate future advancements. The presence of skin openings that permit natural ventilation distinguishes these systems from the buffer and extract air systems. The air cavity contents (shading mechanisms) are mostly shielded from the environment by the single glazed exterior layer (Sawant, 2023). This method reduces heat loss by utilizing the insulating properties of the inner skin. High-rise buildings employ their outer covering of glass to block or impede the wind while yet enabling access to fresh air through interior openings without the related noise or turbulence. The openings on the internal façade are open while the ventilation apertures in the outside skin regulate the temperature extremes among the façade. A building's interior can be cooled at night by employing windows, which alters the cooling demands placed on the HVAC system. For sound management, the apertures within the outer skin are separated from the windows on the inner façade (Azarbayjani, 2011, p. 513).

2.4. Summary for Buffer, Extract-Air, And Twin-Face Façade Systems

The classification system previously mentioned makes the assumption that a façade is mostly constructed of glass layers. The literature review examined past techniques for using DSF systems that included extra opaque parts and screen elements that could be changed for ventilation, solar gain, and indoor temperature. These structures were regarded as not fitting into the three major groups. Buffer

systems create a conditioned air system without any contact (Navarro et al., 2020). The air conditioning is created by mechanical or natural ventilation. The temperature of the cavity is continuously raised by extract-air systems using warm exhaust air from the interior space. There is a mechanical ventilation system in every room. For a continual exchange operation, Exchange-Air-Systems utilize natural ventilation within the cavities to move tempered air into the rooms and remove used air, as shown in Figure 3. (Fabian et al., 2019).
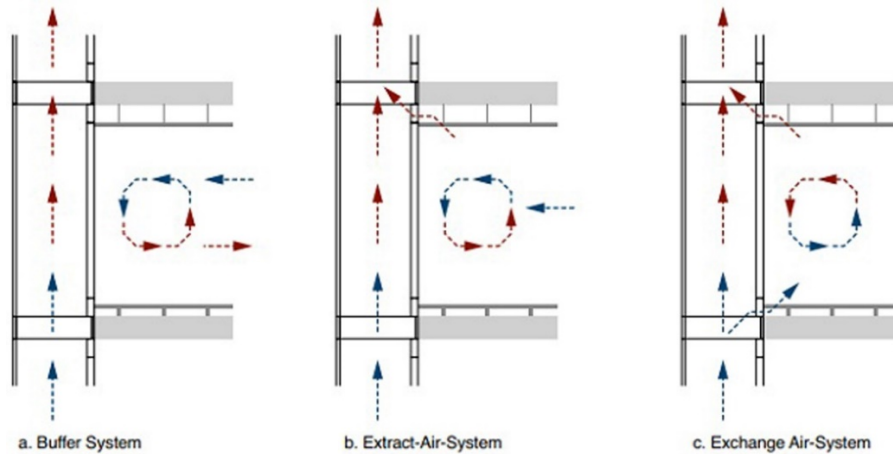

a. Buffer System   b. Extract-Air-System   c. Exchange Air-System

Figure 3. Double skin façade with different separation concepts between cavity and interior

2.5. Hybrid System

Building systems that do not fit into one of the aforementioned systems are classified by the hybrid system, which combines many of the components of those systems. Such buildings may have a layer of screens or non-glazed materials applied to either their inside or outside surface (Rezazadeh & Medi, 2017).

2.6. Box Window

In this type, the interface is separated both horizontally and vertically, and its envelopes are completely transparent. The first type of DSF is window, which is divided into sections on both the horizontal and vertical axes in more compact, distinct packing. The area that separates two facade levels in both directions along the structural axes and floors, respectively. This style of window is common in high outdoor settings sound levels and particular needs (Oesterle et al., 2001).
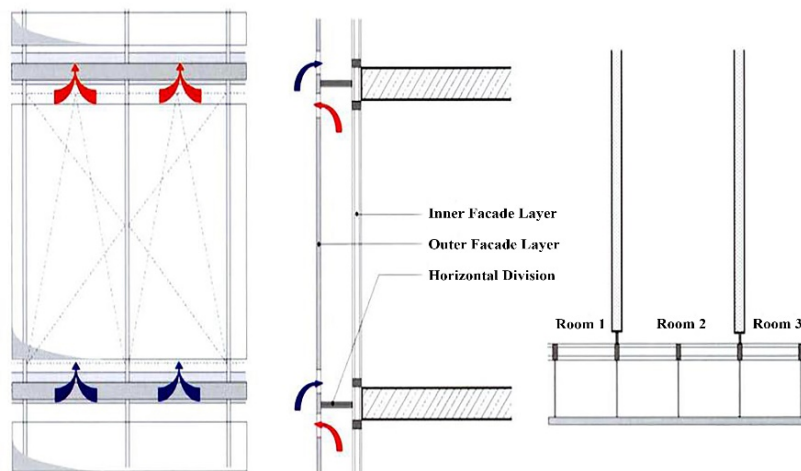

