Simulated comparative investigation of the daylight and airflow of the conventional Egyptian shutter 'sheesh' and a proposed latticework device 'new mashrabiyya'

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Simulated comparative investigation of the daylight and airflow of the conventional Egyptian shutter '*sheesh*' and a proposed latticework device 'new *mashrabiyya*'

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Abstract

Most urban and, recently, rural households in Egypt live in apartment buildings. Their façades typically consist of openings equipped with glass panels and wooden louvred shutters, known as *sheesh*. Although it blocks direct sunlight and ensures privacy, *sheesh* impedes entry of needed air and daylight and obstructs the view. In previous studies, a preliminary proposal concerning the replacement of the conventional *sheesh* has been presented. This paper reports the investigation that compared the daylight and airflow performances of the *sheesh* and the proposed latticework device (new *mashrabiyya*). A simulated comparative investigation of daylight and airflow in a southward facing room (when equipped with *sheesh* vs. when equipped with the new *mashrabiyya*) was carried out using Ecotect, Radiance, Evalglare and WinAir simulating programs. The findings show that when occupants shut the *sheesh* for shading or privacy purposes, no air was admitted at all and would give a very dim interior as a result. By contrast, opening *sheesh* for ventilation purposes would likely produce visual discomfort. On the other hand, the use of the *mashrabiyya* was shown to provide a favourable airflow pattern. Illuminance in most of the room was better than the case of when *sheesh* was used; and when adjusted, would provide comfort for the occupants.

Keywords

Louvred shutters, Egyptian *sheesh*, *Mashrabiyya*, Daylight simulation, Airflow, Glare, Simulation, View

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Introduction

Most urban and, recently, rural households in Egypt live in apartment buildings. The façades of these buildings typically consist of regular compositions of openings equipped with glass panels and wooden louvred shutters, known as *sheesh*. Fathy[1], a noted Egyptian architect who pioneered appropriate building technologies, analysed the problem with *sheesh*. He explained that the shutter is made of fixed narrow slats closely set at an angle that intercepts sunrays, within a wooden frame. When closed for privacy purposes, the shutter completely obstructs the view to the outside and considerably darkens the interior as well. In addition, the angle at which the slats are fixed means that breezes would move upwards, flowing uselessly over the heads of building occupants. Rearranging the slats to direct the wind downwards would allow the intense sunrays of Cairo to penetrate the building, directly on the heads of its occupants[1] (Figure 1). Therefore, although *sheesh*

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blocks direct sunlight and ensures privacy, it also impedes entry of needed fresh air and daylight and obstructs the view.

In general, the threshold problem in apartment buildings in Egyptian cities arises from a conflict between social and environmental needs. On the one hand, there are privacy needs and how they can affect daily and social activities that take place near a window or on a balcony. On the other, there are needs for natural light, ventilation, views and shade. Environmental concerns also can conflict with one another, because with the current combinations of balconies, windows and wooden shutters, the *sheesh* fails to address these concerns and needs simultaneously.

According to Fathy, the traditional *mashrabiyya* (a latticework applied to the windows of traditional residences in the Arab world, which served to both shield women from the gaze of men and to ameliorate the region's hot arid climate) is the best natural solution both for protecting women from gazes and for thermal regulation in hot and arid regions. Its design hinders the flow of heat into a home while enhancing the cooling effects of wind and humidity through a process called evapo-transpiration.[1] In 1995, The Research Centre for Islamic History, Art, and Culture in Istanbul and the Egyptian Ministry of Culture sponsored the first academic conference to focus on the *mashrabiyya*. The final recommendations of the conference agreed with Fathy that *mashrabiyya* should be revived, improved and adapted to contemporary lifestyle.[2] However, they offered no suggestions as to how to realize this common goal.

Reintroducing the *mashrabiyya* as it is (small fixed pieces of turned wood in complex patterns) raises several issues linked to many factors. Among these are changing privacy concerns since late 20th century; the high cost of construction; the negative impacts of urban pollution and difficult maintenance due to dust accumulation, which also reduces the evapo-transpiration process.[3,4] Most attempts to make modern *mashrabiyya*s were either only suitable for public buildings because of their thermal functions, or simply abstract, simplified forms of the traditional *mashrabiyya*. The complexity of environmental and social needs and activities related to the unit's threshold and the costliness of wood were not taken into consideration. A more flexible device is needed for the units' openings.

The increasing popularity of air-conditioning may lead one to doubt the worthiness of reintroducing the cooling functions of such screens. According to the 2003 Egypt Demographic and Health Survey (EDHS), 91.8% of all households in Egyptian urban governorates (major cities) owned an electric fan, and 11.2% owned at least one air-conditioning unit.[5] Surprisingly, this rate decreased to 8.8% in the 2005 survey and fan owners rose to 92.1%.[6] The most recent EDHS (2008) reports only 9.7% of households owning at least one air-conditioning unit, while 93% owned an electric fan.[5] An obvious explanation is the rising price of the air-conditioning units and the desire to save on electricity bills, of which air-conditioning represents 32%.[7] Compared with other parts of the world, the popularity of air-conditioning in Egypt is very low; applying a natural thermal regulation solution such as an improved *mashrabiyya* would thus be suitable.

In the course of this study, Abdel-Gelil[3,4] (one of the authors) has addressed in detail the problems associated with temperature control and social customs

