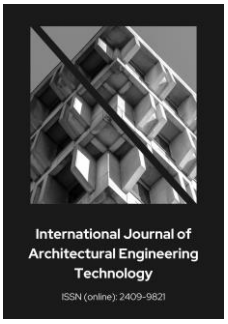
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Perforated Double-Skin Façades in Contemporary Mosque Architecture: A Comparative Precedent Analysis for Hot-Arid Climates

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ABSTRACT

Introduction: Mosques in hot-arid climates experience intense solar radiation and high cooling loads that conventional single-skin façades manage inefficiently. The double-skin façade (DSF) combined with an Islamic-pattern perforated outer screen offers a passive envelope strategy that simultaneously regulates daylight, buffers heat gain, and expresses cultural identity. While DSF research has grown substantially for temperate-climate office buildings, its deployment in mosque architecture in hot-arid contexts has not been systematically documented by structural logic or material strategy.

Methods: This study presents a structured comparative analysis of 24 contemporary mosques employing perforated façade strategies across hot-arid, hot-humid, Mediterranean, and temperate climatic contexts, classifying each case by structural logic (full double-skin envelope, perforated structural envelope, dome/roof perforation, perforated curtain wall, or applied screen/cladding), material system, and climatic and cultural role. Classification was based on documented secondary sources including architectural publications and project descriptions. EnergyPlus and Radiance-based simulations were also conducted to determine the effectiveness of reviewed DSF in reducing heat gain and allowing sufficient daylighting.

Results: The analysis finds that genuine full double-skin configurations remain rare, present in only five of twenty-four cases (20.8%) with the majority (50.0%) instead applying perforation as a partial decorative or shading screen rather than a thermally active cavity system. Glass-reinforced concrete (GRC) is the dominant material across the Gulf hot-arid cases, appearing in four of the five full-double-skin configurations. Fourteen of the 24 cases (58.3%) fall within hot-arid or hot semi-arid contexts, including twelve Gulf cases, indicating strong regional precedent but a comparatively narrow range of structural strategies tested. Tested DSF with an openness ratio of 25% reduced heat gain through the qibla wall by 11.4% compared to without a DSF and the daylight analysis showed that the main prayer hall was overlit at 100% spatial daylight autonomy (sDA) and 39% annual sunlight exposure (ASE).

Discussion and Conclusion: There are very few applications of DSF in modern contemporary mosques throughout the world and none were designed to fully envelope a mosque's façade even in the hot and arid regions. Despite being culturally decorative, a DSF with 25% openness ratio could significantly reduce heat gain while allowing sufficient daylight into the main prayer hall. A DSF is therefore a viable design option for mosques in hot and arid climate.

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1. Introduction

Perforated façades have long been a defining element of Islamic architecture, shaping the visual, climatic, and spiritual identity of mosques across cultures and centuries. From the historic stone *jali* screens of India to the intricate *mashrabiya* latticework of the Middle East [1, 2], these porous envelopes mediate between light and shadow, inside and outside, privacy and openness. In contemporary mosque design, perforation has re-emerged as a performance-driven architectural strategy, reinterpreted through parametric modelling and materials such as glass-reinforced concrete (GRC) and aluminium, addressing daylighting, thermal comfort, ventilation, cultural symbolism, and urban presence simultaneously.

Mosques in hot-arid climates such as the United Arab Emirates experience extreme solar heat gain and elevated cooling-energy demand. Conventional single-skin façades are largely inefficient in responding to these pressures. The double-skin façade (DSF) which introduces a ventilated cavity between an outer and inner layer offers a promising passive environmental control strategy [3-5]. Combining the thermal-buffer function of a DSF with the light-modulating, culturally resonant qualities of a perforated outer screen makes it possible to develop a façade system that addresses climate performance and architectural identity simultaneously.

The intense solar radiation, high ambient temperatures, and dust-laden winds characteristic of the Arabian Gulf impose severe thermal loads on building envelopes, driving a significant dependence on mechanical cooling [4, 5]. The DSF has emerged internationally as a high-performance envelope solution offering passive environmental control through a ventilated cavity that channels heated air away from the interior [3, 6, 7]. When the outer skin is perforated or features shading derived from Islamic geometric patterns, the DSF simultaneously addresses daylighting quality, glare control, and cultural expression [1, 2, 8].

Despite this technical potential, the majority of DSF research has been conducted in temperate European climates, predominantly for office and commercial typologies [9, 10]. A significant knowledge gap exists regarding DSF performance in hot-arid climates [4, 11], and an even more pronounced gap exists for the mosque typology, with its distinctive spatial and occupancy characteristics [12].

A DSF consists of two skins separated by an air cavity, with typological variants including the box-window, shaft-box, multi-storey, and corridor configurations [3]. DSFs are generally documented to improve thermal comfort, reduce air-conditioning loads, and support solar control [9]. However, most DSF research has been developed within temperate climatic contexts [10, 13]. In hot-arid regions such as the UAE, DSF behaviour is highly climate-dependent [4, 11], meaning that ventilation strategy, cavity depth, and shading effectiveness become considerably more critical than in cooler climates [5-7].

Mosques possess distinctive architectural characteristics that directly influence thermal and daylighting performance. Prayer halls are typically large-volume, open-plan spaces with concentrated occupancy at peak prayer times [12]. Worshippers spend extended periods within these spaces particularly at *Dhuhr* and *Asr* prayers, making glare control and thermal comfort the primary concern rather than maximised illuminance [12, 14]. Mosque daylighting performance can be significantly enhanced through parametric shading systems [1], but most mosque-specific environmental research to date has addressed daylighting in isolation without simultaneously considering energy consumption or airflow dynamics [12].

The *mashrabiya*, a traditional Islamic perforated screen performs multiple simultaneous functions: solar shading, glare control, natural ventilation, privacy, and cultural expression [1, 2, 15]. Studies consistently demonstrate that perforation percentage directly governs both daylight distribution and solar heat gain reduction [8, 16, 17]. Research on parametric perforated screens reports effective configurations within the 20–40% openness range, although the optimum varies with screen geometry, orientation, separation distance, climate, and performance objective [1, 8]. Field studies in Saudi Arabia and Bahrain report measurable effects on indoor thermal conditions and daylight/glare performance relative to unscreened conditions [2, 18].

Despite the documented thermal and cultural potential of perforated DSF strategies, the extent to which contemporary mosque architecture actually deploys genuine cavity-ventilated double-skin systems as opposed to decorative perforated screens applied as a single layer has not been systematically documented. This distinction is

critical: decorative screens reduce solar heat gain but lack the convective cavity-venting mechanism that the DSF literature identifies as the primary driver of cooling-load reduction [3, 4, 6]. Thus, could a DSF effectively limit heat gain through a mosque façade in the hot and arid climate of the UAE? The present study addresses this gap through a structured comparative classification of built contemporary mosques with DSF, and simulate their effectiveness in limiting heat gain in hot-arid climates, with specific reference to UAE conditions. Significantly, this study distinguishes the substantial difference in heat gain reduction between a full DSF to a partial DSF.