Inner Facade Layer
Outer Facade Layer
Horizontal Division

Room 1   Room 2   Room 3

Figure 4. Elevation, Section, and Floor plan of a Box Window double skin façade

2.7. Corridor (Shaft Box)

However, in order to reduce street noise, this design needs fewer apertures on the exterior layer. It consists of a unique kind of box window that rises vertically across several floors to create a stack effect (Mohammed Saleh & Alibaba, 2015).
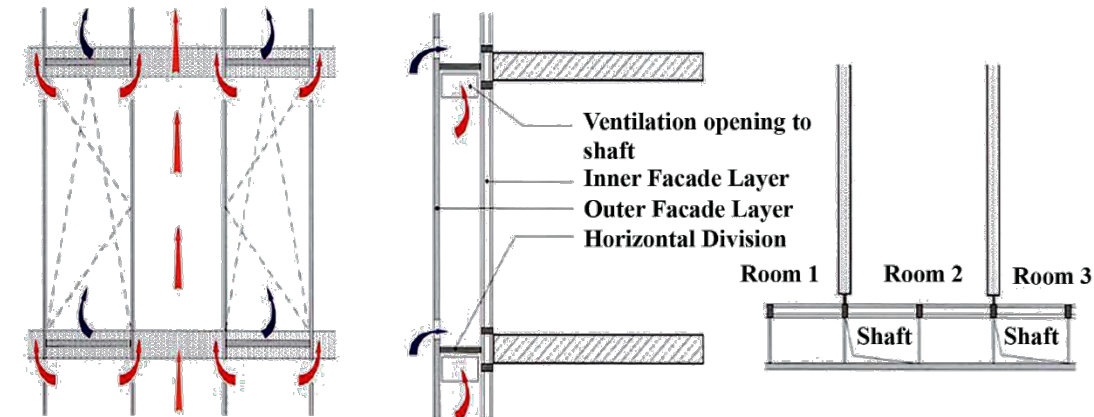

Figure 5. Elevation, Section, and Floor plan of a Shaft Box Façade

2.8. Multi-Story Cavity

This design of façade doesn't necessarily need apertures on the external skin because it draws air in from the bottom and releases it out at the top while the space between the two skins is vertically and horizontally adjoined.
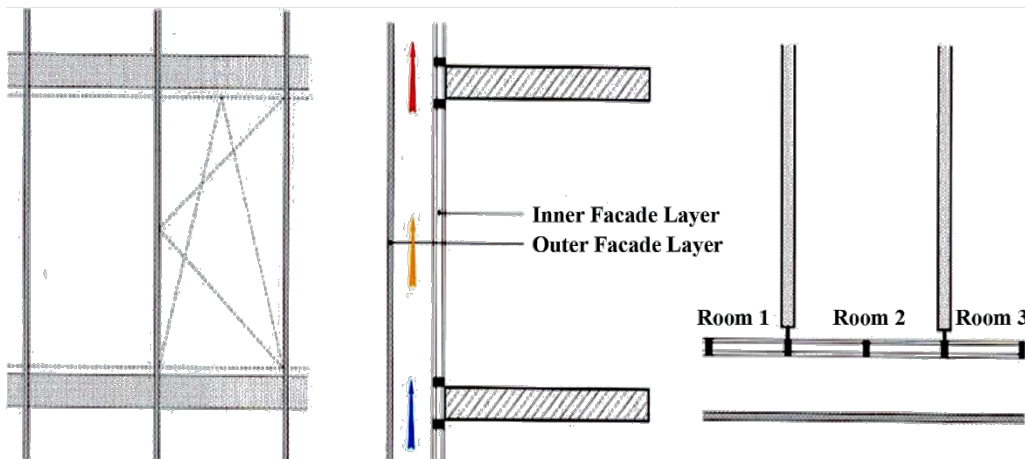

Figure 6. Elevation, Section, and Floor plan of a Multi-Story Façade

3. CLASSIFICATION OF THE VENTILATED DOUBLE FAÇADE CONCEPTS

Building skins have become a major focus in the effort to reduce a building's energy consumption, and the double glass façade has had a significant impact on how structures are designed. The basic components of the double façade are compensated by glass, a cavity, shade, and ventilation. However, a range of aspects, from aesthetics to acoustics, will lead to a varied mix of these fundamental elements in a complex, integrated setting (Barkkume, 2007, p.7).