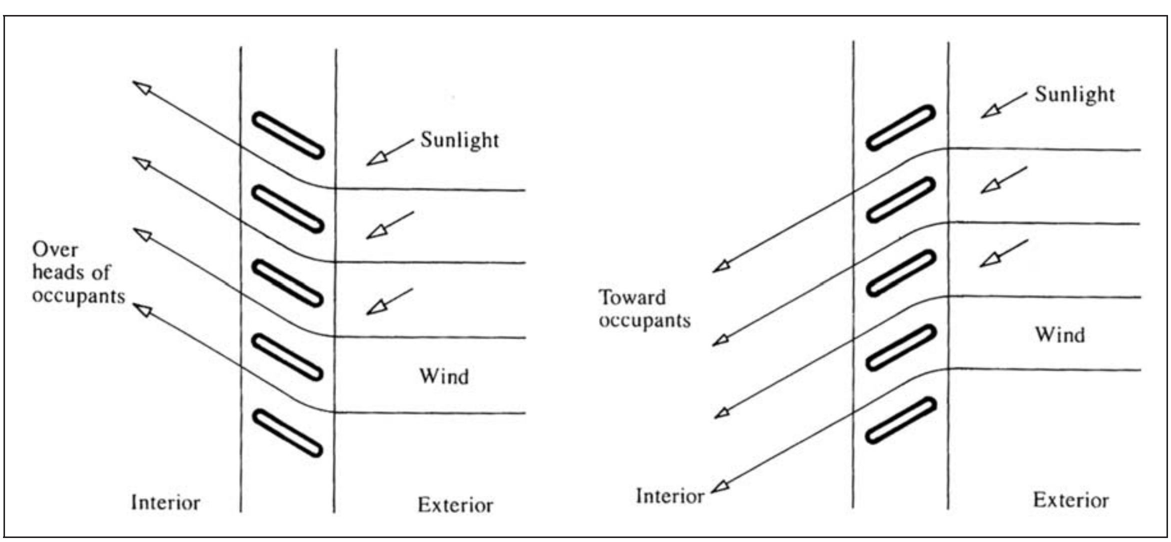


Figure 1. The *Sheesh* used in Egypt. Left: the optimal position for blocking sunlight is undesirable with regard to the wind direction. Right: the position for the optimal direction of the air movement is undesirable with regard to sunshine.[1]

and presented a preliminary proposal concerning the replacement of the conventional *sheesh* for application to apartment buildings in contemporary Cairo. First published in 2006,[3] the latticework device being proposed in this paper here is more developed and elaborated. It has a new framed latticework device derived from a combination of the traditional Islamic *mashrabiyya* and the Japanese *machiya no kōshi* (traditional townhouse lattices, to which Abdel Gelil was introduced during her studies in Japan).

This paper reports the investigation of the daylight and airflow performances of the new *mashrabiyya* (the proposed latticework device) in comparison with the performance of conventional *sheesh*. Thermal performance will be investigated in a separate study.

Climate in Cairo

Cairo has only two seasons: almost 8 months of summer (March to October) and 4 months of winter (November to February).[8] Overwhelming, dry heat, intense sunlight, a dazzling sky and a light breeze characterize summer days, with cooler and more humid weather from midnight to early morning. Average maximum and minimum temperatures are 37.5°C and 16°C and the daily average is 25°C. On the hottest days, the temperature often reaches 43°C. Cairo winters are warm, with average maximum and minimum temperatures of 25°C and 8°C, and a daily average of 16°C. The air is dry all year round, with an average relative humidity of 56% in the summer and 65% in the winter. Rain is extremely rare – zero mm of rainfall in the summer and a 5.08 mm average in the winter.[9] A constant northern breeze – hot during the daytime and cool at night – blows at an average speed of 3.35 m/s for most of the year[10] (Figure 2). For a period of 1–3 days, in either March or May, the city experiences south and southwest winds, called *khamaseen*, that carry fine particles of sand from the nearby desert, resulting in hot and dusty weather.[11]

