From Romance to Performance: Assessing the Impacts of Jali Screens on Energy Savings and Daylighting Quality of Office Buildings in Lahore, Pakistan

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ABSTRACT

Jali Screens are traditional window treatments used in vernacular buildings throughout South Asia and the Middle East. Historically, the screen treatments are successful in providing shade and privacy for building occupants in hot arid and hot humid climates. With interest in traditional building features, recent trends in contemporary buildings design have started to incorporate Jali screens or other screens as decorative façade elements. However, the use of these screens has been widely approached from the aesthetic and romantic attitude representing an architectural fascination with the vernacular. Their impact on overall building energy and daylighting performance, however, has been largely ignored. This paper reports on the results of a multi-methods research project to evaluate the impact of traditional Jali screens with various perforation ratios on energy utilization and daylighting quality in contemporary office buildings in Lahore, Pakistan. The study combined a field assessment of traditional Jali screen performance in historical settings with various geometries and an experimental simulation of the different screen perforations on contemporary offices' energy behavior and daylighting autonomy. The hypothesis studied is that Jali screens with 30%-50% perforations will provide an optimized condition between energy savings and daylighting quality in office buildings. Independent variables including building envelope insulation, shading factor, and perforation percentages of Jali screens were manipulated through different simulation models of an existing office building. The dependent variables in the form of overall energy utilization intensity (kbtu/sf/yr), daylighting autonomy, and annual solar exposure were analysed for the different screen attributes. Simulations, using computational energy modeling, have revealed that Jali screens impact cooling loads and improve visual comfort in office buildings. Moreover, it suggests that designers should look at traditional building strategies from a holistic perspective employing a whole-building approach including aesthetics and an intent to quantify its performance and learn from it without over-romanticizing it.
INTRODUCTION

Lahore, a modern financial center in Pakistan, is dominated with office buildings. These offices are air-conditioned throughout the year. In Pakistan, the current energy crisis makes evaluating building performance an urgent need in design practice. The climate of Lahore is typically characterized by a high intensity of solar radiation. Solar heat gain reduction is of primary concern as a means to reduce energy use and provide comfort to occupants in warm weather (Boake, 2014).

Unprotected glass curtain walls are not very climate friendly in warm and hot-humid Lahore. Typically occupants use blinds on the inside of the window to control glare only, while significantly increasing the total building energy when compared to external shading devices (Moeck et al.). Prior research based on the Lahore region did not use the weather data for Lahore, instead similar climate data was used to draw relevant conclusions. Figure 1 shows a psychrometric chart for Lahore, Pakistan (Source: Climate Consultant 5.5 (B1). While the climate of Lahore is such that comfort is only achieved 15% of the time; an additional 24% comfort time can be achieved through sun protection or shading of windows alone.

![Psychrometric Chart for Lahore, Pakistan](attachment:psychrometric_chart.png)

Figure 1. Psychrometric Chart for Lahore, Pakistan (using ASHRAE Handbook of Fundamentals Comfort Model, 2005)

Certain envelope-design strategies have already proved to serve the purpose of energy saving in buildings (Olgyay et al., 1957; Dekay et al., 2014). There are several prescriptive sets of building criteria available to attain the thermal and comfort benefits, and ASHRAE has published several of them (Zhivov et al., 2010). However, such standards pertaining to thermal comfort are not available in Pakistan and the thermal properties of building construction in buildings are very poor. Single glazed curtain wall systems with low thermal resistance envelope designs are still prevalent. A few buildings in the Gulf area and in Pakistan have performance claims, which are not backed by any hard numerical evidence (Boake, 2014).

Jali screen façades have been widely used as vernacular shading devices in the Pakistan, India and Middle Eastern countries. Previous studies have proved their climatic adaptation and environmental
Jali, in Urdu language, means a perforation or perforated screen. Over the years, architects and builders have acknowledged its benefits as a screen that filters light and air, while allowing selective privacy. Traditional Jali facades are replicated and used in contemporary buildings in Lahore, Pakistan. However, there is a lack in understanding of their performances in a quantitative manner and unavailability of scientific means that could be used for developing new efficient designs that suit the modern façades of office buildings in Lahore. Figure 2 shows an example of a contemporary building in Lahore where Jali facades are used as ornament and daylight is blocked out. Fathy (1986) indicated that perforated screens, for example Mashrabiya in Egypt (Fig. 3) affect the quality of space and improve visual comfort in spaces by reducing glare. Several studies show that external screens reduce solar penetration as solar radiation is rejected before hitting the glazing (IESNA Lighting Handbook 2013; Kwok et al., 2011). The hypothesis of this study was that Jali Facades in Lahore would help achieve thermal comfort and as well as improve daylighting performance in office environments.

Figure 2. Mall of Lahore (left) is a commercial building with ornamental Jali Facades, Lahore (Source: author); Figure 3. The House of Suhaymi (right) in Cairo, with one of the Mashrabiyas, Egypt (Source: Wikipedia accessed on September 16, 2014).

