

Veiled Facades: Impacts of Patterned-Mass Shades on Building Energy Savings, Daylighting Autonomy, and Glare Management in Three Different Climate Zones

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Abstract

Patterned massive screen shading systems are traditionally applied to vernacular buildings' facades in hot climates to provide protection from direct solar radiation and regulate social interaction. These screens are traditionally constructed from stone or massive materials and have geometric motifs and patterns with deeper profiles than lattice or solar-screens. While the impacts of light-weight solar-screens systems on building energy use and daylighting distribution have been previously investigated, there is a current gap in knowledge related to the impacts of other screen types on building energy use, thermal comfort, visual comfort, glare management, and dynamic daylighting metrics from a holistic approach of energy performance and occupants' multi-comfort perspective.

By employing a combination of field measurements and dynamic yearly computer simulations using IES-VE software, this study compares the performance of patterned massive-screens, such as Jali systems with three different traditional geometries and for three different hot climate zones; hot-humid, hot-arid, and hot-moderate. Results show that perforation geometries and patterns differ in their performance from one hot climate zone to the other. While a 30% perforation ratio achieved a better thermal comfort in hot-arid climate, it was under performing in hot-humid climate and have lower impacts in hot-moderate climate. The paper highlights different performance results to aid future designs of screen pattern and perforation for future buildings based on an evidence-based metrics. In addition, it sheds light on the importance of learning from vernacular precedents without over generalizing and romanticizing their performance.

Solar screens environmental performance

Solar screen systems have been used in commercial buildings to help with reducing glare and controlling solar heat gain through fenestration areas. When properly designed, these systems not only can improve visual and thermal comfort, but also can greatly reduce electric lighting, cooling, and heating energy consumption (Lee, DiBartolomeo, and Selkowitz 1998). Previous studies (De Carli & De Giuli 2009; Atzeri, Cappelletti & Gasparella 2014) showed that the amount of energy reductions attained varies depending on shading geometry, and climatic variations. In hot climates, external perforated screen shadings affect the building energy use for lighting, heating and cooling, as well as the occupants' visual and thermal comfort (Batool and Elzeyadi 2014, Bellia et al. 2014). Although these types of screens have been traditionally used in vernacular architecture

precedents throughout the Middle East, few existing studies compared their performance based on different screen geometries, orientations, and climatic contexts. This study investigates the impact of external patterned massive-screens, such as Jali and Guss walls, predominantly used in the Middle East and South Asia, on building energy performance, lighting energy loads, as well as thermal and visual comfort, in three hot climate zones. The variables studied include screen geometries, perforation percentages, orientations, and hot-climatic zone differences.

Buildings in hot climates face a growing challenge of high cooling loads. This is because most often commercial buildings in hot and hot-humid climates such as Lahore, Doha, and Los Angeles are often reliant on air conditioning and mechanical ventilation systems to sustain and improve indoor thermal comfort (Kwong et al. 2014). External solar screens are becoming popular shading devices in contemporary buildings, in order to improve cooling loads by reducing incident solar radiation (Batool 2014). Traditionally marked by the hot climate regions, solar screens were designed according to the performance requirements and the availability of regional craft in hot climates. Contemporary buildings in such climates most often take inspiration from the visual aspects of traditional screen designs, such as Jali and Mashrabiya, without paying attention to their performative metrics across different hot climates. This problem is further amplified due to the lack of quantitative analysis of these massive screen systems based on geometry, perforation percentages, and suitability to different hot-climate zones, which still needs exploration.

Veiled Facades vs. Solar Screens

Lightweight solar screen such as *Mashrabiya* and perforated-screens have been implemented centuries ago in Arab Architecture as well as other hot-climate contexts (Harris 2006). Previous studies conclude that lightweight screens (Figure 1) with 70-85% perforation ratios and 1:1 depth profile are effective in reducing solar heat gains, achieving thermal comfort, and improving energy performance in residential buildings in hot-moderate climates (Sherif et. al 2010; Alzoubi & Al-Zoubi 2010). The energy and thermal impacts of the equally important yet overlooked massive screens with visual motif patterns, however, was not comprehensively evaluated. These stone screens with pattern perforations are traditionally named as Jali, Guss, or vernacularly referred to as "Veiled Facades" (Figure 2) since their perforation geometry and decorative patterns conceals the aperture shape of windows behind them providing both solar and privacy protection and control (Kenzari & Elshehtawy

2003). Moreover, the impact of both types of screens on energy and indoor environmental quality performance of non-residential building types have not been widely compared across different hot-climate zones.



Figure 1: Light Solar Screens (such as Mashrabiya) in (a) traditional setting and (b) contemporary application

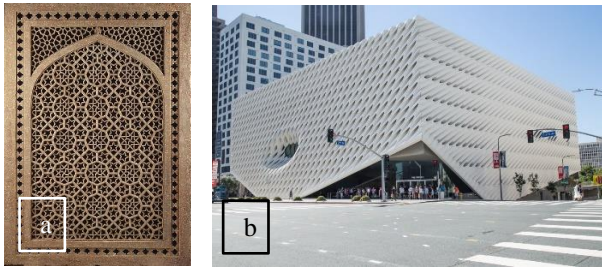


Figure 2: Massive Screens – Veiled Facades (such as Jali) in (a) traditional and (b) contemporary applications

Sherif, et al. (2012) studied the impacts of different perforations of lightweight solar screens on energy consumption and daylight distribution in residential building types in a hot-moderate climate zone. Their studies concluded that an optimum range of depths and perforation percentages of these solar screens are 80–90% perforation rate and 1:1 depth opening to depth ratio. In a related study, changing the perforation percentage of external perforated solar screen on the thermal performance of desert buildings was examined through Energy Plus software. The results showed that the thermal loads dropped by 30% and lighting distributions improved when screens with high perforation ratios of 85% were employed in a residential building lounge area (Sherif et al. 2010).