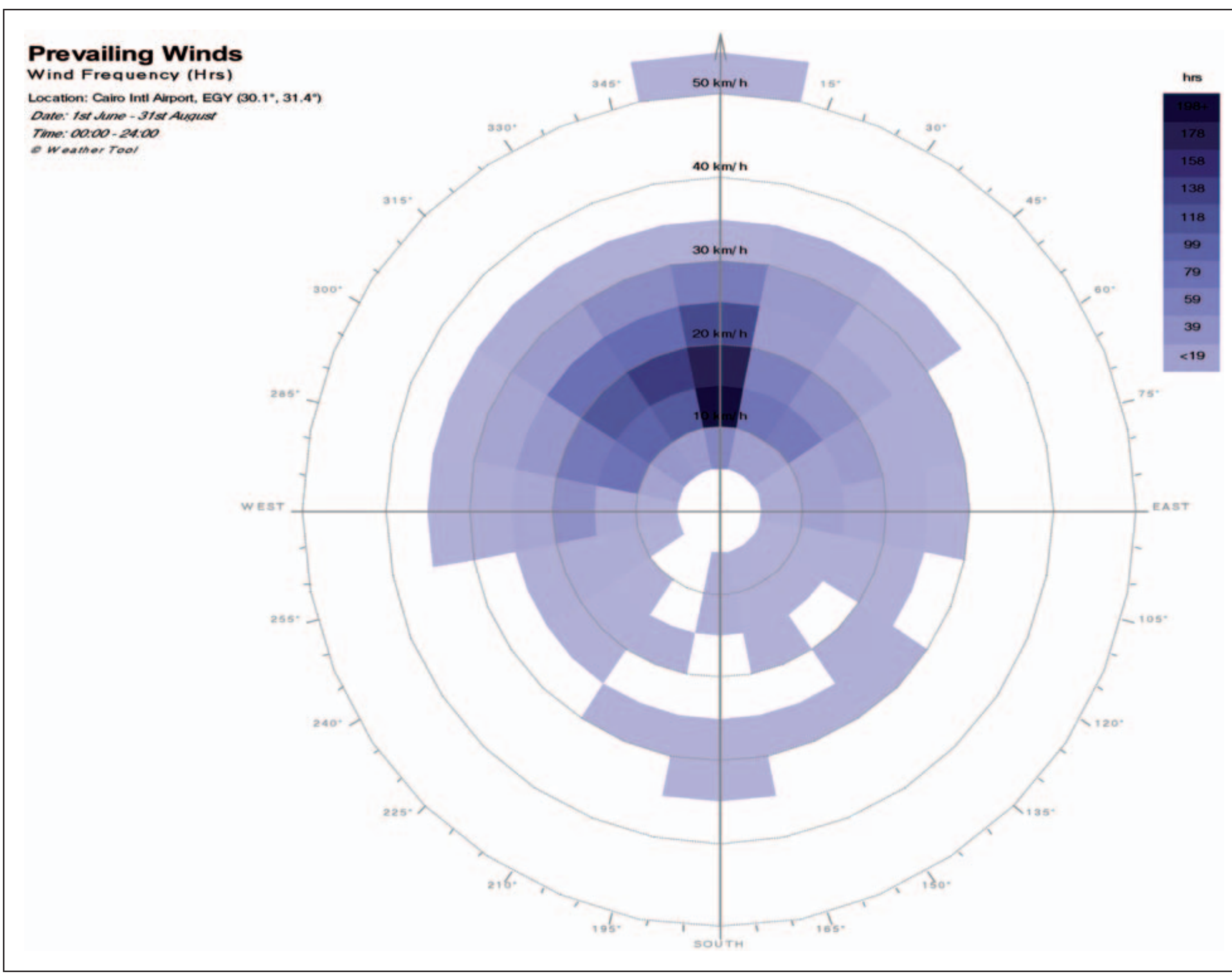


Figure 2. Prevailing winds in Egypt (Ecotect).

Experiment models

Room

The selected room represents a standard living room in a housing unit. Its dimensions are 3.30 m (W) × 5.20 m (L) × 2.80 m (H) and it has one window (Table 1). The wall is 12 cm thick and is made of Egyptian fired clay brick coated with a 3 cm layer of plaster, both inside and outside. This study does not take into account the effect of any furniture that may be in the room, and it is assumed that the door to the room is closed. An analysis of the shading percentage on the south and north façade in Cairo shows that the average annual shading on the north façade is 83.7%, which means that this facade does not need a shading device (a well-known fact in Egypt, see Figure 3). The average annual shading on the south façade, however, is 15.8%, indicating the need for a shading device, a point that is worthy of investigation (analysis of the **east and west** directions was neglected because the sun angle changes rapidly throughout the day and year so we cannot trace the sun to design a shading device). Therefore, the living room selected as a model for the experiment has to face southward.

Conventional shutter (sheesh)

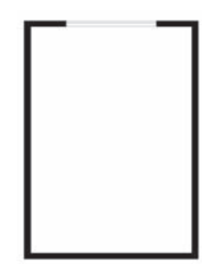
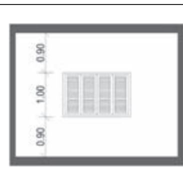
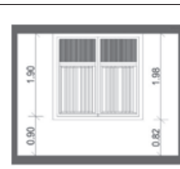
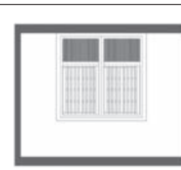
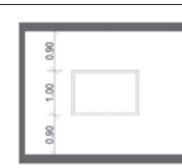
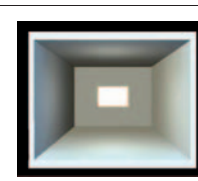
The largest size of standard *sheesh* is 138 cm wide and 100 cm high, including the main (5 cm wide) frame (Figure 4). It has four panels, each of which is framed and measures 32 cm wide (frame included). A panel consists of small horizontal fixed slats tightly set at 30–60° angles. *Sheesh* is usually made of low-grade Russian or Scandinavian spruce – a kind of softwood, also called 'whitewood' or *moski*.

Proposed latticework device: new Mashrabiyya

The new *mashrabiyya*[3,4] can be constructed as a large window or balcony flush, or extending out from the wall (see Figure 5(a) and (b)), as a smaller *mashrabiyya* flush with, or extending out from, the wall (Figure 5(c) and (d)) or simply as a window (Figure 5(e)). The latter (Figure 5(e)) was investigated and compared with the *sheesh*. It consists of two parts and has the following characteristics (Figure 6):

- A part below eye level (lower part) that consists of two lattices comprising mainly vertical mullions. The external lattice is fixed and the internal one slides to

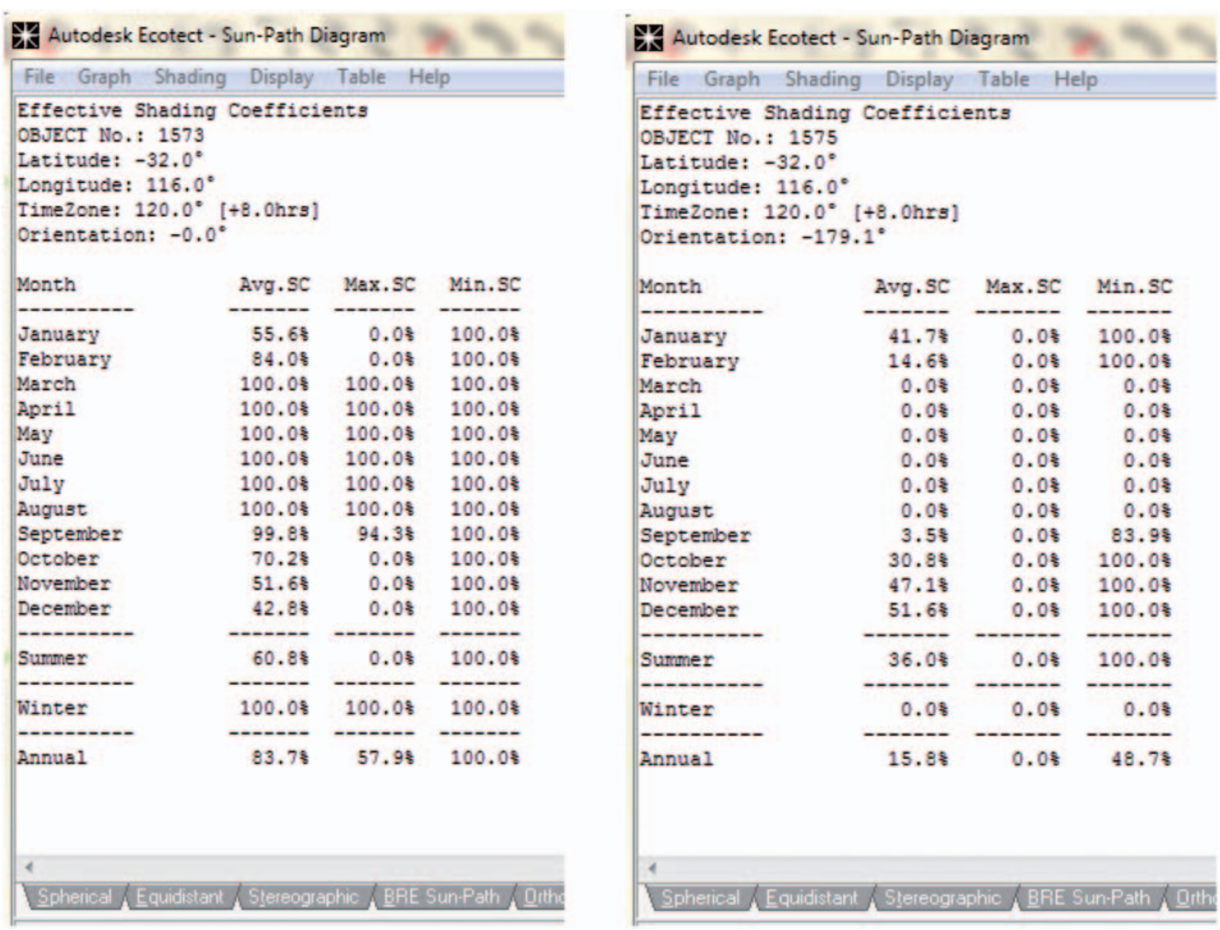
Table 1. Experiment models: four room models were investigated: (1) equipped with *sheesh*, (2) equipped with *mashrabiyya* with closed intervals, (3) equipped with *mashrabiyya* with open intervals and (4) equipped with an open window.