2. Methods

2.1. Case Study Selection

To answer the research question, contemporary mosques that were listed in the Mosqpedia were selected. Mosqpedia is an inventory that was compiled by the Abdullatif Al Fozan Award (AAFA) for Mosque Architecture, which is a triennial award held over six cycles since 2011. Awarded modern mosques were evaluated by esteemed international expert juries based on the quality of their designs in connection with spiritual and architectural heritage [19]. Included case studies either have comprehensive DSF or a DSF that partly covered the mosque's façade. The DSF could be decorative or purely functional and made of any material. Further, all such mosques in any climatic condition that were listed in Mosqpedia [20] were selected for this study to establish a baseline for future research. A total of 1,049 modern contemporary mosques were screened and a total of 39 were initially selected based on their façade designs. 25 mosques were eventually excluded as they did not have clearly designed DSFs which were part of arched exterior colonnades, curtain walls, perforated exterior walls, or exterior wall claddings that did not resemble a DSF. In addition to the 14 Mosqpedia-selected mosques, 10 other modern mosques were included as they meet the inclusion criteria. One of the authors has visited and documented these mosques prior to this study.

To classify the selected mosques, the authors thematized the DSF designs based on their perforated elements, and climatic or cultural roles. Photographs and drawings that were available in Mosqpedia as well as material found through listed references were carefully evaluated to determine their compliance against the classification themes. Table **1** documents twenty-four contemporary mosques employing perforated façade systems selected from diverse climatic and geographic contexts. This case-study record is the basis for the subsequent classification and comparative analysis.

2.2. Classification Framework

Each case was coded across four categories drawn directly from the documented description of its façade strategy:

- **Climate zone —** hot-arid (Gulf), hot-humid (including Gulf coastal and tropical contexts), Mediterranean/semi-arid, or temperate.
- **Material system —** the primary façade material (GRC, stone, brick, steel mesh, glass, or metal cladding).
- **Climatic and cultural role —** the documented function of the perforation (solar shading, daylight diffusion, passive ventilation, cultural/spiritual reference, or a combination).
- **Structural logic —** whether the perforated element forms a full or near-full double-skin envelope, a perforated structural envelope, a dome/roof perforation, a perforated curtain wall, or an applied screen/cladding used as a partial shading/decorative layer.

Table **2** reports the classification of selected mosques based on their climate zone, material, and structural logic.

2.3. Classification Limitations

This classification is based on documented secondary sources rather than on as-built drawings, site measurement, or simulation, and should be read as an indicative typological analysis rather than a quantified

performance comparison. No claims are made about the relative thermal or daylighting performance of individual cases beyond what is explicitly reported in the cited literature [1, 3, 4, 8].

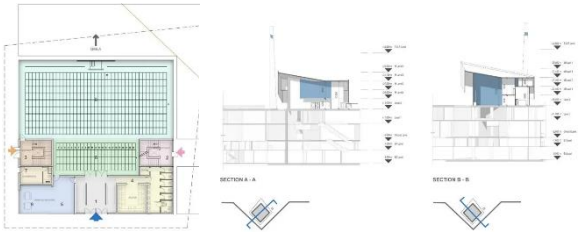
2.4. Parametric Simulation

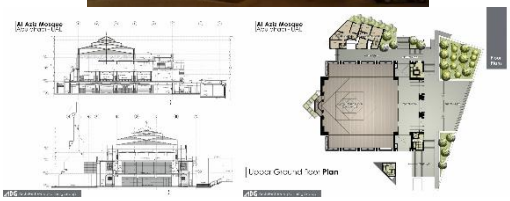
To analyze further, two cases were selected for parametric simulation to determine the DSFs effectiveness in limiting heat gain and affording sufficient daylighting Both cases were modelled using Sketchup and analyzed with Sefaira. To improve Sefaira simulation, all surfaces within both models do not have thicknesses and decorative motifs on the DSF were substituted with vertical slits to accurately model openings at 25%, 50% and 75% of the DSF total surface area. Exact locations were set using Sketchup's Geolocation and this is to allow for accurate Sefaira simulations. After completing the simplified models, each surface was tagged as either a wall, floor, roof, internal wall, shading, or ignored in preparation for Sefaira energy simulations. It is important to mention here that Sefaira's energy simulation is based on the highly recognized EnergyPlus engine and utilizes the EnergyPlus Weather (EPW) file for analyses in line with the ASHRAE 90.1: 2019 standard assumptions.

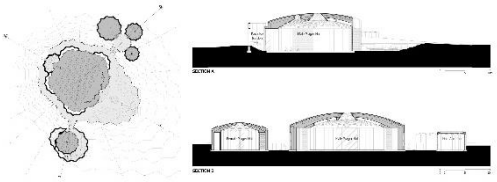
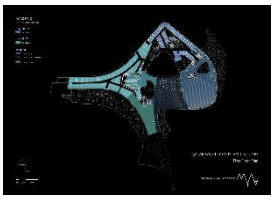
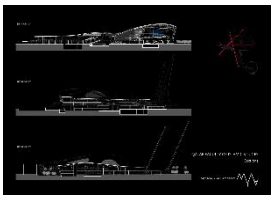
Based on the USDOE recommended Radiance engine [21], Sefaira's daylight analysis is comparable to benchmarks such as Daysim 3.0 and Radsite without prolonged simulation time [22]. Sefaira's daylight analysis could simulate the spatial daylight autonomy (sDA) and the annual sunlight exposure (ASE) to determine the daylighting effect of DSF designs. Previous studies used Sefaira to simulate not just building energy consumption, but also daylighting and thermal comfort [23, 24]. Sefaira was chosen instead of DesignBuilder or other simulation software as it has a user-friendly interface.

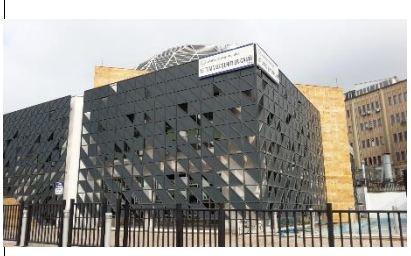
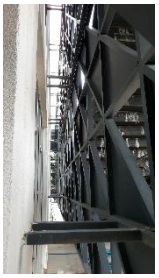
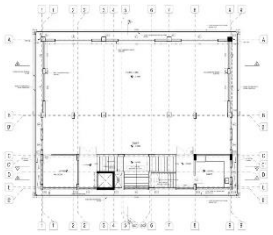
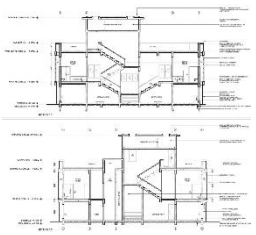
For this study, basic energy simulations were conducted to ascertain the amount and direction of heat gain through the facades besides estimating the energy use index (EUI) for five different scenarios as detailed in Table **3**. The two case studies are the DIFC and Estidama mosques as they were built in the hot and arid climate of the UAE (ASHRAE Climate Zone 1B). The DIFC has a full double skin façade while the Estidama represented cases with the smallest DSF coverage. The scenarios were set to test five DSF configurations which are no DSF, DSF with solid walls, DSF with 25%, 50%, and 75% openness ratio. The mentioned openness ratios were selected to inform future DSF designs while testing the recommended 20-40% openness ratio as reported in past studies [1, 3, 8]. Only the planes, opening designs, and resulting energy calculations based on the floor areas with Sefaira's default VAV return air package (system 5/6) air-conditioning system were tested in this explorative study. Future studies could test the effect of DSF thickness and airflow within the DSF cavity in relation to heat distribution. The results will identify potential DSF configuration for both mosques which can be implemented on other mosques.