Other studies found that a lighter screening approach by using external cables and dense foliage reduced cooling loads in residential buildings while maintaining privacy at the same time (Raymond and Hattice 2008). Research using computer simulations shows that shading devices on south façades with horizontal, vertical and 45° tilted horizontal louvers can decrease lighting energy consumption (Alzoubi & Al-Zoubi. 2010). External fixed horizontal light louver devices of different slat lengths and tilts were examined using TRNSYS simulation (Datta 2001). It was found that optimizing the louver design decreased the cooling loads in summer achieving significant savings in the annual primary energy loads.

In an earlier field study, McCluney et al. (1984) compared the effects of external shades on heat gain reduction for several window treatments such as window tinting,

reflective window films, screens, awnings, and overhangs in Florida, USA. They found that changing the orientation slightly affected the potential shading with screens outperforming a number of other approaches. This could be attributed to the high average diffuse radiation component. Another field study examined the perceived environmental quality and indoor comfort in two houses in Cairo, the first is a neo-vernacular house designed by the late architect Hassan Fathy with solar screens and the second is a contemporary villa in Cairo with deep overhangs for south facing windows (Elzeyadi 1996). Recessed windows covered with wooden lattice screens in Hassan Fathy's Mit Rehan achieved a similar or better thermal performance as windows shaded with overhangs and double the insulation glazing value (R-value) in the Cairo contemporary villa.

There is evidence that external fixed deep perforated solar screens could effectively achieve energy savings up to 30% of the total energy consumption in South orientations (Elzeyadi et. al, 2016). Moreover, a comprehensive literature review of shading studies using simulation modelling to predict energy performance in buildings conducted by Kirimtat et. al (2016) reveals a gap in studies comparing similar shading strategies across climate zones and commercial building shade strategies.

Objectives

There is an urgent need to develop the science and engineering knowledge that will enable designers, architects, and developers accurately predict energy performance and emissions reductions for shade technologies (Lutzkendorf & Lorenz 2005). The strong links between energy and water use in hot arid and hot humid climates may become common in other parts of the world with scarce water, notably Southern California, South Asia and the Middle East (Meier et al. 2013). Meek and Breshears (2010) assessed energy performance of blind systems in California, based on their location; e.g. exterior, interior, or a combination; and found that exterior shading provides the highest daylight and view quality with lowest possible energy consumption. In a similar study Atzeri, Cappelletti, and Gasparella (2014) concluded that using external shading, cooling loads are reduced and heating loads are slightly increased., By adjusting the shade geometry, however, energy performance and cooling load reductions can be greatly improved (Ye et al. 2016).

Currently, most hot and hot dry locations are facing significant building booms and interest in sustainable energy efficient buildings (Elzeyadi, 2013). A growing interest by architects and engineers in these regions are focused on revisiting vernacular strategies, such as external veiled facades and solar screens, and adopting them to contemporary buildings. The lack of comparative energy performance studies to provide evidence based design guidelines for the proper use and design of these traditional solar screens could result in their unsuccessful adoption to contemporary commercial buildings. This paper quantitatively investigates the influence of veiled façades--defined as massive screen shading systems with

notable geometries of perforations--on decreasing the cooling, heating and lighting energy loads in the building environment of the hot-moderate, hot-arid and hot-humid climates, such as Lahore Pakistan, Doha, Qatar and Los Angeles, United States. The goal is to get a better understanding of the performance of solar traditional screens geometries in order to help with reaching contemporary, efficient, and sustainable buildings that abstract historical precedents in a performative manner.

Study Context and Methods

The study adopted a mixed methods approach combining two phases. In phase 1, a field measurement survey assessed the performance of traditional Jali screens (a type of veiled facades) in Lahore, Pakistan. The aim is to document the visual and thermal performance of different traditional screen types as well as their perforation ratios and depth (Batool, 2014). In addition, a typical mid-rise commercial building was selected and assessed in terms of properties, thermal, and visual comfort as well as archival energy consumption bills. This information was used to build and calibrate a simulation model for phase 2 of the study. In phase 2, a 3x4 experimental design using a dynamic simulation environment (IES-VE) tested the performance of three common Jali screens designs and a control case with no screens in three hot climate zones; a hot-moderate, hot-humid, and hot-arid climates. The summary of both phases are described below.

Field Measurements 1 – Jali Screens

To survey the different traditional geometries, perforation, and depth of massive screens associated with veiled facades, a field study in Lahore, Pakistan was conducted (Batool & Elzeyadi, 2014). Lahore Fort was chosen as it has the largest collection of Jali screens from the Mughal times. It is also a publicly accessible place, which allowed for the selection of pavilions and orientations. Jali patterns were investigated and derived in the traditional research settings. It was found that most shapes were derived from a hexagonal pattern in the Jali screens (Figure 3).