Double skin facades are classified in a variety of ways. The majority of them are based on the facades' geometric design. A double skin façade has been employed for a variety of envelop functions, including improved ventilation, natural daylight optimization, and thermal and acoustic insulation (Yazdizad et al., 2014).

3.1. Types of Ventilation

It has to do with the many forms of ventilation systems for the space between two glass facades. Natural, fan-supported, or mechanical ventilation alternatives are available for the cavity. In a double glass façade, there are three types of ventilation: Natural airflow in this type of ventilation, heated air rises and circulates inside the hollow, and the occupants can access the air flow.

It is related to the various driving forces that ventilate the space between two glass façades. The cavity may be ventilated mechanically, naturally, or both. Three different types of ventilation are present in double glass façades: - Fresh air circulation Hot air rises in this type of ventilation, air flows in the cavity, and the occupants can access the air flow (Sarihi & Derakhshan, 2018).

If performed appropriately, natural ventilation reduces energy consumption. Ventilation using machinery Air moves with the help of a motorized air movement component during mechanical ventilation as shown in Figure 7. Hybrid air conditioning when natural ventilation is insufficient or unable to function effectively, we use mechanical ventilation, which is referred to as hybrid ventilation.
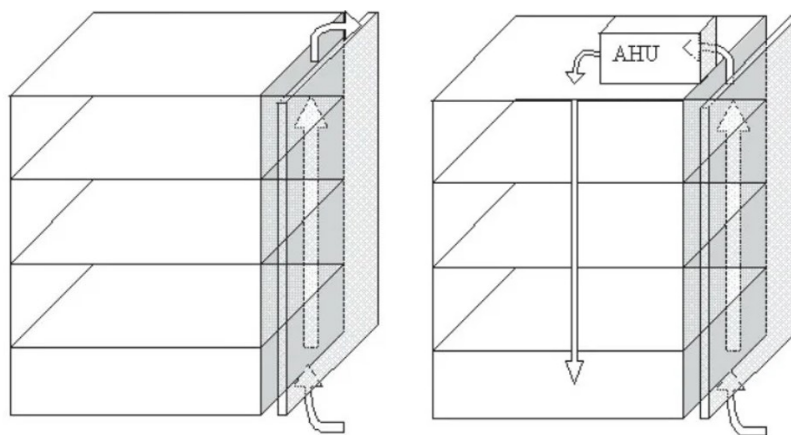

Figure 7. Natural and Mechanical ventilation systems (Poirazis, 2004, p. 46)

3.2. Shading Angle and Energy Efficiency

Under a substantially cloudy sky and in direct sunlight, the natural day lighting illumination can vary from 5000 lx to 40,000 lx, respectively. However, average indoor illumination levels should range from 200 to 500 lumens, therefore shading systems, particularly those on DSF façades, should reduce daylight absorption (Yazdizad et al., 2014).

The thermal efficiency of the DSF is closely tied to the operation of the sun shading device since air and surface temperature are determined by the sun-shading device angle and air flow rate as a second parameter. To determine the color and position of the sun shading device in the buffer zone, thermal view must be the primary consideration. However, DSF could adjust a modest amount of variation in sun-shading angle without affecting energy efficiency. The angle of the sunshade device allows for enhanced day lighting in interior spaces. Due to the thermal aspect and access to natural light both together, high glazed surfaces with adverse effects on thermal comfort and excellent effects on visual comfort can be managed with sun shading devices (Gavan et al., 2010).

4. CASE STUDY

4.1. Offices at AASTMT, Alexandria, Egypt

Based on the challenges that are expressed, several integrated systems are created and innovated to improve building energy consumption and guarantee environmental advantages. Modern systems like multifunctional façade modules effectively address energy demands and challenges. Their key demands are to create a structure with a high degree of flexibility, to include technological and aesthetic standards that will be acceptable to both developers and consumers, and finally to create a modular system for simpler installation and maintenance.