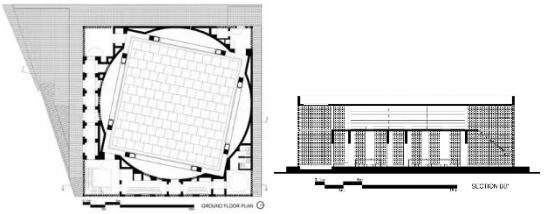
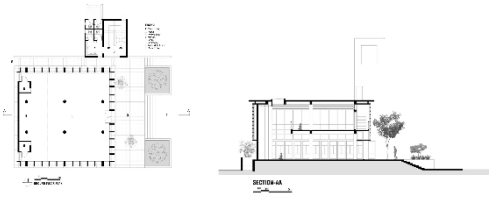
Table 1: Comparative summary of precedent perforated-façade mosques. Source: Mosqpedia [20] and authors.

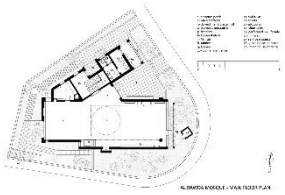
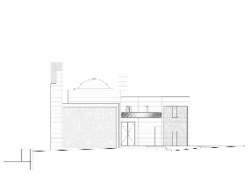
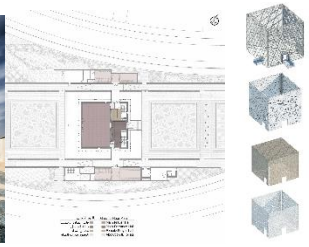
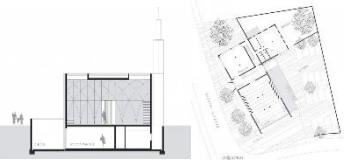
No.	Mosque / Location / Listed in Mosqpedia	Architect / Year	Perforated Element	Photographs / Drawings
1	DIFC Mosque, Dubai, UAE Yes	RMJM, 2020	Fully perforated cubic volume over glazed colonnade	 

No.	Mosque / Location / Listed in Mosqpedia	Architect / Year	Perforated Element	Photographs / Drawings
2	City Walk Mosque, Dubai, UAE Yes	Benoy, 2016	Perforated metal cladding on upper volume	
3	Al Aziz Mosque, Abu Dhabi, UAE Yes	APG Architecture & Planning Group, 2016	Perforated minaret screen + calligraphy wall panels	
4	Gargash Mosque, Dubai, UAE No	Dabbagh Architects, 2021	White stone/GRC triangular perforated panels (*mashrabiya*-derived)	
5	Al Tasamuh Mosque - Blue Water, Dubai, UAE No	Architect unknown, 2018	Mashrabiya latticework colonnade screens	
6	Sharjah Driving Institute Mosque, Sharjah, UAE No	MJU Engineering Consultancy, 2022	GRC diamond-lattice entrance panels	
7	Al Bishara Mosque, Sharjah, UAE No	Architect and opening year are unknown	GRC panels covering ~80% of building envelope	

No.	Mosque / Location / Listed in Mosqpedia	Architect / Year	Perforated Element	Photographs / Drawings
8	Abu Dhabi Islamic Bank Mosque, Abu Dhabi, UAE No	Architect unknown, 2017	Perforated GRC dome + wall panel inserts	
9	Estidama Mosque, Masdar City, Abu Dhabi, UAE No	X-Architects, 2024	Full GRC double-skin perforated envelope	 
10	Majid Al Futtaim Mosque, Tilal Al Ghaf, Dubai, UAE No	Kettle Collective (MAF is the developer/ client); 2024	Carved travertine + 630 triangular glass prisms in Qibla wall	
11	Qatar Faculty of Islamic Studies Mosque (Education City Mosque), Doha, Qatar Yes	Mangera Yvars / Qatar Foundation, 2013)\	Qur'anic calligraphy perforated glazed screen	  
12	Alacaatlı Uluyol Mosque, Ankara, Türkiye Yes	Esra Aydoğan Moza, 2016	Geometric sunlight-control panels on prayer hall façade	

No.	Mosque / Location / Listed in Mosqpedia	Architect / Year	Perforated Element	Photographs / Drawings
13	Çamlıvadi Camii, Istanbul, Türkiye No	Architect unknown, 2021	Perforated metal screen panels (partial façade)	
14	15 Temmuz Şehitler Camii, Istanbul, Türkiye No	Architect and opening year are unknown	Dark perforated curtain wall + perforated minaret	  
15	Mashrabiya Mosque, Pune, India Yes	NUDES (Nuru Karim), 2018	GRC veil wrapping entire building volume	   
16	Aman Mosque, Aman Economic Zone, Narayanganj, Bangladesh Yes	Nakshabid Architects, 2018	Triangular perforated concrete lattice wrapping full building volume	 

No.	Mosque / Location / Listed in Mosqpedia	Architect / Year	Perforated Element	Photographs / Drawings
17	Bait Ur Rouf Mosque, Dhaka, Bangladesh Yes	Marina Tabassum Architects, 2012	Randomly distributed circular brick perforations (walls and roof)	 
18	Shaer Mohammad Para Jame Mosque, Bangladesh Yes	3 Points Consultant, 2021	Continuous perforated screen spanning between structural columns	 
19	Zebun Nessa Mosque, Dhaka, Bangladesh No	Studio Morphogenesis, 2023	Brick/concrete shell with regularly spaced slot perforations	
20	Masjid Daing Abdul Rahman, Johor Bahru, Malaysia Yes	Razin Architects, 2019	Perforated cladding over glazed inner skin	 

No.	Mosque / Location / Listed in Mosqpedia	Architect / Year	Perforated Element	Photographs / Drawings
21	Al-Rawda Mosque, Amman, Jordan Yes	Uraiqat Architects, 2011	Patterned eastern glass screen + freestanding patterned wall	  
22	Mohammad Rasul-Allah Mosque, Shiraz, Iran Yes	Paya Payrang Architectural Group, 2016	Perforated curtain wall with Islamic geometric pattern	 
23	KAPSARC Mosque, Riyadh, Saudi Arabia Yes	HOK," 2014	Glass outer layer separated by ~0.9m cavity from inner stone-clad perforated concrete screen	 
24	Penzberger Mosque, Bavaria, Germany Yes	Alen Jasarevic (Jasarevic Architekten), 2005	Perforated stone/metal minaret and entry panels	 