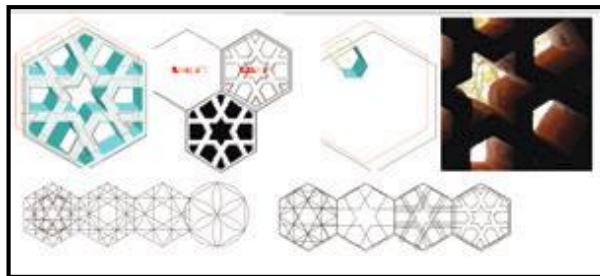


Figure 3: Traditional hexagonal patterns of Jali screens

In order to simplify the process, basic shapes of a hexagon was selected for the purpose of comparing the impacts of the different perforation pattern and ratio on luminance distribution and solar insolation of the screens. A calibrated Canon 550D camera was used for luminance mapping and glare measurements, located in the farthest corner from the western wall. The camera was mounted

on a tripod at 42 inches (120 cm.) height simulating an average seated occupant's eye level. For creating High Dynamic Range Imagery (HDRI), Photosphere software was used (<http://www.anywhere.com/>). Results of the analysis show that the three most common screen perforations are 30%, 40%, and 50% respectively (Figure 4). The typical ratio of void to depth is 1:1 with an average depth of 4-5 inches (10-12 cm). The three types of screen perforations were effective at managing glare with DGP values below 35% and reduced solar loads on the building facades but differed in their daylighting penetrations and solar insolation, thus are suitable to be further studied for their cooling loads reduction impacts as well as their visual and thermal comfort performance.

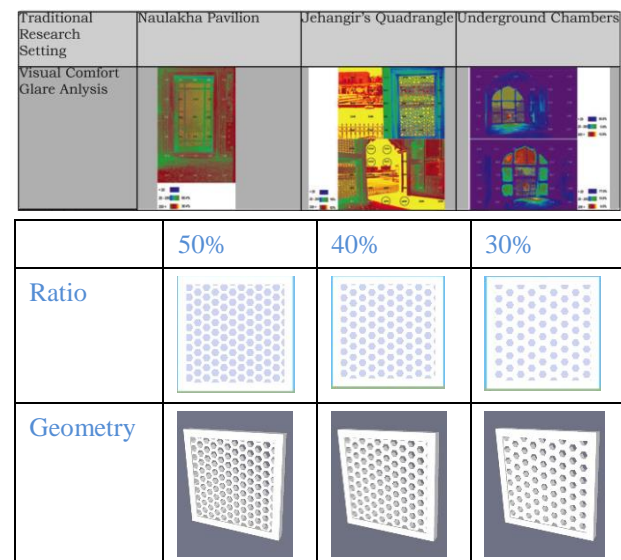


Figure 4: Perforation percentages of traditional Jali

Field Measurements 2 – Case Study Building

A low-rise office building with all-glazed facades was selected. This represents the modern façade design trend of office building, across the globe, in particular, South Asia and Middle East. The base case was located in the commercial area of Y-Block, Defence Housing Authority (DHA) in Lahore, Pakistan. This building occupies a corner site at the intersection of two main roads with facades in the south and west directions. Both facades have 80% WWR with no solar protection. The building consists of five floors including a basement, ground, mezzanine, first, and second floors. Information on building characteristics such as location, orientation, environmental factors, envelope characteristics, installation systems, comfort ranges, schedules and occupancy were gathered during the field study.

A total building energy audit was acquired for the whole year and thermal comfort was recorded using multi-channel data loggers to measure, ambient temperature, relative humidity, mean radiant temperature, and light levels in typical offices as well as outdoor weather conditions. The recorded readings show that in the month of April when the temperature is relatively mild, indoor temperature of a typical office space is outside the ASHRAE-55 2013 thermal comfort range for most of the

occupied hours (ASHRAE Standard 55-2013). Similarly, intolerable glare levels, measured by Daylighting Glare Probability (DGP) metric were above 45% and Annual Solar Exposure (ASE) as well as Spatial Daylight Autonomy (sDA) metrics were not met (IES RP-5-13; IES LM-83) (Figure 5).