	Sheesh	*Mashrabiyya* with closed intervals	*Mashrabiyya* with open intervals	Open *Sheesh*
Plan				
Section				
Shot				

the left or to the right to adjust the degree of openness and closeness. This enables households to adjust the open intervals between the vertical mullions according to the desired degree of daylight or airflow, without affecting the need for privacy or obstructing outside views. The present study investigates this aspect of the device. In addition, the part that is below eye level opens upwards at any angle and is equipped with a section that can be lowered. This mechanism (not investigated in the present study) provides privacy and daylight while intercepting direct sunlight. It also enables a woman to hang out the washing or sit in the balcony and still be shielded from the view of passersby. Attached to part below eye level is another piece that can be lowered to provide additional privacy from neighbours at the same or lower level, and from people on the street below.

- An upper part, above eye level, that compensates for the reduction in daylight and airflow when privacy or light intensity necessitates shutting the lower

Figure 4. Left: the dimming effect of the *sheesh* (from www.e-dar.com) and right: section in the *sheesh* showing the slats.



Autodesk Ecotect - Sun-Path Diagram

File Graph Shading Display Table Help

Effective Shading Coefficients
OBJECT No.: 1573
Latitude: -32.0°
Longitude: 116.0°
TimeZone: 120.0° [+8.0hrs]
Orientation: -0.0°

Month	Avg.SC	Max.SC	Min.SC
January	55.6%	0.0%	100.0%
February	84.0%	0.0%	100.0%
March	100.0%	100.0%	100.0%
April	100.0%	100.0%	100.0%
May	100.0%	100.0%	100.0%
June	100.0%	100.0%	100.0%
July	100.0%	100.0%	100.0%
August	100.0%	100.0%	100.0%
September	99.8%	94.3%	100.0%
October	70.2%	0.0%	100.0%
November	51.6%	0.0%	100.0%
December	42.8%	0.0%	100.0%
Summer	60.8%	0.0%	100.0%
Winter	100.0%	100.0%	100.0%
Annual	83.7%	57.9%	100.0%

Spherical Equidistant Stereographic BRE Sun-Path Ortho

Autodesk Ecotect - Sun-Path Diagram

File Graph Shading Display Table Help

Effective Shading Coefficients
OBJECT No.: 1575
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Longitude: 116.0°
TimeZone: 120.0° [+8.0hrs]
Orientation: -179.1°

Month	Avg.SC	Max.SC	Min.SC
January	41.7%	0.0%	100.0%
February	14.6%	0.0%	100.0%
March	0.0%	0.0%	0.0%
April	0.0%	0.0%	0.0%
May	0.0%	0.0%	0.0%
June	0.0%	0.0%	0.0%
July	0.0%	0.0%	0.0%
August	0.0%	0.0%	0.0%
September	3.5%	0.0%	83.9%
October	30.8%	0.0%	100.0%
November	47.1%	0.0%	100.0%
December	51.6%	0.0%	100.0%
Summer	36.0%	0.0%	100.0%
Winter	0.0%	0.0%	0.0%
Annual	15.8%	0.0%	48.7%

Spherical Equidistant Stereographic BRE Sun-Path Orth

Figure 3. Analysis of the annual shading percentage on the south and north façade in Cairo using Ecotect.

section's intervals. The mullions of this part are bevelled and installed with the narrow portion facing outwards, thus ensuring privacy from the upper floors of the surrounding buildings, without any substantial decrease in daylight and airflow. An appraisal of this characteristic is included in the present study.

- The two parts described above are fixed together within a single removable frame that, when removed, transforms the new device into an open window, making it suitable for socializing and providing ventilation during the frequent gatherings and celebrations held at Egyptian homes (obligations related to social and religious customs in Egypt).
- To enhance sturdiness and to reduce the number of corners and the amount of horizontal surfaces on which pollutants and dust can gather, most of the latticework's mullions are vertical, and only a few horizontal mullions are used. The device is thus less subject to damage, easier to clean and enables the evapo-transpiration process.
- To mitigate the intense Egyptian daylight and to reduce glare below eye level, the corners of all the mullions are rounded.
- The material suggested for the manufacture of the proposed device is date palm leaves' midribs (DPLM). Located in the hot and arid subtropical region, Egypt has no forests and imports wood for needs. The price of DPLM, available in huge quantities in the country, is nine times cheaper than that of commercial wood. A number of research centres in Egypt are presently working on substituting wood with DPLM and they have already succeeded in testing its properties and manufacturing commercial products using this material.[12–18]

Method

A simulated comparative investigation of daylight, including discomfort glare probability, and airflow in a southward facing room (when equipped with *sheesh* vs. when equipped with the new *mashrabiyya*) was carried out using Ecotect, Radiance, WinAir and Evalglare simulating programs.