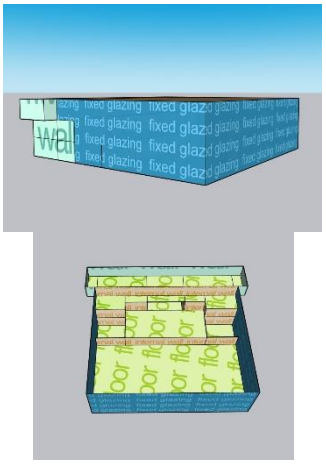
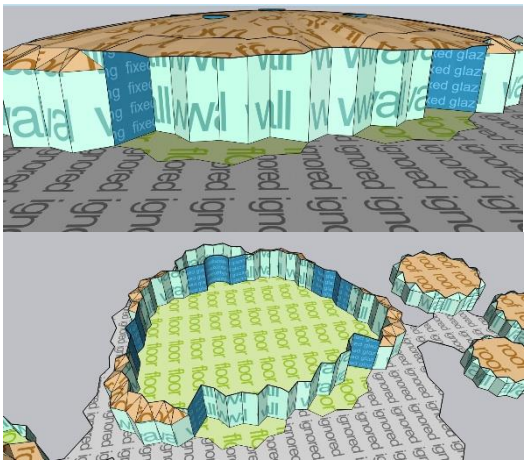
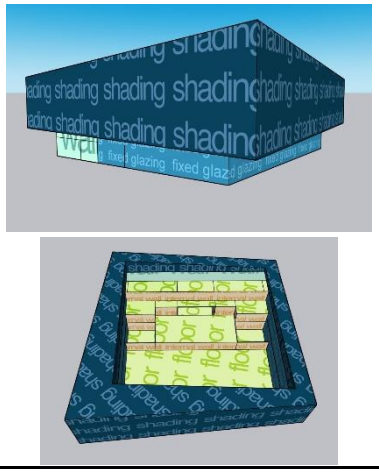
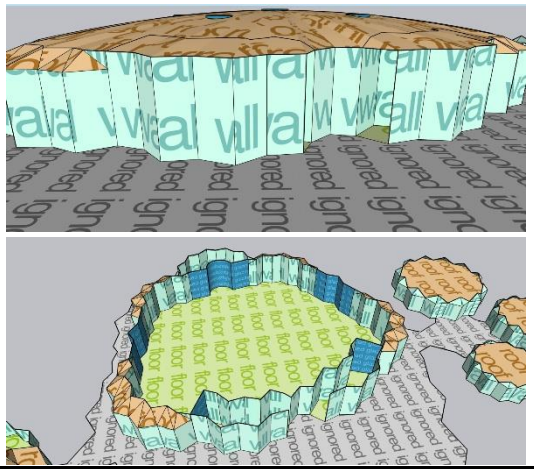
Using the same five scenarios, daylighting was simulated to determine the sDA and ASE for the main prayer hall. sDA and ASE are important at determining the viability of a DSF designs especially during afternoon and early evening congregational prayers. Based on images and drawings sourced from Mosqpedia, both DIFC and Estidama mosques were modelled in Sketchup as shown in Figs. (**1** and **2**). As mentioned, the designs were simplified with no surface thicknesses to facilitate Sefaira simulations.

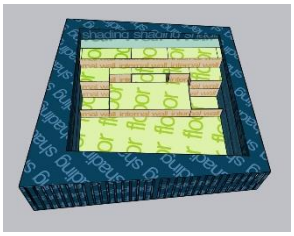
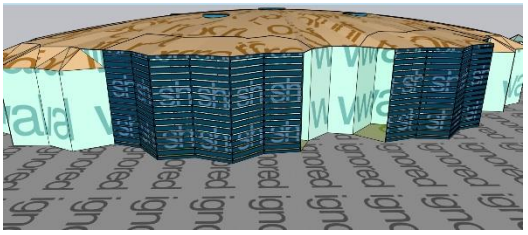
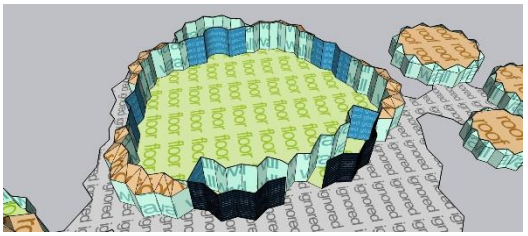
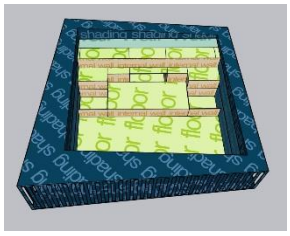
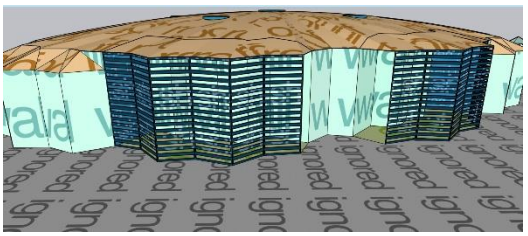
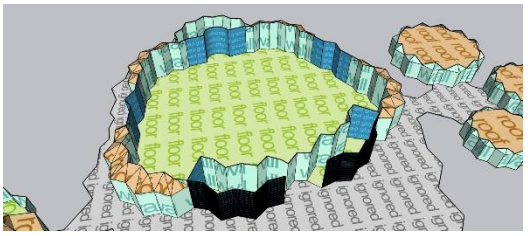
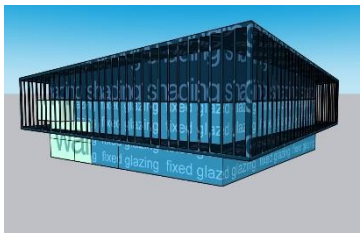
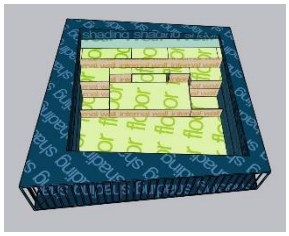
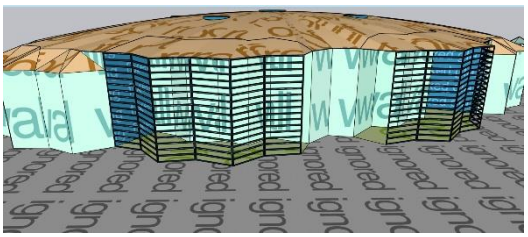
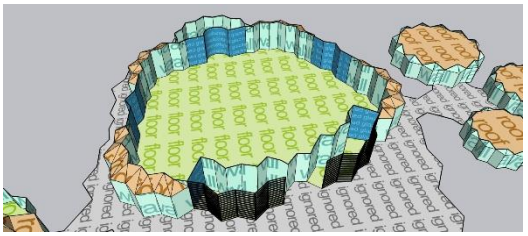
Table 2: Classification of selected mosques.

No.	Mosque / Location	Climate Zone	Primary Material	Climatic/Cultural Role	Structural Logic
1	DIFC Mosque, Dubai, UAE	Hot-arid (Gulf)	GRC	Omnidirectional solar control and filtered daylighting	Full / near-full double-skin
2	City Walk Mosque, Dubai, UAE	Hot-arid (Gulf)	Metal cladding	Dual visual/ environmental device; illuminated as lantern at night	Applied screen/cladding (partial)
3	Al Aziz Mosque, Abu Dhabi, UAE	Hot-arid (Gulf)	GRC / calligraphy	Contemporary Abu Dhabi perforated/ calligraphic treatment	Applied screen/cladding (partial)
4	Gargash Mosque, Dubai, UAE	Hot-arid (Gulf)	GRC / stone	Diffuses glare into soft scattered light; GRC as performative and aesthetic material	Applied screen/cladding (partial)
5	Al Tasamuh Mosque - Blue Water, Dubai, UAE	Hot-arid (Gulf)	GRC latticework	Shade, privacy, cultural identity at waterfront public realm	Applied screen/cladding (partial)
6	Sharjah Driving Institute Mosque, UAE	Hot-arid (Gulf)	GRC panels	Solar shading and identity marker within institutional context	Applied screen/cladding (partial)
7	Al Bishara Mosque, Sharjah, UAE	Hot-arid (Gulf)	GRC panels	GRC as dominant envelope material at urban scale	Full / near-full double-skin
8	Abu Dhabi Islamic Bank Mosque, UAE	Hot-arid (Gulf)	GRC dome	Controlled top-lighting; reinforces dome as iconic form	Dome/roof perforation
9	Estidama Mosque, Masdar City, UAE	Hot-arid (Gulf)	GRC	Convective cavity removes heat; LEED Platinum; most directly analogous to DSF under study	Full / near-full double-skin
10	Majid Al Futtaim Mosque, Dubai, UAE	Hot-arid (Gulf)	Travertine / glass prisms	Glass prisms refract controlled daylight; net-positive energy building	Material-integrated (non-screen)
11	Education City Mosque, Doha, Qatar	Hot-arid (Gulf)	Glass / calligraphy screen	Awarded in the AAFA Second Cycle Calligraphy as literal shading geometry; blocks high-angle sun, casts patterned shadow	Applied screen over glazing (partial)
12	Alacaatlı Uluyol Mosque, Ankara, Türkiye	Mediterranean/ semi-arid	Cast concrete geometric panels	Controls interior daylight and glare via geometric motif panels; distinctive minaret identity	Applied screen/cladding (partial)
13	Çamlıvadi Camii, Istanbul, Türkiye	Temperate	Perforated metal panels (material unconfirmed)	Ornamental geometric screening; partial shading and visual identity in an urban context	Applied screen/cladding (partial)
14	15 Temmuz Şehitler Camii, Istanbul, Türkiye	Mediterranean/ semi-arid	Metal curtain wall	Departs from conventional palette while retaining solar/daylight control	Perforated curtain wall
15	Mashrabiya Mosque, Pune, India	Hot semi-arid	GRC veil	Varied opening sizes modulate light/ shadow; affords privacy and ventilation	Full / near-full double-skin
16	Aman Mosque, Aman Economic Zone, Narayanganj, Bangladesh	Hot-humid	Perforated concrete (triangular lattice)	Diffuses tropical daylight and enables cross-ventilation across a column-free hall	Perforated structural envelope
17	Bait Ur Rouf Mosque, Dhaka, Bangladesh	Hot-humid	Brick	Directional skylight shafts; brick thermal mass moderates temperature	Perforated structural envelope
18	Shaer Mohammad Para Jame Mosque, Bangladesh	Hot-humid	Perforated screen panels	Vernacular screen tradition; effective shading for the prayer hall below	Applied screen/cladding (partial)