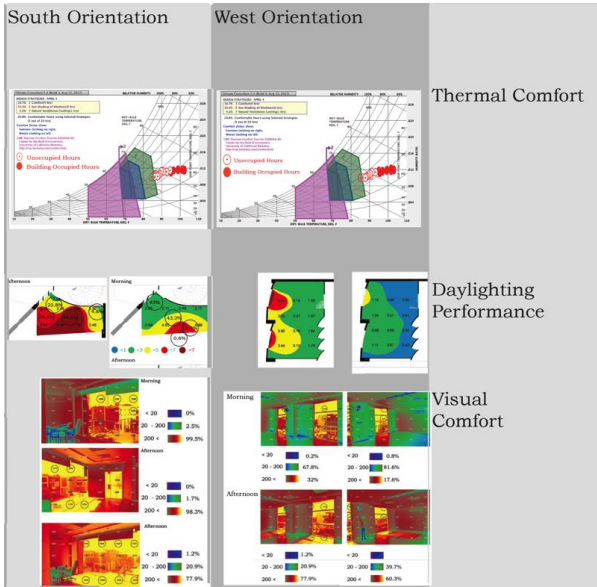


Figure 5: Thermal & visual comfort of the case study site

Experimental design

In hot climates, external perforated screen shadings affect the building energy use for lighting, heating and cooling, as well as the occupants' visual and thermal comfort (Batoool and Elzeyadi 2014, Belliaa et al. 2014, Elzeyadi & Batoool 2017). Although these types of screens have been traditionally used in vernacular architecture precedents throughout the Middle East, few existing studies compared their performance based on different screen geometries, orientations, and climatic contexts. This study investigates the impact of external traditional perforated screens, Jali and Guss walls, predominantly used in the Middle East and South East Asia, on building energy performance, lighting energy loads, and thermal comfort in three hot climate contexts. The variables studied include screen geometries, perforation percentages, orientations, and hot climate zones differences applying a 3x4 experimental comparative design.

Simulation Software

Integrated Environmental Solutions Virtual Environment (IES-VE) was selected as the simulation software for this study. The selection was made based on the comparisons of various building thermal simulation software, their capabilities, and accuracy aspects (Lau et al. 2016). IES-VE provides a variety of dynamic yearly simulation engines for analysis including; solar (suncast), thermal (apache), energy (apache HVAC), ventilation (macroflow), and light (radiance) in one interconnected package as well as output graphical forms in simulation of buildings. Previous studies concluded that there were

no considerable statistical difference in the mean values of building performance metrics between IES-VE simulated results and field measured data (Elzeyadi 2013 & 2016).

Optimization of case study building

The case study office building was constructed in the IES-VE software based on actual building specifications and construction materials (Figure 6). After having calibrated the simulation model with the real base case scenario, it was also found beneficial to validate the efficiency of solar screens with better thermal constructions. Envelope design in Lahore is very leaky and has low R-value due to material quality and poor construction practices. High performance buildings require not only good shading design but also thermal constructions with higher R-values.

Research has shown that with bad thermal construction and leaky envelopes, shading devices cannot achieve the same effect as a good thermal construction (Sourced from GCT High Performance Template; Elzeyadi 2013). High performance materials were used for the final simulation to test all veiled facades/screen perforations (Table 3.1). Further optimization was achieved by using a dimming profile for lighting controls (High performance Template; Elzeyadi 2008). According to this template, a value of 360 lux was set on the work surface to optimize lighting controls such that maximum utilization of daylighting was achieved and electric lighting was minimized during an ASHRAE workday of 8:00 am to 6:00 pm.

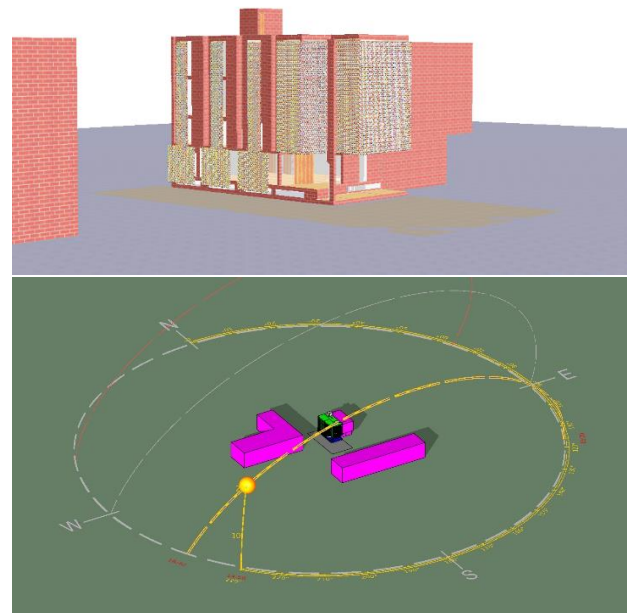


Figure 6: Case Study mid-rise office building modelled after an existing building in Lahore, Pakistan

Table 1: Construction material of simulation model

| | |
|------------------|------------------------------|
| Roof | High Performance Roof [R-40] |
| External Wall | High Performance Wall [R-30] |
| External Glazing | Low-e Triple Glazed [R-5] |
| Ground Floor | Super Insulated Floor [R-25] |

Three Climate Zones

Three representative cities of the different hot climates were selected for the study. Doha, Qatar, a subtropical desert / low-latitude hot arid climate (Köppen-Geiger classification: BWh, 2016); Lahore, Pakistan, a subtropical steppe/ low-latitude hot-humid climate (Köppen-Geiger classification: BSh, 2016); and Los Angeles, USA, an ASHRAE 169-2006 Climate Zone (CZ) 3 B, classified as a Mediterranean climate, which is a type of dry subtropical climate (Köppen-Geiger climate classification: Csa). In all three cities, hot weather conditions during most part of the year with predominantly large number of cooling degree-days are major design concerns. Climate analysis to assess the impacts of shading on the three climate zones was carried out using Climate Consultant 6.0 software (Figure 7) (<http://www.energy-design-tools.aud.ucla.edu>).