Recent revision of Leadership in Energy & Environmental Design (a green building verification tool developed by the US Green Building Council) and other complicated inclusive certification processes have recently recognized Ecotect as the simulation tool for assessing daylighting, air movement and thermal performance, performed by the Radiance, WinAir and EnergyPlus programs.[19] In addition, Evalglare was developed and validated at the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany to predict glare. Integrated early into the architectural design process, these building performance simulation tools can be a powerful and helpful instrument. Qualitative input obtained using Ecotect may be applied advantageously in investigations at the conceptual architectural design stage, when it is not vital to work with absolutely accurate calculation results. Furthermore, since they contribute to the identification of the relative performance of several design options, the advantage presented by Ecotect and similar simulation tools therefore concerns comparative studies in particular as is the case being reported here in this paper. The basis of all comparative calculations is the same, thus ensuring that relative accuracy is maintained.[20,21]

A common method to obtain more accurate daylight analysis results is to perform the analysis using both Ecotect and Radiance.[19,22,23] The latter, a physically based, backward ray tracer, produces more reliable daylight factor calculation results than Ecotect (which uses a split-flux method). Calculation results obtained using Radiance consider building location,[24] direct and diffused light, as well as multiple daylight reflectance.[25] Exporting results to Radiance was possible through Ecotect–Radiance export manager plug-in.

WinAir was used to obtain airflow patterns. It is a plug-in to carry out computational fluid dynamic analysis using Ecotect. Although the program, produced at the University of Cardiff and developed for research

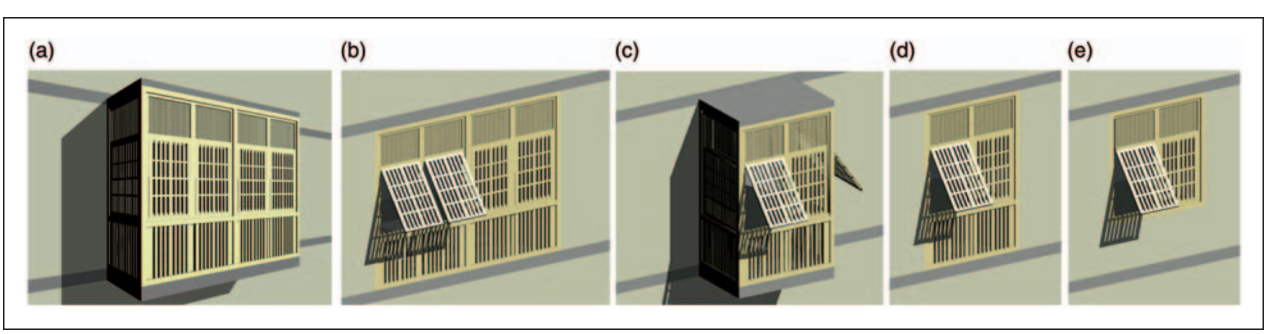


Figure. 5. Designs and variations of the proposed latticework device of new *mashrabiyya*.

purposes (it is not commercially available), is generally reliable, it does have certain shortcomings. It was designed mainly as an application for smaller projects (the case of this study), and it can only analyse a single wind direction and a single wind speed at a time, which is not an issue in a comparative study.[26] Data from Ecotect were exported to WinAir in the same manner as Radiance; results were then imported into Ecotect and presented in a graphical interface.

Evalglare simulation tool was used to measure and compare five glare indexes: Daylight Glare Probability (DGP), Daylight Glare Index (DGI), Unified Glare Rating (UGR), CIE Glare Index (CGI) and Visual Comfort Probability (VCP). Evalglare was developed