No.	Mosque / Location	Climate Zone	Primary Material	Climatic/Cultural Role	Structural Logic
19	Zebun Nessa Mosque, Dhaka, Bangladesh	Hot-humid	Brick / concrete	Filtered daylight and passive ventilation in hot-humid climate	Perforated structural envelope
20	Masjid Daing Abdul Rahman, Malaysia	Hot-humid (tropical)	Perforated cladding panels	Filters tropical sun; stack ventilation cools cavity; climatic transferability	Applied screen/cladding (partial)
21	Al-Rawda Mosque, Amman, Jordan	Mediterranean/ semi-arid	Metal screen	Shades glazed east façade; dynamic shadow choreography through the day	Applied screen/cladding (partial)
22	Mohammad Rasul-Allah Mosque, Shiraz, Iran	Hot semi-arid	Perforated curtain wall	Representationally driven, yet yields measurable glare and heat-gain reduction	Perforated curtain wall
23	KAPSARC Mosque, Riyadh, Saudi Arabia	Hot-arid (Gulf)	Glass (outer) + stone-clad concrete (inner)	Genuine ventilated double-skin cavity; *mashrabiya*-inspired pattern filters daylight, modulates day/night appearance	Full / near-full double-skin
24	Penzberger Mosque, Bavaria, Germany	Temperate	Stone / metal	Diaspora-context cultural beacon; minaret glows at night	Applied screen/cladding (partial)

Table 3: Sefaira simulation scenarios.

Scenario	Configuration	Sefaira Models	
		DIFC	Estidama
1	Baseline (no DSF)		
2	DSF with solid walls		

Scenario	Configuration	Sefaira Models	
		DIFC	Estidama
3	25% openness ratio	 	 
4	50% openness ratio	 	 
5	75% openness ratio	 	 

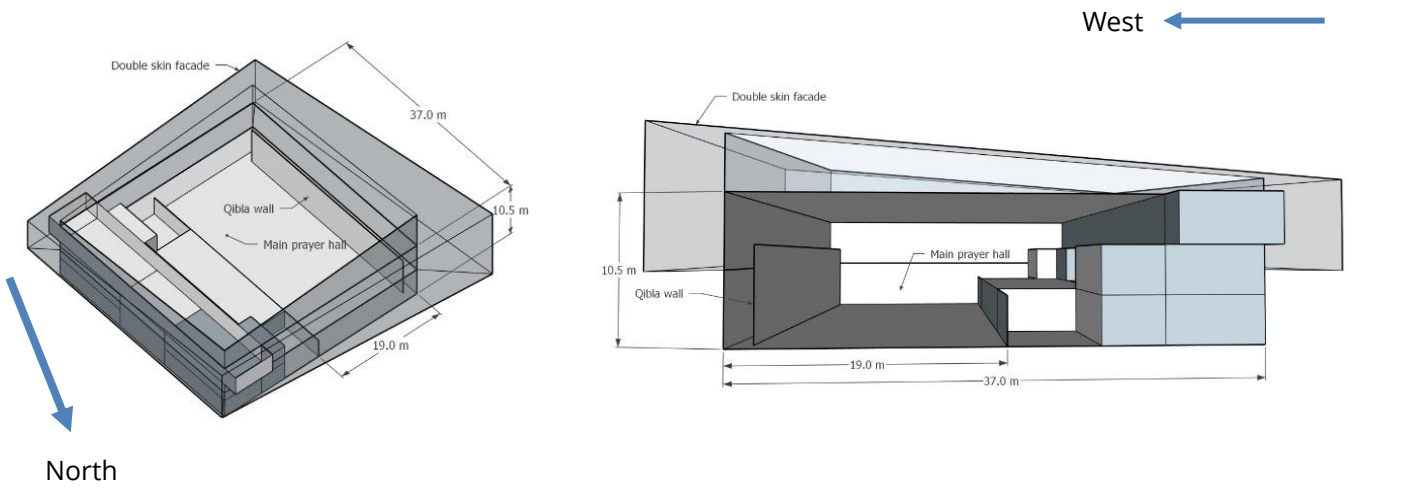


Figure 1: DIFC mosque design.

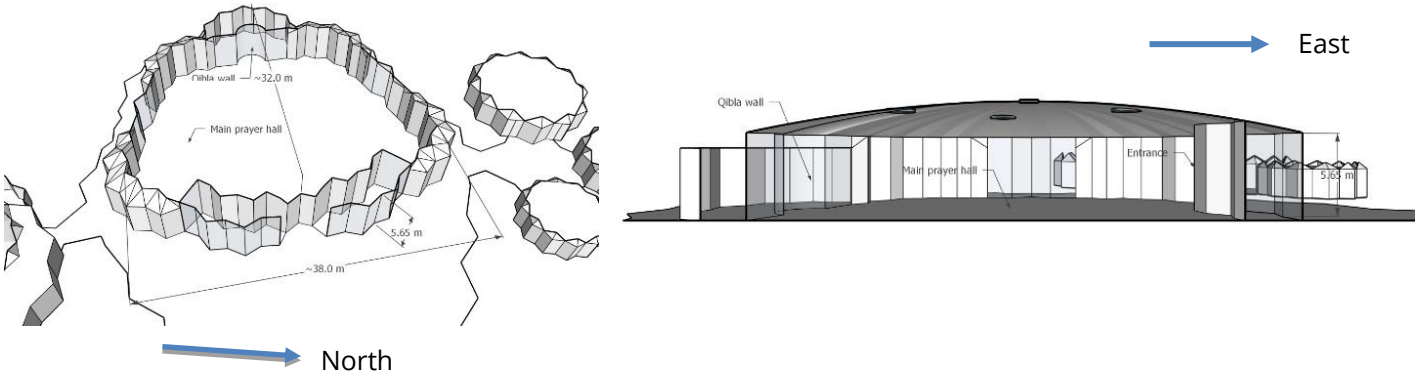


Figure 2: Estidama mosque design.