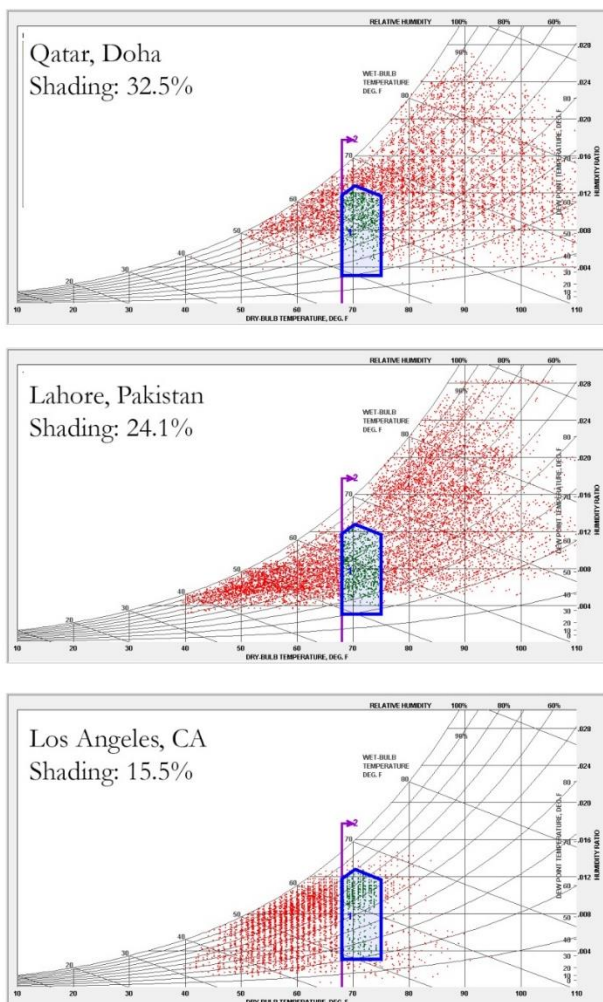


Figure 7: Impact of shading on thermal comfort in Qatar, Doha; Lahore, Pakistan; and Los Angeles, USA (Climate Consultant 6.0)

The analysis focused on the impacts of shading strategies on indoor comfort probability based on the psychrometric chart plot for ASHRAE-55 2013 comfort metrics. For Doha, Qatar, a well-designed external shade provided

substantial increase in indoor comfort for both cooling and heating seasons ranging from 13.3% to 50% with an average of 32.5% increase for time spent within the comfort range. A similar analysis for Lahore, Pakistan results in 24.1% increase for time spent within the comfort range yearly. For the climate of Los Angeles, USA, shading impact on thermal comfort was almost half that of Doha. This is due to the hot-moderate climate of Los Angeles. It can be concluded that successful implementation of deep massive screens can have a bigger impact during the summer months for climate zones in hot dry followed by hot humid regions as well as regions with more substantial cooling degree-days.

In addition to thermal comfort improvements, external shading screens play an important role in the mitigation of solar heat gains in buildings in warm and hot-arid climates over hot-humid climates. The question remains to whether this substantial difference in climate could result in different perforation percentage for the screen and substantial total energy savings as well as energy savings for lighting verses cooling systems.

Parameters of veiled facades simulated

Traditional patterns were investigated and derived in research settings in Lahore and compared with other traditional patterns in the Middle East. According to the literature, nearly all geometric designs used in Jali screens can be reduced to a series of comparatively simple geometric shapes (Hill and Grabar, 1964). To find a screen configuration of highest energy saving potential, a range of massively patterned screen designs were examined by performing parametric computer simulation using IES VE dynamic simulation software. The investigation focused on varying the perforation ratios of solids to voids while controlling for void geometry of hexagonal patterns (Figure 4). This represented the common patterns observed in vernacular precedents and focused the study to the investigation of the perforation ratios only.

Earlier simulations aimed at replicating the perforation patterns recommended in previous studies of 80-90% perforation ratios and 1:1 width:depth ratios (Sherif et. al, 2012). These light screens with high perforation ratios were not effective in reducing energy loads in both Lahore and Doha (Elzeyadi & Batool 2017). In addition, these open perforation ratios of 80-90% were not applicable to vernacular examples of Jali screens and Guss walls, which were examined to be historically between 30-55% perforations (Batool & Elzeyadi, 2014).

Based on this analysis, perforation ratios of approximately 30%, 40%, and 50% were tested for the base case model and used for the purpose of further analysis. As the depth of Jali screens was fairly in proportion to the minimum width of the shape of each module, the depth to width ratio of Jali was kept constant at 1:1 between simulation models. With all other building parameters controlled, the variations of perforation ratios and control case of no-screens, climate conditions of Los Angeles, USA; Lahore, Pakistan; and Doha, Qatar were simulated. The outcome variables are Energy Utilization

Intensity (EUI) measured at KBTU/ft²/yr, thermal comfort plots within the ASHRAE-55 2013 thermal comfort range, as well as dynamic daylighting metrics (ASE, sDA₃₀₀) and Glare (DGP & Glare threshold).