The selection of The University of Arab Academy for Science, Technology and Maritime

Transport has been chosen as the case study based on the creation of integrated façades is proposed using two main approaches. First, this façade needs to be technically and aesthetically appealing because even the best performing facades won't be accepted by architects and the institution if they aren't visually adequate. Next, these facades need to be suggested as modules that can be produced industrially, justified economically, and technically applied to and installed on building systems. the case study location is in Alexandria, Egypt, at latitude 31° 12' 20.7108" N and longitude 29° 55' 28.2936" E. The case study location was chosen due to its characteristic Mediterranean climate. During the whole winter season, while the offices were fully occupied, some statistics were calculated. Three offices in the south zone will be examined in this study.
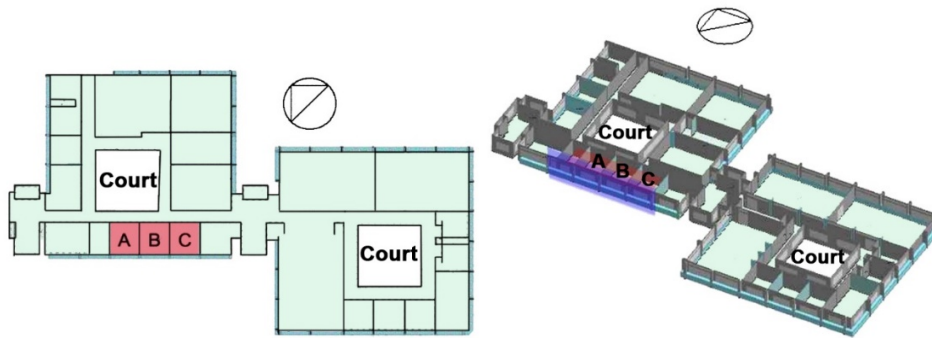

Figure 8. Key Plan and 3D for Simulation Cases (A, B, and C)

In the case study, CFD simulation will be employed to determine the air flow rate and thermal comfort in the three scenarios. The Design Builder v7 software will be employed for simulation. EnergyPlus 9.4 Simulation Program is compatible with this software. The ASHARE international standard shall be followed in the implementation of the air flow modelling.

The following characteristics were taken into account when choosing offices based on the literature review. The main factors were: the length and width, height, and floor of the offices; the ventilation strategies used (1-door/s open and windows open, 2-door/s open and windows open according to CO_2 measurements, 3-door/s open and only one window open); the total number of openings of both doors and windows; whether windows and doors are opened or closed and for how long; the number of occupants; the type of DSF; the wall; the glass; and the ceiling Properties.

Offices have the following measurements: (W, L, and H) and are square in shape. Because offices are arranged linearly throughout the building, openings can be placed on the outside wall and the wall facing the court. It has been chosen to assess the thermal comfort and air quality of offices in the educational building. The air velocity is 1.5 m/s. additionally, internal gains from the equipment and people were anticipated from 8:00 am to 5:00 pm, six days a week.

The interior spaces are well enclosed since it has thermal zones that are completely contained. As a result, the thermal efficiency of each area may be measured. After the model was finalized, the assets features were distributed. Materials from the Design Builder material catalogue were selected. All of the meteorological data was uploaded in the climatic file. Each building in the initial simulation had its current single-skin thermal performance, which was utilized as the base case. Mixed-mode ventilation was taken into account.