3. Results

3.1. Structural Logic Across the Sample

Table **4** and Fig. (**3**) summarize the structural logic classification across the 24 cases. Genuine full or near-full double-skin configurations in which the perforated outer layer forms a continuous ventilated cavity across most of the building envelope are present in only four cases (16.7%): the Mashrabiya mosque (Pune), DIFC mosque (Dubai), Al Bishara mosque (Sharjah), and KAPSARC mosque (Riyadh). The majority of cases (13 of 24, 54.1%) apply perforation as an applied screen or cladding layer without a continuous ventilated cavity; in these cases, the perforated layer functions primarily as a shading and cultural-identity device rather than as a thermally active double-skin system [3, 4, 6].

3.2. Climate Zone Distribution

Table **5** summarises the climate-zone distribution. Fourteen of the 24 cases (58.3%) fall within hot-arid or hot semi-arid contexts, including twelve Gulf cases, reflecting the strong regional precedent for perforated mosque façades as identified earlier. Notably, three of the four full-double-skin cases (DIFC, Al Bishara, KAPSARC) are in this hot-arid Gulf zone, while the fourth (Mashrabiya mosque) is in a hot semi-arid context; no full double-skin case was identified in the hot-humid or temperate (Europe) sub-samples.

Table 4: Structural logic categories: frequency and representative cases.

Structural Logic Category	n	% of Sample	Representative Cases
Full / near-full double-skin	5	20.8%	Estidama (Masdar), Mashrabiya mosque (Pune), DIFC mosque, Al Bishara mosque, KAPSARC mosque (Riyadh)
Perforated structural envelope	3	12.5%	Zebun Nessa mosque, Bait Ur Rouf mosque, Aman mosque
Dome/roof perforation	1	4.2%	Abu Dhabi Islamic Bank mosque
Perforated curtain wall	2	8.3%	Mohammad Rasul-Allah mosque, 15 Temmuz Şehitler Camii
Material-integrated (non-screen)	1	4.2%	Majid Al Futtaim mosque
Applied screen/cladding (partial)	12	50.0%	Remaining 12 cases

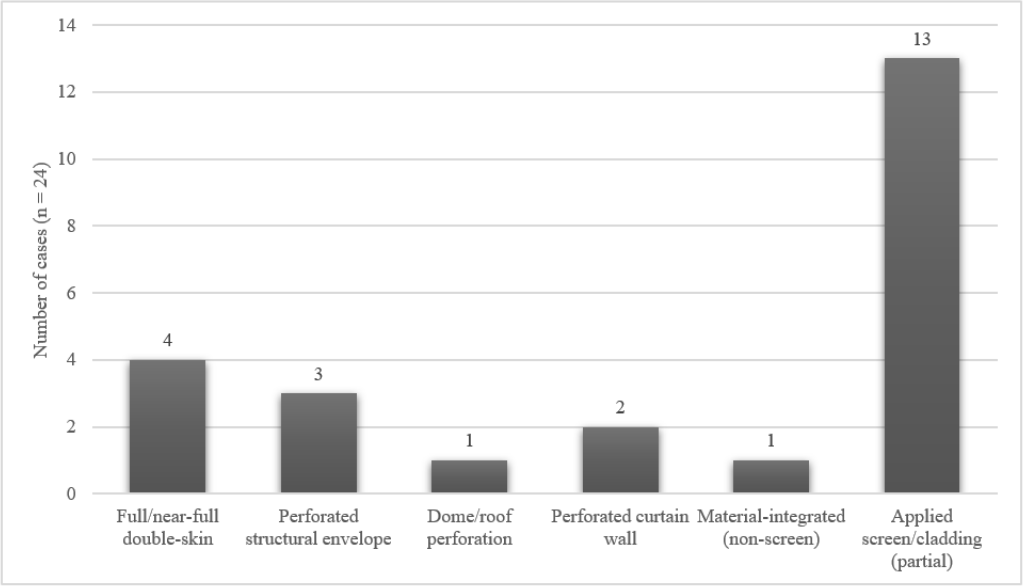


Figure 3: Structural logic of perforated façade strategies across 24 precedent mosques.

Table 5: Climate zone distribution of the 24 precedent cases.

Climate Zone	n	% of Sample
Hot-arid / hot semi-arid	14	58.3%
Hot-humid (incl. Gulf coastal / tropical)	5	20.8%
Mediterranean / semi-arid	3	12.5%
Temperate (Europe)	2	8.3%

3.3. Material and Climatic Role Patterns

Glass-reinforced concrete (GRC) is the most frequently documented primary material among the Gulf hot-arid cases, consistent with its established role in regional fabrication practice [25] and its appearance in three of the four full-double-skin cases (Mashrabiya, DIFC, and Al Bishara mosques); the remaining full-double-skin case (KAPSARC mosque) instead uses a glass outer layer over a stone-clad concrete inner layer. Brick and concrete perforated-structural-envelope strategies (Zebun Nessa, Bait Ur Rouf, and Aman mosques) are concentrated in the hot-humid South and Southeast Asian sub-sample, where thermal mass and passive ventilation are reported as the primary climatic functions [12, 26]. Calligraphic and glass-integrated strategies (Education City, and Majid Al

Futtaim mosques) recur as a distinct sub-category in which cultural and representational intent is an important design driver alongside environmental functions [15].

3.4. Heat Gain Reduction and Building Energy Consumption

The energy analysis revealed interesting findings concerning heat gain through the façade with DSF. It is important to note that the DSF at DIFC mosque surrounds the top two floors of the mosque and installed at between 3.5 to 7.0 m from the fully glazed façade. On the contrary, the DSF at Estidama mosque only covers the entrance area into the mosque facing East. Although the original materials are different, the energy simulation analyzed the design and showed that the EUI for the DIFC mosque reduced marginally by 1.2% of the baseline scenario. Nevertheless, the amount of heat gain reduction through the Western façade (*qibla* wall) was reduced by 11.4% of the baseline due to the presence of DSF in scenario 3, and 11.2% for scenarios 4 and 5. However, although the solid wall DSF (scenario 2) performed less than scenarios 3-5 in heat gain through the Western façade, the HVAC cooling energy needed is better at 3.1% lower than the baseline compared to 2.1% for other scenarios. Wall conduction for the whole building for a solid wall DSF (scenario 2) was the lowest at 18.0% below the baseline level as shown in Table **6** compared to only 10% for scenarios 3 through 5. This shows that double walls could significantly reduce a building's cooling load, but indoor daylighting could be severely affected instead.

Unlike results for the DIFC mosque, energy simulation for the Estidama mosque as shown in Table **7** however, revealed a less convincing result as the DSF which covered the entrance area did not have any impact on heat gain through the Eastern façade and the EUI. The recorded EUI is constant at 163 kWh/m2/year, the East solar gain at 385 kWh/year, the wall conduction remained at 60,621 for all scenarios, and the HVAC cooling energy is also constant at 389,560 kWh/year. This could be due to the limited coverage and size of Estidama's DSF compared to DIFC, plus its position facing to the East rather than to the West. Nevertheless, the energy simulations using Sefaira concluded that larger DSF could effectively reduce heat gain in the hot and arid climate.

Table 6: Energy simulation results for DIFC mosque, Dubai.