Analysis

A comparative analysis of the EUI in the three climates reveals that Lahore climate is more challenging to achieve a substantial savings. Los Angeles climate, however, is milder to see a big difference on energy performance based on screen perforation ratios. An energy target building that represents the median of building energy performance for office building types have an EUI of 77 kbtu/ft²/yr. for Lahore and EUI 62.3 kbtu/ft²/yr. for Doha and an EUI 47.2 kbtu/ft²/yr. for Los Angeles (Figure 8). Interestingly, a Jali screen of 80-90% perforation was cost ineffective, as it would provide less than 5% energy savings only for all climates. A perforation ratio of 50%, however, provided a starting point to consider energy efficiency savings resulting of 30-40% energy reduction in average. While reducing perforation further led to a slight decrease in energy savings in Lahore, it resulted in better performance in Doha, and has very little effect in Los Angeles as the three screen perforations performed in similar ways, with the 30% and 40% perforations slightly out-performing the 50% by 5%.

An optimum perforation ratio of 30% provided the best energy savings performance for the Doha building resulting in 45% energy savings reduction mainly in cooling loads and improvements in light energy savings from the base case due to daylighting controls strategies through continuous dimming. Increasing the perforation ratio in Doha to 40% and 50% resulted in better daylighting energy savings but lower overall energy savings. This trend is reversed for Lahore where increased perforation ratios from 30%-50% led to improved daylighting performance yet lower energy savings performance in an inversely proportional relationship (Figure 8). A 40% perforation ratio for Los Angeles is the best-optimized condition for both lighting energy savings and cooling load reductions.

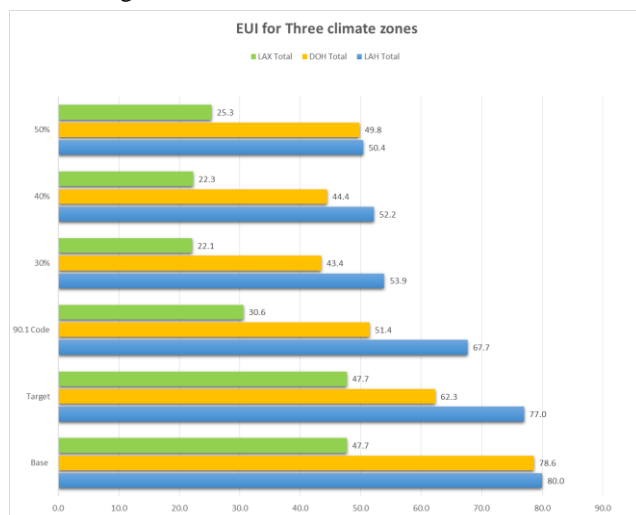


Figure 8: Comparative Energy Utilization Intensity (EUI) across climate zones and perforation ratios (kbtu/ft²/yr.)

As for thermal comfort, applying Jali screens was correlated to better thermal comfort performance in all three climates. With better thermal comfort indices for the 30% Jali screens as compared to base case (Figure 9). The application of 30% screen helps bring indoor thermal comfort to the ASHRAE standard 55-2013 comfort range for the Equinox in both Doha and Lahore and both Equinox and Summer season for Los Angeles. Percentage reduction in solar heat radiation on the facades was calculated for the three screen types and a base case and was expressed in the form of Solar Heat Gain Coefficient reduction percentage (SHGC%), higher SHGC% indicate better performance of the shade in controlling solar heat gains on the glass. Obviously, the 30% perforation screens are the best performing across all climates, especially for the hot-humid climate of Lahore (Figure 10).

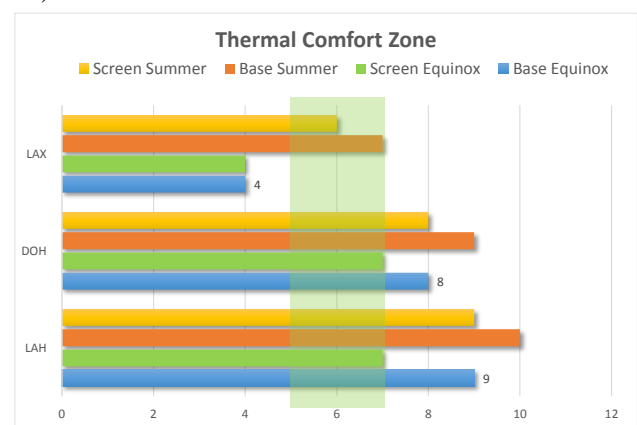


Figure 9: Comparative thermal comfort indices plotted on a psychometric chart with comfort zone highlighted in light green.

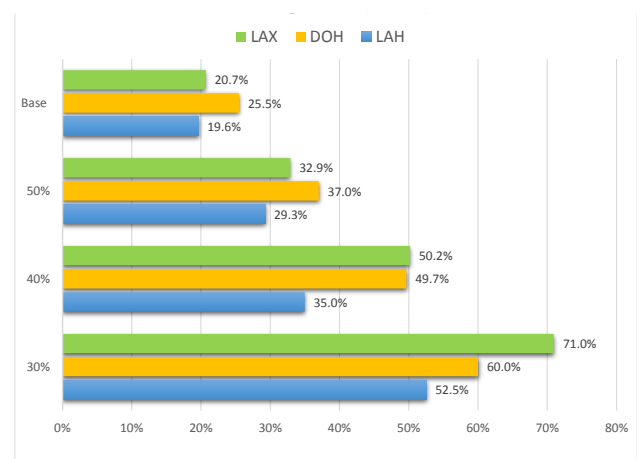


Figure 10: Comparative SHGC reduction

From a dynamic daylighting metrics (IES RP-5-13; IES LM-83), all screen perforations passed the sDA₃₀₀ metric for both south and west facing offices that are 10-15 ft. deep (3-4 m). The ASE metric test, however, failed for most screen perforations with the exception of 30% for both Doha and Lahore. The 30% perforation screen in Los Angeles was close to passing the ASE test with only 14%

of the office area not apssing it during the winter months when the sun is lower in the sky (Figure 11).