4.2. Base Case Simulation Results

Offices A, B, and C are square and measure around (5*5*3.30) M. they are in the south. There is one door that is closed and one large window that is open. Low air velocity inside the office, particularly in the winter, has an impact on the quality of the indoor air since it only reaches 0.006 m/sec, which is unsuitable for improving the indoor air.
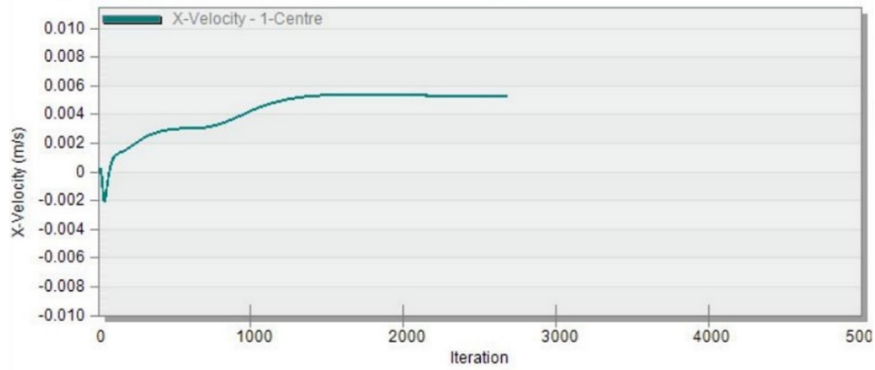
Figure 9. Air Velocity Simulation for Base Case.

The room temperature was high, which is acceptable in the winter but very unpleasant during summer days, reaching an average of 26.00 C with a maximum air change rate of 0.70 m/sec as a result of poor ventilation and low air velocity as shown in Figure 10 and simulation measures in Table 1.
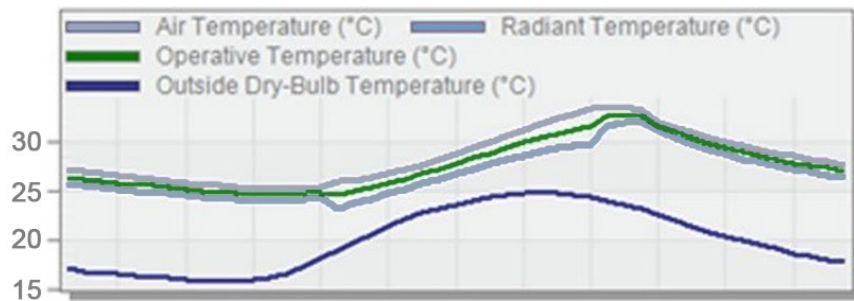

Figure 10. Meteorological Parameters Simulation for Base Case.

Table 1. Meteorological Parameters Simulation for Base Case from 8:00 am to 5:00 pm

Time Parameters	08:00-09:00	09:00-10:00	10:00-11:00	11:00-12:00	12:00-01:00	01:00-02:00	02:00-03:00	03:00-04:00	04:00-05:00
Air Temperature (c°)	25.07	25.47	25.51	25.60	26.59	26.43	26.89	26.43	25.60
Radiant Temperature (c°)	25.26	25.73	26.03	25.28	26.70	26.77	27.31	26.77	25.28
Relative Humidity (%)	53.15	49.21	45.81	44.20	46.84	51.65	46.15	51.65	44.20
Nat Vent + Infiltration (AC/H)	0.72	0.72	0.72	0.71	5.75	5.73	5.74	5.73	0.71

4.3. Scenario A: Multi-Story Double Skin Façade simulation

A second skin was attached in the simulation with the DSF installed 600mm away from the building wall. The building's materials, location, and construction techniques were all maintained across the several simulations. Mixed mode ventilation was taken into consideration in both simulations, and each building's single and double glazing for each of the three types of DSF was validated. The DSF's inlet apertures were made to be open continuously throughout the year. The multi-story double skin façade doesn't show a significant change in air velocity as the simulation appears almost the same values of air speed as it reaches to 0.006 m/sec as shown in Figure 11.
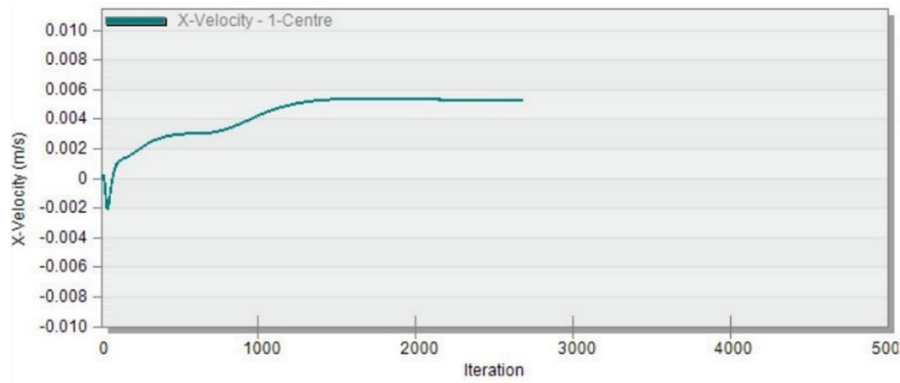
Figure 11. Air Velocity Simulation for Scenario A