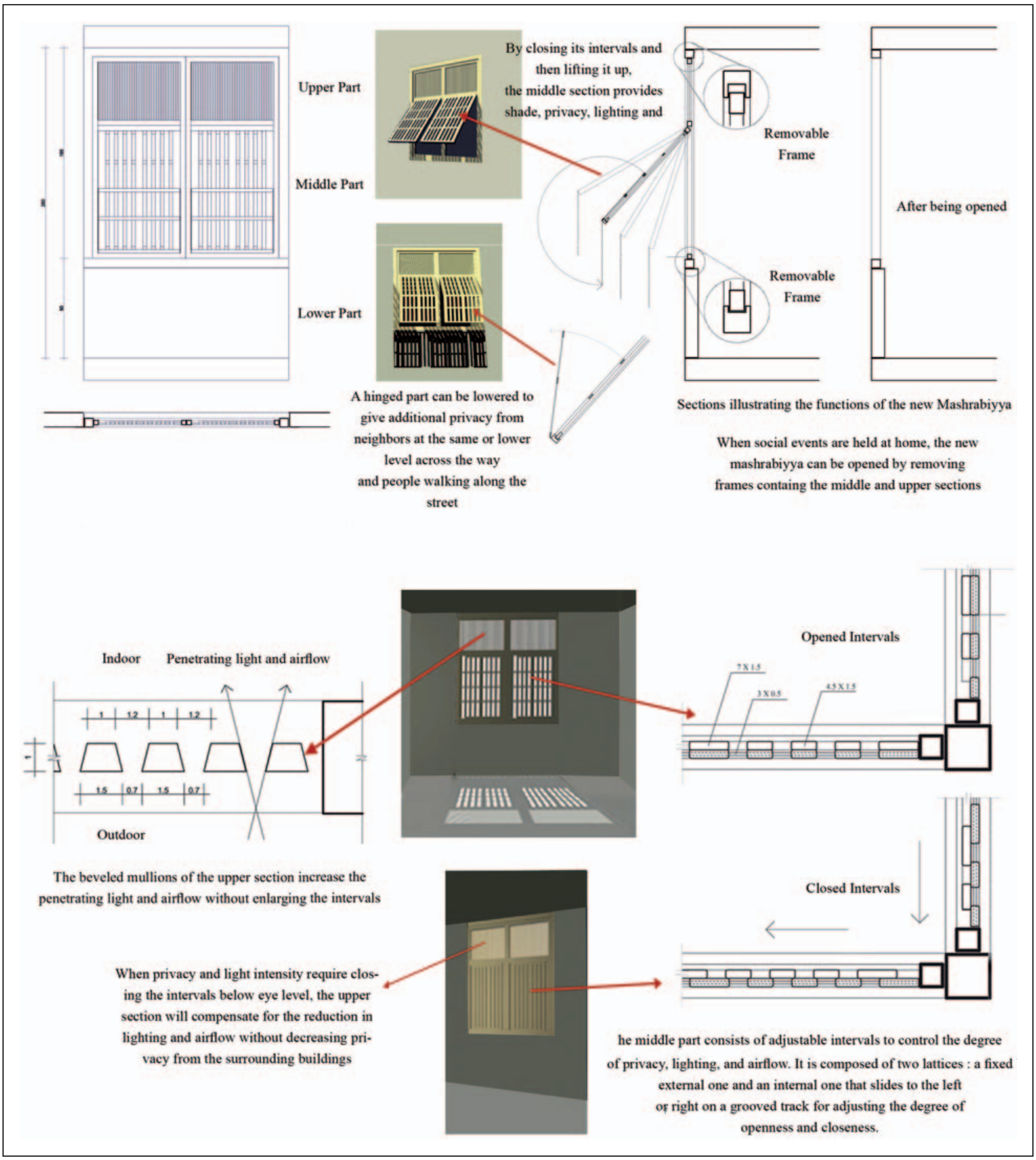


Figure 6. Design, details and functions of the new *mashrabiyya*.

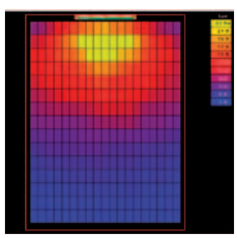
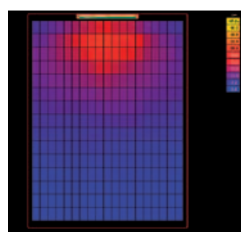
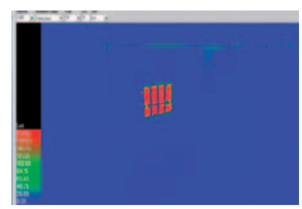
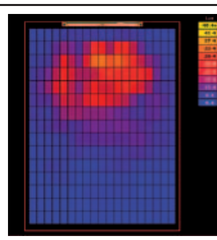
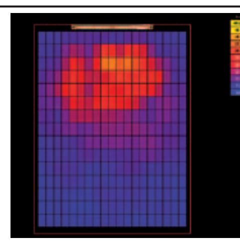
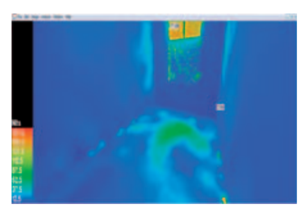
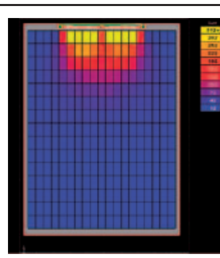
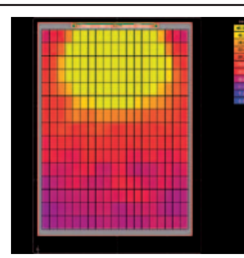
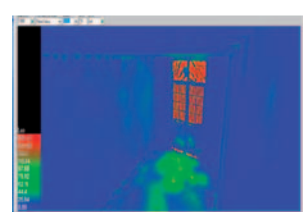
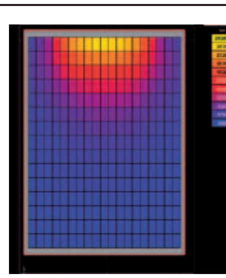
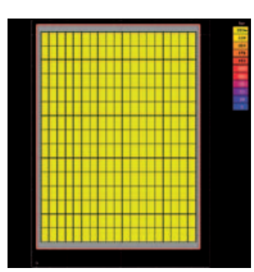
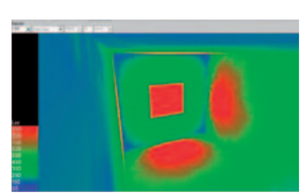
and validated at the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany to evaluate glare metrics from Radiance RGBE image format.[27–29]

Four room models were investigated (Table 1): (1) equipped with *sheesh*, (2) equipped with *mashrabiyya* with closed intervals, (3) equipped with *mashrabiyya* with open intervals and (4) equipped with an open window. First generated in Archicad, they were then saved as 3ds files and imported into Ecotect. Daylight analysis was carried out in Ecotect then exported to Radiance through Ecotect export manager to obtain more accurate results and images. For the airflow analysis, data from Ecotect were exported to WinAir using the same plug-in. Results were then imported into Ecotect and presented in a graphical interface.

Daylight and glare simulations

Daylight simulation was performed on 1st July, the day of the year with highest loads, at 12 o'clock noon and at a height of 70 cm (measured from living room floor level). Results are presented in Table 2.

Table 2. Daylight simulation results.

	Lighting intensity in lux	Lighting with fixed scale	Radiance image	Lighitng range in lux
Sheesh				**3-23**
***Mashrabiyya* with closed intervals**				**5-38**
***Mashrabiyya* with open intervals**				**12-312**
Open *sheesh*				**300-2820**

Glare is a measure of the physical discomfort of an occupant caused by excessive light or contrast in a specific field of view.[29] Direct glare is produced by poorly shielded luminaires, bright windows or from reflecting areas of high luminance, such as a ceiling plane receiving the light output from an indirect luminaire.[30]

High dynamic range luminance images with wide angle view (fisheye) were first generated using Radiance. Since discomfort glare prediction is difficult to perform because glare varies not only with the location, size and brightness of the light source, but also with the observer's position, view direction and the adaptability of the eye,[31] the analysis was simplified by having one camera overlooking the main glare source from the centre of the room.[32] Two sets of parameters were determined before starting the simulation: indirect calculations (ambient) and direct calculation parameters (Table 3).