Scenario	Configuration	EUI (kWh/m2/year)	West Solar Gain (kWh/year)	Wall Conduction kWh/year	HVAC Cooling (kWh/year)
1	Baseline (no DSF)	167	14,890	49,087	417,532
2	DSF with solid walls	165	13,237	40,261	404,589
3	25% openness ratio	165	13,194	44,156	408,603
4	50% openness ratio	165	13,225	44,156	408,628
5	75% openness ratio	165	13,225	44,156	408,628

* The equipment & people gain for all DIFC scenarios is 176,502 kWh/year.

Table 7: Energy simulation results for Estidama mosque, Masdar City

Scenario	Configuration	EUI (kWh/m2/year)	East Solar Gain
1	Baseline (no DSF)	163	385
2	DSF with solid walls	163	385
3	25% openness ratio	163	385
4	50% openness ratio	163	385
5	75% openness ratio	163	385

* The equipment & people gain for all Estidama scenarios is 150,498 kWh/year, wall conduction is 60,621 kWh/year, and the total HVAC cooling energy needed is 389,560 kWh/year.

Fig. (**4**) shows Sefaira screenshots for both mosques containing gains and losses diagrams with highlighted heat gain through the Western façade (DIFC mosque) and Eastern façade (Estidama mosque).

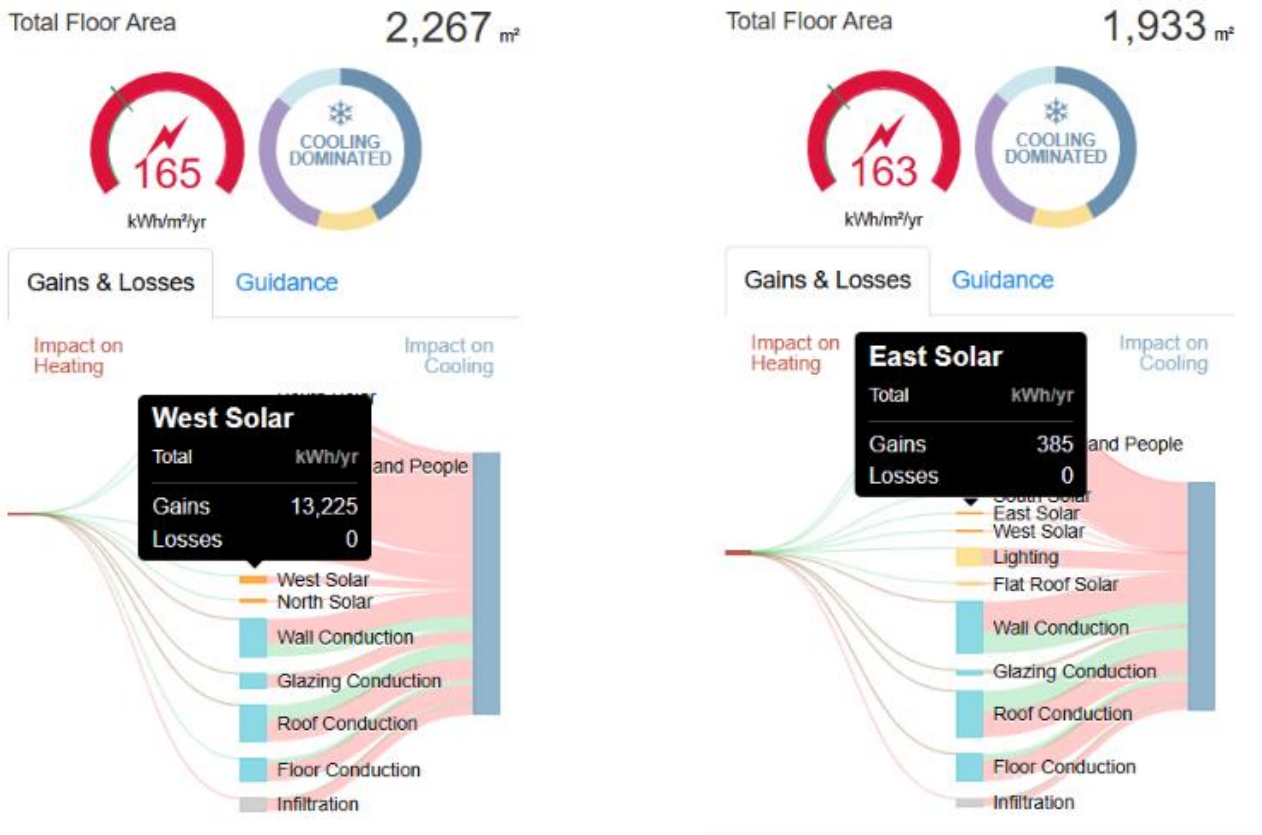


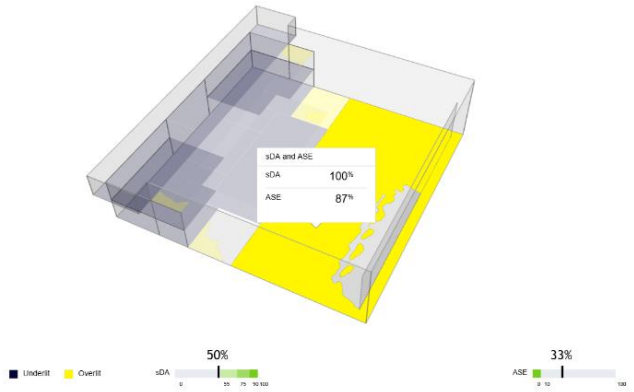
Figure 4: Sefaira energy simulation results screenshots for scenario 5 (75% openness ratio) for both DIFC and Estidama mosques.

3.5. Daylight Analysis

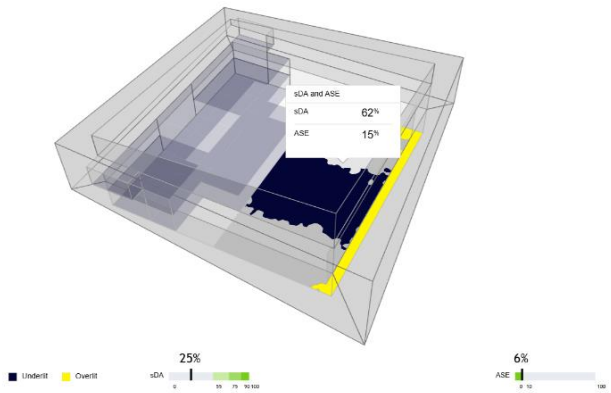
To investigate further the benefits of a DSF, a daylighting analysis was done using Sefaira for the DIFC mosque as its DSF covered three sides of the glazed main prayer hall. It is found that the spatial daylight autonomy (sDA) was 100% (all scenarios except for scenario 2 – DSF with solid walls) for main the prayer hall. sDA is the percentage of regularly occupied floor area that is daylit at 300 lx for 50% of occupied hours according to LEED v4 [27]. Further, as shown in Table **8**, the main prayer hall in in all scenarios except for scenario 2 (DSF with solid walls) was overlit with 39% to 87% ASE of floor area that received more than 1,000 lx for more than 250 occupied hours annually. This is substantially higher than the 10% ASE recommended by LEED v4 [27]. The simulation results suggested that the DSF with 25% openness ratio could be a viable future design option considering shading from adjacent buildings and structures. Fig. (**5**) shows the sDA and ASE results from Sefaira daylight analysis for the main prayer hall at the DIFC mosque, Dubai.

Table 8: Spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) for DIFC mosque, Dubai.