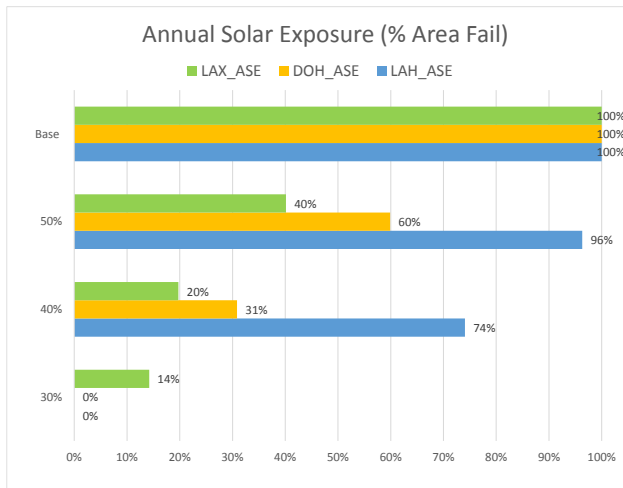


Figure 11: Comparative ASE test performance indicating the percentage of floor area that did not meet the metric

Glare indices as representative of visual comfort metrics in the space were simulated and computed using IES-VE radiance module. Both Glare Thresholds (GT) and Daylighting Glare Probability (DGP) were in the noticeable to intolerable ranges across all climate zones for the base case with untreated glass. Applying different percentages of screen types brought these metrics down to the tolerable to unnoticeable DGP ranges (Figure 12). It is interesting to note that while the 30% perforation screen achieved the highest reduction in GT, its performance related to DGP metric was comparable to the rest of the screens.

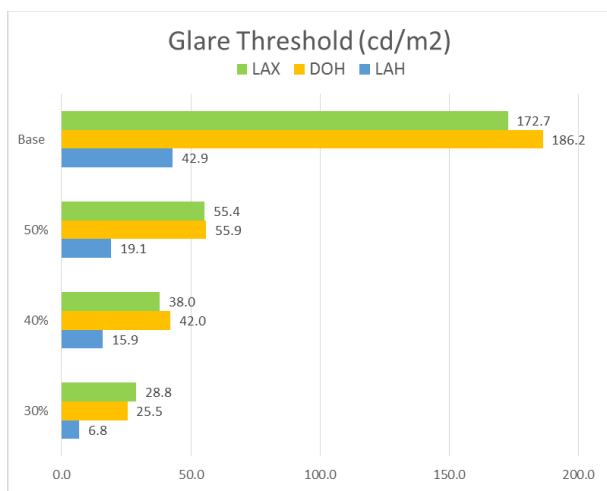


Figure 12a: Glare-threshold comparative analysis

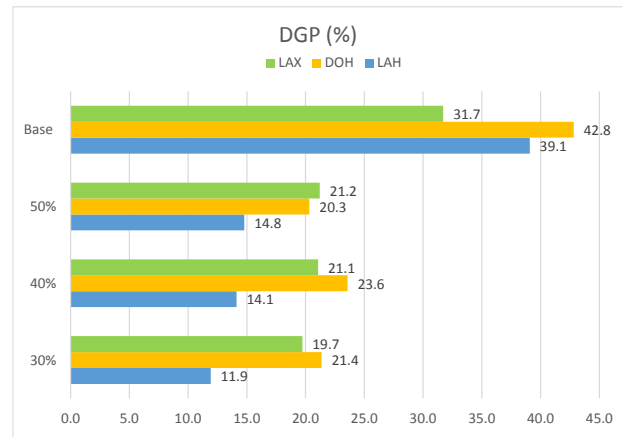


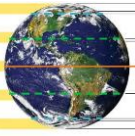

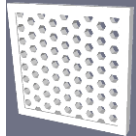
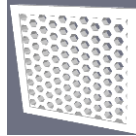
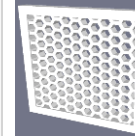
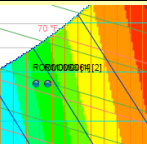