According to the measures in air temperature, the multi-story DSF controls the heat gain in the internal spaces as the air temperatures shows a slightly reduction by 2% compared to base case simulation, also there are no significant changes in relative humidity as shown in Figure 12 and simulation measures in Table 2.
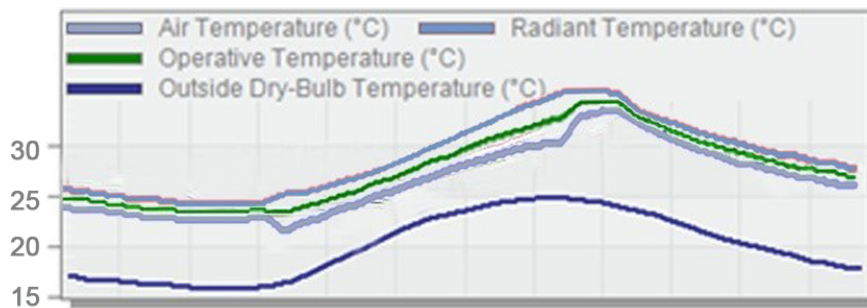

Figure 12. Meteorological Parameters Simulation for Scenario A

Table 2. Meteorological Parameters Simulation for Scenario A from 8:00 am to 5:00 pm

Time Parameters	08:00-09:00	09:00-10:00	10:00-11:00	11:00-12:00	12:00-01:00	01:00-02:00	02:00-03:00	03:00-04:00	04:00-05:00
Air Temperature (c°)	25.00	25.30	25.40	24.50	26.45	26.40	26.80	26.40	24.50
Radiant Temperature (c°)	25.50	25.90	26.40	25.30	26.65	26.75	27.30	26.75	25.30
Relative Humidity (%)	53.00	49.00	45.80	44.18	46.82	51.64	46.10	51.64	44.18

4.4. Scenario B: Shaft Box Double Skin Façade simulation

Installing a shaft box meanwhile temperature inside the workplace decreases, DSF air velocity rises. Low air velocity inside the office has an impact on indoor air quality, especially in the winter when it drops below -0.01 m/sec, which is unsuitable for improving indoor air as shown in Figure 13.
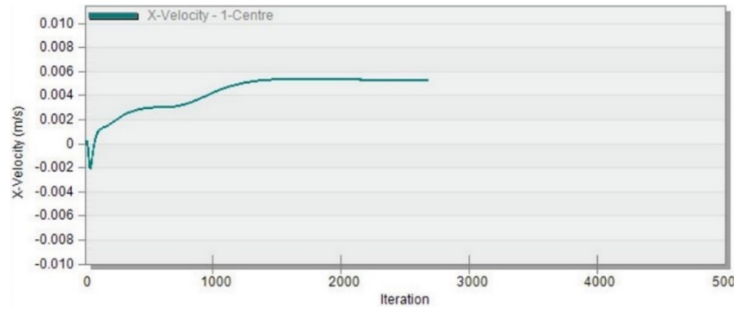
Figure 13. Air Velocity Simulation for Scenario B

In Scenario B, the average air velocity, humidity and air temperature shown relatively insignificant variation in measurements compared to base case simulation, as shown in Figure 14 and Table 3.
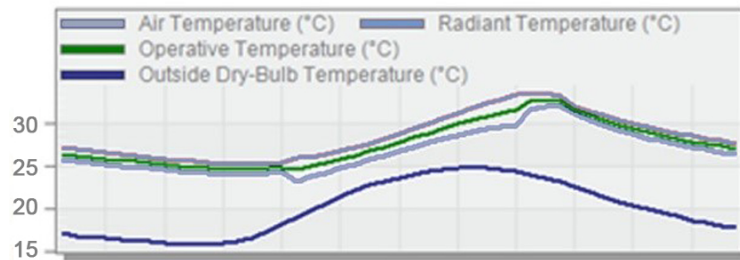

Figure 14. Meteorological Parameters Simulation for Scenario B

Table 3. Meteorological Parameters Simulation for Scenario B from 8:00 am to 5:00 pm