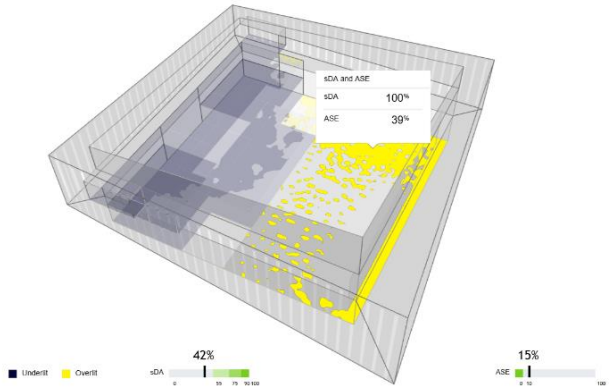
Scenario	Configuration	Spatial Daylight Autonomy (sDA)	Annual Sunlight Exposure (ASE)
1	Baseline (no DSF)	100%	87%
2	DSF with solid walls	62%	15%
3	25% openness ratio	100%	39%
4	50% openness ratio	100%	60%
5	75% openness ratio	100%	74%



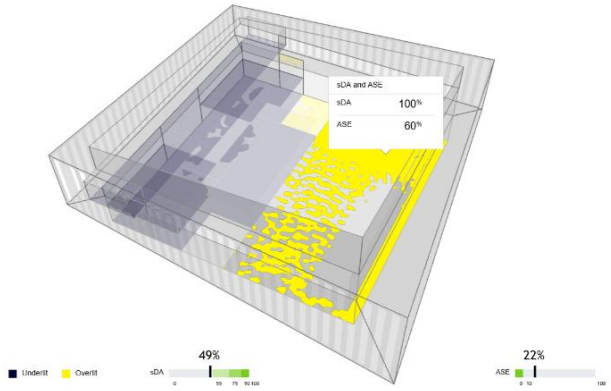
(**a**). Scenario 1 (Baseline with no DSF)



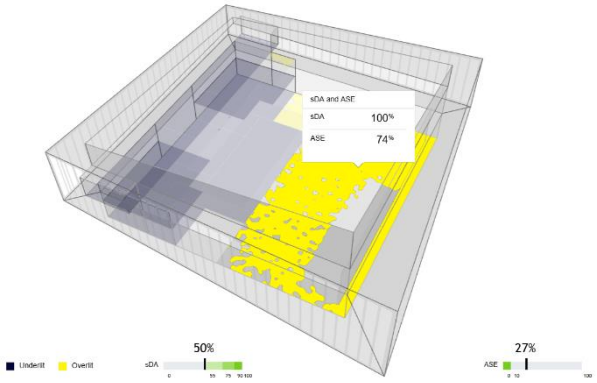
(**b**). Scenario 2 (DSF with solid walls)



(**c**) Scenario 3 (DSF with 25% openness ratio)



(**d**) Scenario 4 (DSF with 50% openness ratio)



(**e**) Scenario 5 (DSF with 75% openness ratio)

Figure 5: Daylight simulation result for the DIFC mosque, Dubai showing the sDA and ASE readings.

4. Discussion

The central finding of this comparative analysis is that genuine cavity-ventilated double-skin façades remain a minority strategy in built mosque architecture (20.8% of the sample), even within the hot-arid Gulf context where the climatic rationale for such systems is strongest. The majority of documented 'perforated façade mosques' apply perforation as a screen or cladding layer, providing shading and cultural expression but not the convective cavity venting that the DSF literature identifies as the primary mechanism for cooling-load reduction [3, 4, 6, 11]. This suggests that built precedent for mosque façades has, to date, more fully explored the cultural and shading functions of perforation than its thermally active double-skin potential.

Based on the mosque DSF classification, three precedent-based priorities follow from this finding for hot-arid mosque design, including the UAE context:

- GRC as a starting material was present in four of the five identified full-double-skin cases, GRC provides a defensible choice for a genuine cavity-ventilated DSF in the UAE, supported by established regional fabrication capacity [25].
- Estidama and DIFC mosques as benchmark precedents — both hot-arid, full-envelope precedents— are the most directly comparable built reference points, with the KAPSARC mosque (Riyadh) offering a further hot-arid Gulf precedent using a genuinely cavity-separated glass-and-stone envelope; all three warrant closer technical study ahead of new simulation work.
- 20–40% openness ratio and intermediate-to-deep cavities — these literature-informed ranges [1, 3, 8] are defensible starting parameters for simulations in this study, since the optimum configuration depends on climate, geometry, orientation, and ventilation strategy. However, for this study the simulations went further with 25%, 50% and 75% openness ratios. Further, the precedent record itself does not report quantified performance data at this level of detail for individual cases.

Further, Sefaira energy simulations revealed that the amount of heat gain reduction was marginal for both DIFC and Estidama mosques which resulted in small EUI changes, thus marginal improvements to the building energy consumption and operational carbon emissions. Additionally, there were no improvements between DSF with 25 to 75% openness ratio in terms of heat gain reduction through selected façades. The reported reduction of 11.4% in heat gain through the Western façade at the DIFC is encouraging but the HVAC cooling energy needed only decreased by 3.1% due the constant floor sizes and calculated “equipment and people” gains of 176,502 kWh/year, which remained constantly large for all scenarios. This substantial amount was 41.3% of scenario 1 HVAC cooling energy, 43.6% of scenario 2, and 43.2% of scenarios 3 through 5. However, daylighting simulation results suggested that a DSF with 25% openness ratio could be a viable design option considering the sufficient sDA at 100% and overlit main prayer hall at 39% ASE, higher than LEED v4 recommendations. To address possible glare discomfort, the DIFC have an existing free-standing wall inside the main prayer hall behind the *qibla* wall. Nonetheless, based on the Sefaira simulation results pertaining to heat gain and daylighting observations, a full DSF with 25% openness ratio is the optimum design option for future DSF designs for mosques in the hot and arid climate, particularly in the UAE.

5. Conclusions

This study has presented a structured comparative analysis of perforated double-skin façade strategies across twenty-four contemporary mosques, classified by structural logic, climate zone, material, and climatic/cultural role. The analysis demonstrates that genuinely cavity-ventilated, thermally active double-skin configurations remain rare (five of twenty-four cases, 20.8%) relative to decorative or partial-screen applications (50.0%). GRC dominates the small set of full-double-skin precedents in the Gulf hot-arid context.

This is, to the authors' knowledge, the first systematic classification of perforated mosque façades by structural logic across multiple climate zones. It reframes the research gap in the DSF literature: the priority is not only to simulate DSF performance for a hot-arid mosque in the abstract, but specifically to validate the small number of full-double-skin strategies that already have built precedent against the much larger population of decorative perforated-screen alternatives that current practice favours.

Energy simulations using Sefaira were conducted to determine heat gain through two selected mosques facades with DSF. At best, a Western façade (*qibla* wall due West in the UAE) DSF with a 25% openness ratio could significantly reduced heat gain by 11.4% of the baseline (without DSF). Daylighting simulations supported this with a 100% sDA but the high ASE of 39% could lead towards glare discomfort. Nevertheless, more investigations are needed to fully estimate the viability of DSF in improving indoor thermal comfort, daylighting, and air flow of mosques in the hot and arid climate.

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Author Contributions

JA: Conceptualization, Investigation, Resources, Supervision, Writing – review and editing. AHC: Methodology, Project administration, Writing – original draft, Writing – review and editing, Validation. MAI: Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – review and editing. RKA: Writing – review and editing, Validation. SS: Writing – original draft, Investigation, Formal analysis, Data curation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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