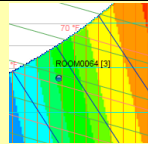
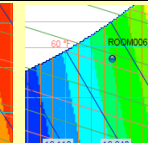
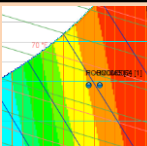
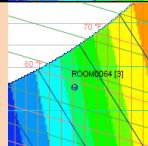
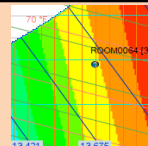
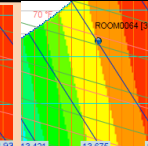
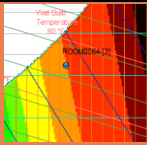
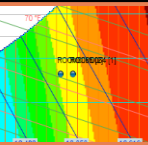
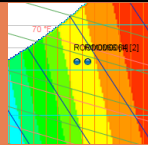
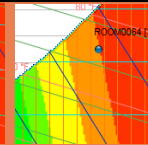
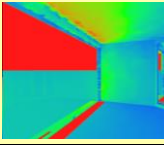
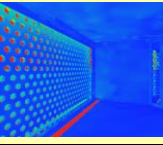
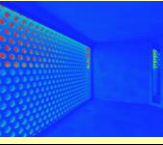
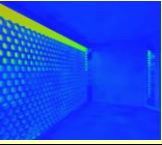

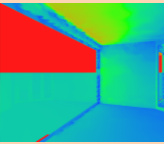
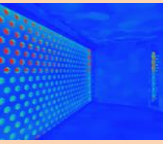
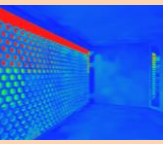
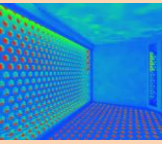
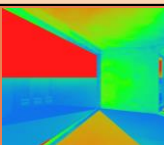
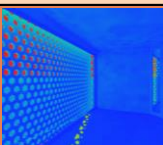
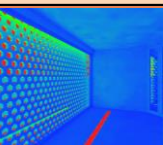
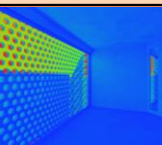
Figure 12b: DGP comparative glare metrics analysis

Conclusion: “one size does not fit all”

The need for contemporary green buildings in hot-arid, hot-humid, and hot-moderate climates is growing in demand (Darwish, 2013). These buildings face a tough challenge of reducing cooling loads while improving daylighting and controlling for glare. External shading provides a cost-effective passive design strategy to reduce energy demands in hot climates while improving occupants’ thermal and visual comfort. Previous studies suggest that light wood screens with wide perforations (80-90%), would have the most energy savings in residential buildings with up to 30% reductions. This study, however, found that this large perforation percentage is not suitable for massive veiled facades such as Jali stone or marble screens in commercial buildings. It suggests that vernacular precedents with 30-50% perforations may provide a more optimized design that balances energy savings in cooling and lighting loads and leads to better occupant’s thermal and visual comfort in hot climates. Contrary to common belief, these screens do not perform equally across the different hot climate zones and while lower perforated screens perform better from an energy perspective higher perforated ones provide better thermal and visual occupant’s comfort.

It is this study’s objective to test different perforation ratios in increments of 10% from 30-50% to evaluate their comparative impacts on energy and indoor thermal and visual comfort. Future studies can investigate other increments of perforation ratios or control the perforation ratios while varying the perforation patterns. The findings support the general observation that energy savings from Jali screens are higher in hot-arid climates over hot-humid and hot-moderate climate zones (Table 2). The 30% Jali screen perforation is best for hot-arid cities as Doha, Qatar, while a 50% Jali perforation is better for hot-humid cities such as Lahore, Pakistan with the 40% perforation is ideal for hot-moderate cities such as Los Angeles, USA. This finding shows that vernacular shading strategies might be well suited to their context and can be successfully adopted to high performance contemporary buildings in hot climates. However, it is good to remember that not all hot climates are created equal and neither are veiled facades and screens perforations.

Table 2: Comparison of veiled screens perforation ratio impact on energy performance, visual, and thermal comfort in three climate zones

| Metric/Unit | Climate zone | Base Case | 30% Jali | 40% Jali | 50% Jali |
|---|---|---|--|---|---|
| |  |  |  |  |  |
| Energy (EUI) | LAX | 47.7 | 22.1 | 22.3 | 25.3 |
| kbtu/ft2/yr | DOH | 78.6 | 43.4 | 44.4 | 49.8 |
| | LAH | 80 | 53.9 | 52.2 | 50.4 |
| Thermal Comfort | LAX |  |  |  |  |
| Psychrometric chart | DOH |  |  |  |  |
| | LAH |  |  |  |  |
| SHGC Reduction | LAX | 20.7 | 71 | 50.2 | 32.9 |
| Solar loads % reduction | DOH | 25.5 | 60 | 49.7 | 37 |
| | LAH | 19.6 | 52.5 | 35 | 29.3 |
| ASE | LAX | 100 | 14 | 20 | 40 |
| % Area Fail | DOH | 100 | 0 | 31 | 60 |
| | LAH | 100 | 0 | 74 | 96 |
| Glare Threshold | LAX | 172.7 | 28.8 | 38 | 55.4 |
| CD/m2 | DOH | 186.2 | 25.5 | 42 | 55.9 |
| | LAH | 42.9 | 6.8 | 15.9 | 19.1 |
| Daylight Glare Probability | LAX | 31.7 | 19.7 | 21.1 | 21.2 |
| DGP % | DOH | 42.8 | 21.4 | 23.6 | 20.3 |
| | LAH | 39.1 | 11.9 | 14.1 | 14.8 |
| False Color Rendering scale 0-1000 cd/m2 | LAX |  |  |  |  |
|  | DOH |  |  |  |  |
| | LAH |  |  |  |  |

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