Research Setting - Traditional vs. Contemporary

Three Jali screens were selected from typical vernacular architecture of Lahore. The Lahore Fort has the largest collection of Jali screens in place from the Mughal times (16th to 19th century). All three cases selected for investigation are west facing with a perforation ratio of 30%, 40% and 50%. Perforation ratio, for this study, is defined as the ratio of void to solid area of a screen. The depth of screen was fairly constant at 0.25’ (3 inches) and after an analysis of screen geometry (Fig. 6) the depth to width ratio of 1:1 was taken as most commonly occurring.

A typical office building was selected to act as the contemporary research setting. This base case building was located in the Commercial Area of Y-Block, Defence Housing Society in Lahore, Pakistan. This building is at the corner junction of two main roads with facades facing South and West composed of single pane unprotected glazing. It consists of 5 floors including Basement, Ground, Mezzanine, First, and Second typical floors (Fig. 4). For detailed daylighting analysis two rooms on the Second floor are selected as shown in Figure 4. Information on building characteristics such as location, orientation, environmental factors, envelope characteristics, installation systems, comfort ranges, schedules, and occupancy were gathered (Caccavelli, 2000; Butala, 1999; Gücyeter et al., 2012). A total building energy audit was acquired for the whole year and readings for daylighting measurements were taken at a 3’ (three feet) grid on working plane for the two offices at morning and afternoon time, on a typical sunny day in April.
RESEARCH METHODS

The impact of Jali screens on energy conservation and visual comfort of typical contemporary office buildings in Lahore, Pakistan formed the core of this investigation. Details of variables, which affect the energy of building, cooling and lighting, were identified and formed the sub-questions of the study and a review of the literature. The results from the field study impacted decisions taken during the experimental design stage. Figure 5 describes the parameters used in the experimental design stage. In order to simulate conditions accurately, this research employs dynamic energy simulation, starting with a building audit of the existing base case scenario, which was then fed into the simulation model to assess existing performance levels and create a calibrated model. Figure 5 shows the flow of methods employed for this research.

![Figure 4. Contemporary Research Setting: West Façade (left); South façade (right).](image)

Computational and environmental simulation software, IES Virtual Environment Pro (IES_VE), program used in this experimental research (Kim et al., 2012) and has been verified in many publications (The American Institute of Architects, 2012; Elzeyadi, 2009). Only four modules of the package were used to carry out this investigation, which are “ModelIT”, “SunCast” for solar shading analysis, “Radiance” for dynamic lighting simulation and “Apache Sim” for thermal simulation (Muhasilen, 2006; Aldossary, 2014).

Next, Jali screens defined from the traditional research setting (traditional building cases) and designed for this experiment were tested through the calibrated model. The calibrated model was further validated with Target finder and the EUI values in the base case were found to be too high for a balanced experiment. High performance thermal constructions were employed and verified as having a significant impact on performance. Furthermore, all shading devices were based on the optimized base case model (Fig. 5).

Envelope design in Lahore is very leaky and has low R-value. 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, 2008). High performance materials were used for further final simulation for testing all shading devices (Table 1).

<table>
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<tr>
<th>Table 1. High Performance Thermal Constructions used in Simulation Model</th>
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<td>Roof</td>
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<td>External Wall</td>
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<td>External Glazing</td>
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<td>Ground Floor</td>
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Further optimization was achieved through the use of 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 minimized during an ASHRAE work day of 8:00 am till 6:00 pm. Figure 5 shows the process through which the simulation model was calibrated and optimized to achieve the best results for assessment of Jali screen façades.

Jali patterns were investigated and derived in the traditional research settings. It was found that most shapes were derived from a hexagon in the Jali screens (Fig. 6). In order to simplify the process, therefore, basic shape of a hexagon was selected for the purpose of experiment. To find a screen configuration of highest energy saving potential, a range of solar screen designs was examined by performing computer simulation using IES VE dynamic simulation software.

**ANALYSIS**

**Energy Performance and Thermal Comfort**

Initial data collection from base case contemporary building indicated that the temperatures were out of comfort range. Both diagrams (Fig. 7) show how the temperature recorded in the study rooms was
found to be out of the comfort zone defined by ASHRAE 2005 Comfort Model (Climate Consultant 5.5 B1) and Center for the Built Environment: CBE Thermal Comfort Tool.

To account for building energy consumption, Energy Utilization Index (EUI) was used to compare the energy benchmarking of building and design strategies. Mean EUI of commercial buildings in the US was calculated from Target Finder and used to compare with the base case EUI in Lahore (Fig. 8). EPA’s online Target Finder Calculator (EnergyStar) was used to find the base case building Site EUI for a similar climate zone in the US. Target finder US Base case was 77 kBtu/ft²/yr and the value of existing building is calculated at 254 kBtu/ft²/yr.