Time Parameters	08:00- 09:00	09:00- 10:00	10:00- 11:00	11:00- 12:00	12:00- 01:00	01:00- 02:00	02:00- 03:00	03:00- 04:00	04:00- 05:00
Air Temperature (c°)	25.09	25.50	25.20	25.40	26.50	26.33	26.70	26.23	24.40
Radiant Temperature (c°)	25.24	25.73	26.03	25.28	26.70	26.77	27.31	26.77	25.28
Relative Humidity (%)	54.15	49.10	45.71	44.15	46.80	51.05	46.00	51.50	44.00

4.5. Scenario C: Box Window Double Skin Façade simulation

The box window DSF shows the most significant change in air velocity as it increases by average 45% compared to the base case and scenarios A &B, thus the air velocity reaches to 0.010 m/sec as shown in Figure 15.
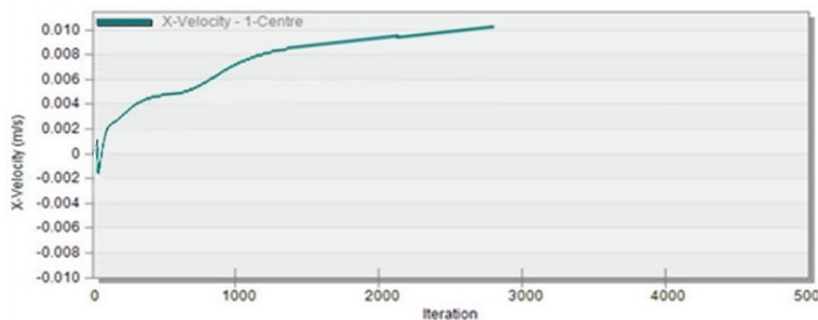

Figure 15. Air Velocity Simulation for Scenario C

The increase in air velocity has a direct impact on the indoor air temperature as it shows an average decrease about 6% less than the base case and scenarios A & B, as shown in Figure 16 and Table 4.
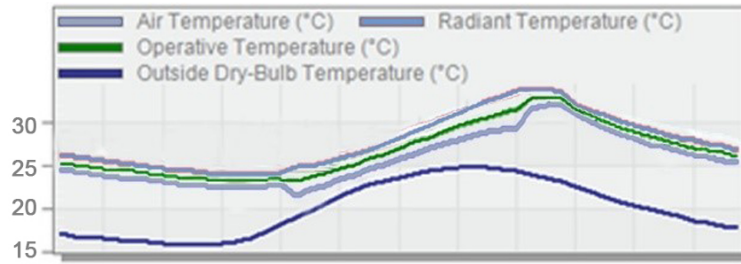

Figure 16. Meteorological Parameters Simulation for Scenario C

Table 4. Meteorological Parameters Simulation for Scenario C from 8:00 am to 5:00 pm

Time Parameters	08:00-09:00	09:00-10:00	10:00-11:00	11:00-12:00	12:00-01:00	01:00-02:00	02:00-03:00	03:00-04:00	04:00-05:00
Air Temperature (c°)	24.00	24.30	24.40	24.50	25.40	25.43	25.80	25.43	24.30
Radiant Temperature (c°)	24.00	24.70	24.0	24.25	25.60	25.70	26.28	25.70	24.25
Relative Humidity (%)	45.00	42.00	40.80	40.20	39.63	43.45	40.53	43.80	39.20

5. DISCUSSION

The probability of a disparity between the energy performance that was anticipated during the modelling stage and the actual energy performance following project completion is known as simulation risk. The primary technique of prediction is energy performance modelling; however, most inputs are estimations based on past performance or code requirements rather than actual or observed data. Risk is still present during a building's construction and operation, even if a high-quality simulation has been completed. No building can be constructed exactly as the design team intended; Data must be both detailed and precise. Even if there may be workarounds to account for the lack of software functionality for some models, the outcomes may not be exact for some design strategies or procedures, despite the fact that they are vital. Another concern is that the simulation program has different types and levels of input detail, so the results shown through the study were based on a specific model even if the same researcher created a new model, it would not produce the same results.

However, there is generally an acceptable error margin that won't alter the study's conclusions as determined by the researchers.