Table 3. Parameters used in Radiance / Evalglare for glare indexes calculations.

Ambient bounces (ab)	2
Ambient accuracy (aa)	0.2
Ambient divisions (ad)	400
Ambient super samples (as)	64
Ambient resolution (ar)	256
Direct pretest density (dp)	512
Direct sampling (ds)	0.3

Table 4. Room surfaces properties.

Element	Reflectance	Specularity	Roughness
Floors	20%	0.02	0
Walls	50%	0.02	0
Ceilings	80%	0.02	0

In addition, the surface properties such as reflectance, specularity and roughness were entered (Table 4). For the *mashrabiyya* with opened intervals, glare was evaluated using increasing luminance values: 500 cd/m^2, 2000 cd/m^2 and 5000 cd/m^2. It was found that the higher the luminance, the smaller the degree of discomfort glare. A whole study by Kim and Kim[33] was dedicated to and confirms this matter. Therefore, for all the examined cases, the luminance was set to 500 cd/m^2. In order to evaluate whether the glare would be comfortable, the results were compared with the glare prediction ranges[29] found in Table 5. The results are illustrated in Table 6.

Airflow patterns and rates

Airflow simulation was also performed on 1st July, the hottest day of the year. Table 7 shows the overall airflow pattern throughout the room section. The airflow pattern on a 60-cm high and a 180-cm high plans are also illustrated in the same table. As mentioned earlier, the effect of furniture was neglected in this study. Since this study assumed that the door to the room was closed, the obtained airflow pattern was presumed to be the result of a single-sided ventilation.

In the following, the air change rate per hour (ACH) and fresh air rate per person were calculated on 1st July at a maximum temperature of 42.8°C and compared with the recommended rates. Air change rate or air change per hour (ACH) is the number of times all air within a building is being exchanged with outside air over the course of an hour.[34] It was calculated by dividing the airflow in volume units per hour by the volume of the space on which the air change rate is based in identical units.[34]

According to ASHRAE residential ventilation standards, the minimum required air change rate should be 0.35 air change per hour for living spaces and the recommended fresh air rate is 2.5 l/s per person in residential living spaces or 0.3 l/s/m^2.[34,35] By obtaining the resulting mass flow rate of the studied cases using WinAir, the air change rate ACH, fresh

Table 5. Glare prediction ranges.

	Imperceptible (green)	Perceptible (yellow)	Disturbing (orange)	Intolerable (red)
DGP	<0.3	0.3–0.35	0.35–0.4	>0.45
DGI	<18	18–24	24–31	>31
UGR	<13	13–22	22–28	>28
CGI	<13	13–22	22–28	>28
VCP	80–100	60–80	40–60	<40

DGP: Daylight Glare Probability; DGI: Daylight Glare Index; UGR: Unified Glare Rating; CGI: CIE Glare Index; VCP: Visual Comfort Probability.

air rate per person and fresh air rate per square metre were calculated and compared with the recommended rates. Following are the calculations of the airflow rates for the *mashrabiyya* with open intervals:

Mass flow rate or the *mashrabiyya* with open intervals = 24.143 g/s
Air density at 42.8°C = 1.13 kg/m^3
Volumetric flow rate = (0.024/1.13)/s = 0.0213m^3/s = 76.915 m^3/h
Room volume = 3.30 m (W) × 5.20 m (L) × 2.80 m (H) = 48.048 m^3
ACH = volumetric flow rate (in m^3/h) divided by the room volume (in m^3)
ACH = 76.915/48.048 = 1.6 air change per hour (recommended ≥0.35)

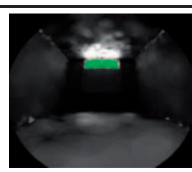
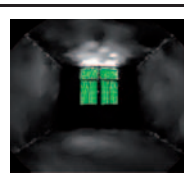
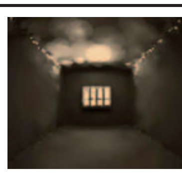
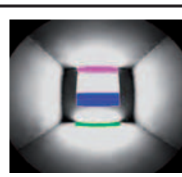
Fresh (outdoor) air rate per person (4–5 persons in the living room)
Volumetric flow rate = 0.0213 m^3/s = 21.3 l/s
Fresh air rate per person = 4.25 l/s – 5.3 l/s (recommended≥2.5 l/s)
Fresh air rate per m^2 = 21.3/(3.30 × 5.20)=1.23 l/s/m^2 (recommended ≥ 0.3 l/s/m^2)

The same steps were followed for the *mashrabiyya* with closed intervals and the closed and opened *sheesh* (Table 8).

Discussion

The Cost-Effective Open-Plan Environment field study conducted by the Institute for Research Construction (National Research Council, Canada) recorded that illuminances larger than, or equal to, 150 lux were classified as appreciable daylight.[36] Furthermore, the Illuminating Engineering Society of North America recommends 50–100 lux, provided directly onto the individual task area, as the general range of illuminance required for working with cathode ray tube screens in laboratory areas.[37] In fact, although standard

Table 6. Glare simulation results.

	Fisheye images	Glare indexes: fixed luminance 500 cd/m^2	Glare prediction	Glare indexes: real luminance	Glare prediction
***Mashrabiyya* with closed intervals**	 	**DGP: 0.006941**	**Imperceptible**	**DGP: 0.007099**	**Imperceptible**
		DGI: 10.599246	Imperceptible	DGI: 10.168557	**Imperceptible**
		UGR: 15.955912	Perceptible	UGR: 15.955912	Perceptible
		CGI: 13.294396	Perceptible	CGI: 13.980573	Perceptible
***Mashrabiyya* with open intervals**	 	**DGP: 0.240179**	**Imperceptible**	**DGP: 0.248295**	**Imperceptible**
		DGI: 18.090773	Perceptible	DGI: 21.545132	Perceptible
		UGR: 21.929411	Perceptible	UGR: 28.585932	Intolerable
		CGI: 25.058653	Disturbing	CGI: 27.485640	Disturbing
Closed *sheesh*	 	**DGP: 0.004899**	**Imperceptible**	**DGP: 0.006250**	**Imperceptible**
		DGI: 5.230422	Perceptible	DGI: 13.496437	**Imperceptible**
		UGR: 5.172379	Perceptible	UGR: 15.770306	Perceptible
		CGI: 8.382017	Disturbing	CGI: 15.996298	Perceptible
Open *sheesh*	 	**DGP: 0.213622**	**Imperceptible**	**DGP: 0.235605**	**Imperceptible**
		DGI: 15.49431	Imperceptible	DGI: 16.978662	**Imperceptible**
		UGR: 18.1687	Perceptible	UGR: 19.907223	Perceptible
		CGI: 21.42654	Disturbing	CGI: 23.468290	Disturbing