The base case contemporary building was then modeled with the existing construction techniques in the building as built in Lahore, Pakistan. The results of this simulation showed a high value of 80.3 kBtu/ft²/yr. When using better construction, i.e., using GCT High Performance template, as shown in Table 1, studies have shown significant impact on the energy performance of buildings (Elzeyadi, 2008). Introducing better thermal construction reduced the EUI to 67.68 kBtu/ft²/yr. Furthermore, the existing conditions of base case were not optimized for lighting and solar gain. By introducing a dimming profile of ASHRAE 8:00 am – 6:00 pm workday, the EUI was further reduced to 55.01 kBtu/ft²/yr (Figure 9).

External shading devices, three types of Jali screens, were then added to this computational building model. As shown in Figure 10, EUI improved with perforation ratio of 30% to 50%, with 50% Jali perforation screen as the best performer due to combination of solar heat reduction and daylighting potential.
Daylight Performance

Experiments for the previous simulations were conducted in Radiance module of IES VE dynamic simulation software. The times of the day were set to the 8:00 am to 6:00 pm workday, per IES standard a given preset in IES VE dynamic simulation software. The reference plane on which daylighting performance was simulated contained sensors at a height of three feet above floor (working plane). Dynamic daylight performance metrics were used to assess the illuminance ratios within the rooms. These simulations extended over the whole calendar year and were based on external, annual solar radiation data for the building site. The key advantage of “dynamic daylight performance metrics compared to static metrics is that they consider the quantity and character of climate and seasonal variations of daylight for a given building site together with irregular meteorological events” (Reinhart et al. 2006). Two metrics used in this research were Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) both defined by IESNA (IESNA Lighting Handbook) and found most suited for assessing daylighting quality in an office environment and solar penetration through the Jali screens.

South Orientation

When assessing through the Spatial Daylight Autonomy (sDA) metric, all shading strategies fulfilled the criteria of being 100% as shown in Figure 10 (Green – pass; red – no pass). There was sufficient daylighting to fulfill the minimum daylighting criteria. However, Annual Sunlight Exposure metric was not fulfilled barely towards the back of the room in 30% Jali perforation ratio. It is predictable due to the lesser lighter penetrating deeper on South. This indicated further shading in the deeper parts of the building.

West Orientation

In the west room, the Spatial Daylight Autonomy (sDA) could not be achieved in lower perforation ratios. For the optimum lighting requirement, dependence on electrical lighting increased, while impacting lighting energy (Fig. 10). Similarly in Annual Sunlight Exposure metric, 50% Jali perforation received maximum amount of direct beams of sunlight in comparison to lower perforation ratios (Fig. 10).

Figure 9. EUI Values derived through Dynamic Simulation Modelling

Figure 10. Comparison of Lights Energy and Total Building EUI
Discussion

Energy was measured and assessed in the EUI metric (Fig. 9 & Fig. 10). The thermal construction of a building had a large impact on its energy performance. This study showed that by optimizing the thermal construction using Green Class Toolbox (Elzeyadi, 2008) high total energy savings were made possible. Earlier, it had been discovered during field research, that thermal constructions of buildings in Lahore is not up to ASHRAE standard. Installing standardized construction by using thermal and vapour barriers in building envelope should dramatically improve performance of buildings (Fig. 9). Solar shading devices on windows are significant components of vernacular building façades in Lahore, Pakistan. This research showed (Fig. 10) how each of the three Jali screen façades affected the total energy of the building. Out of the three screen geometries, it can be concluded from this study that the 50% perforation ratio performed best (1:1 perforation to depth). As the perforation ratio was increased from 30% to 50% whole building energy performance improved due to decreased reliance on electrical lighting for daylighting (Fig. 10 & Fig. 11). In comparison, 50% Jali perforation was the better option for a balanced energy approach to provide thermal comfort and provide optimum daylighting. The impact of Jali screen geometry on energy performance is significant to suggest that designers may use this research to improve thermal visual comfort in contemporary buildings and reduce dependence on electricity.

![Figure 11. South Orientation (left) Spatial Daylight Autonomy: (left) and Annual Sunlight Exposure (right); West Orientation (right) Spatial Daylight Autonomy: (left) and Annual Sunlight Exposure (right).](image)

CONCLUSION

This research examined the effect of Jali Screen façades on the year round energy performance and
daylight performance through a dynamic simulation model. The conclusion is focused on the impact of shading devices beyond the aesthetic application; in particular, the geometry of Jali screens façades on Energy Saving and Daylighting Performance in contemporary office spaces in Lahore, Pakistan. For each of the two orientations, South and West, three Jali screens were designed and simulated. In order to draw a conclusion from this study, a holistic approach towards cooling and lighting energy is required, using a whole building design approach. While implementing Jali screens in contemporary façades, designers may seek aesthetic quality along with thermal and visual comfort. Masterbuilders had embedded this information in the various screens found in the traditional architecture of Pakistan, especially Lahore, and we can re-learn from these façade systems to develop a high-performance building design. Jali screens can be optimized for beauty and performance given the parameters are carefully designed.

REFERENCES