6. CONCLUSIONS AND RECOMMENDATIONS

According to the simulation's findings, the natural ventilation provided by DSF is efficient in enhancing the comfort of a space and can be used to improve natural ventilation and lessen the drawbacks of mechanical ventilation in office buildings by re In terms of air temperature, scenario C indicates the lowest values during the simulation test between 8:00 am and 5:00 pm, by an average of -1.00 to -1.20 °C, which is recognized to be between 5-8% less; scenario A presents the second-lowest air temperature values by an average of -0.5 to -0.8 °C, which is considered to be between 1-2% less; and scenario B shows nearly the same values for the base case with a few hours exhibiting significant changes as shown in Figure 17.
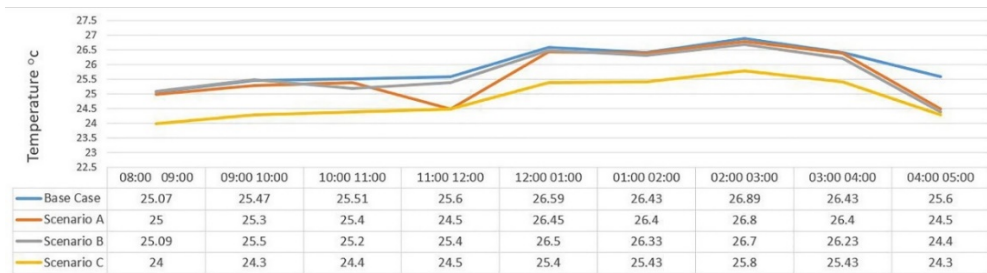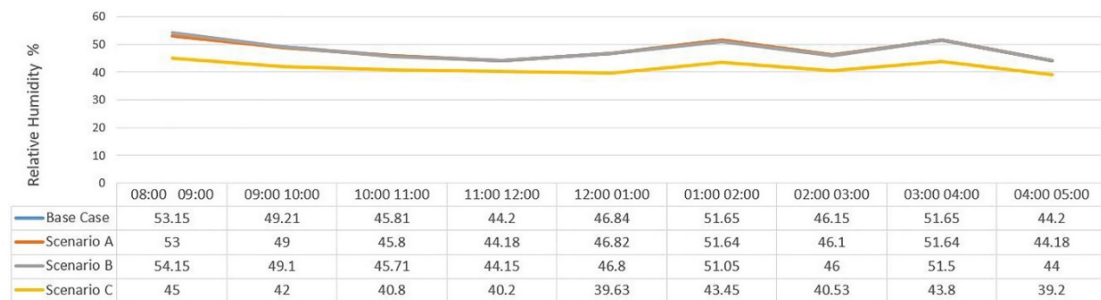
Figure 17. Air Temperature Values Comparison

	08:00 09:00	09:00 10:00	10:00 11:00	11:00 12:00	12:00 01:00	01:00 02:00	02:00 03:00	03:00 04:00	04:00 05:00
Base Case	25.07	25.47	25.51	25.6	26.59	26.43	26.89	26.43	25.6
Scenario A	25	25.3	25.4	24.5	26.45	26.4	26.8	26.4	24.5
Scenario B	25.09	25.5	25.2	25.4	26.5	26.33	26.7	26.23	24.4
Scenario C	24	24.3	24.4	24.5	25.4	25.43	25.8	25.43	24.3

Figure 18. Relative Humidity Values Comparison

	08:00 09:00	09:00 10:00	10:00 11:00	11:00 12:00	12:00 01:00	01:00 02:00	02:00 03:00	03:00 04:00	04:00 05:00
Base Case	53.15	49.21	45.81	44.2	46.84	51.65	46.15	51.65	44.2
Scenario A	53	49	45.8	44.18	46.82	51.64	46.1	51.64	44.18
Scenario B	54.15	49.1	45.71	44.15	46.8	51.05	46	51.5	44
Scenario C	45	42	40.8	40.2	39.63	43.45	40.53	43.8	39.2

According to relative humidity, Scenario C shows the most significant reduction in humidity by 5 to 8 % that considered between 15 to 20 % lower in mean value, scenario A & B showing almost the same values of the base case as they have almost same air temperature and air velocity as shown in Figure 18.

DSF has the capacity to improve the thermal comfort level of office buildings. Comparing shaft box, multi-story and box window DSF, which has demonstrated an improvement of roughly 25%, shows the best performance in managing and allowing air velocity in the indoor spaces. Building restoration that uses manufactured construction can be quick, energy-efficient, and high-quality. During restoration, DSF can be used to existing structures to improve their thermal comfort and energy efficiency.

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