DGP: Daylight Glare Probability; DGI: Daylight Glare Index; UGR: Unified Glare Rating; CGI: CIE Glare Index; VCP: Visual Comfort Probability.

workplace lighting regulations call for 300–500 lux illuminance at desk level, a survey carried out at a computer distribution company (measurements were taken in offices that contained at least two computers each) revealed that the majority of employees were most comfortable with a daylight illuminance of approximately 100 lux.[38] Most people also seem to have a tendency to tolerate considerably lower daylight illuminance levels than artificial light levels. This is especially true towards the end of the day (e.g. many

Table 7. Airflow patterns.

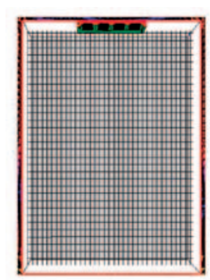
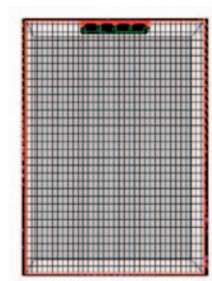
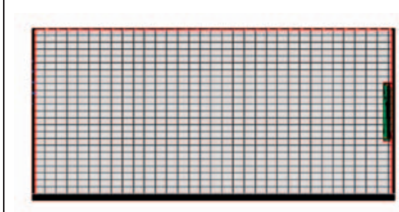
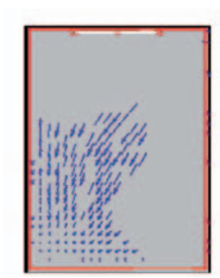
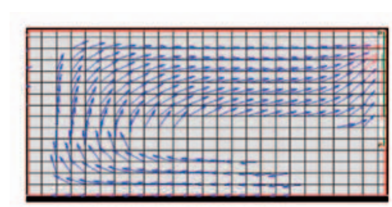
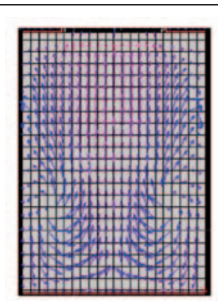
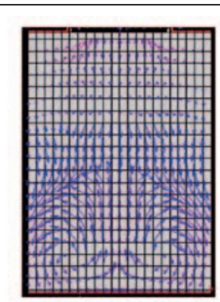
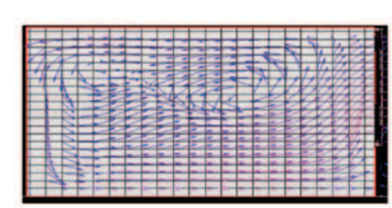
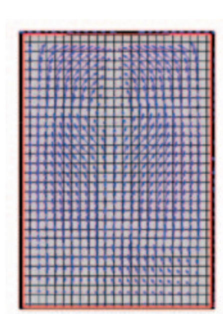
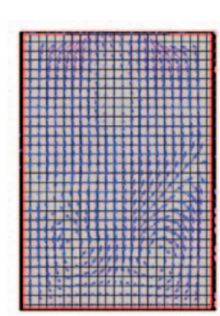
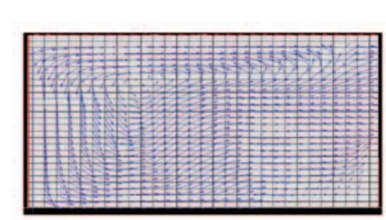
	Level 60 cm	Level 180 cm	Section	Air velocity m/s
Sheesh				 0
Mashrabiyya with closed intervals				 0.1-0.24
Mashrabiyya with open intervals				 0.1-0.3
Open *sheesh*				 0.1-0.22

Table 8. Airflow rates.

	Mass flow rate g/s	ACH (air change per hour)	Fresh air rate per person l/s	Fresh air rate per m^2 l/s/m^2
Mashrabiyya with closed intervals	24.025	1.59	4.25–5.3	1.23
Mashrabiyya with open intervals	24.143	1.6	4.25–5.3	1.23
Closed Sheesh	14.98	0.99	2.65–3.31	0.77
Open sheesh	29.28	1.94	5.18–6.48	1.5
Recommended (ASHRAE 62.1 & 62.2)		$\geq$0.35	$\geq$2.5	$\geq$ 0.3

people continue to read after daylight levels drop as low as 50 lux.[39]

When occupants shut the *sheesh* for shading or privacy purposes, the result would be a very dim interior, with daylight illuminance of 3–23 lux; 3–7 lux in the half of the room furthest from the window and 23 lux directly by the window. Iluminance resulting from the *mashrabiyya* with closed intervals, mainly from the upper part with bevelled mullions, was between 5 lux and 38 lux. Illuminance in the first third of the room, away from the opening, was from 5 lux to 13 lux, increasing to 18 lux in the second third of the room, and rising to between 20 lux and 38 lux in the third part, nearest to the opening. The room was still dark, but illuminance in most of it is obviously better than in the case of *sheesh*. Moreover, occupants were able to increase daylight penetration without affecting their privacy needs by regulating interval openings. When the *mashrabiyya* intervals were opened to the maximum, the resulting illuminance was between 12 lux and 312 lux. Apart from a few dark spots (12–20 lux), the illuminance in two-thirds of the room area ranges from 20 lux to 100 lux and increases to between 160 lux and 312 lux in the corner nearest the window, which was comfortable for the occupants. By contrast, opening the conventional *sheesh* for ventilation purposes had resulted in illuminances ranging from 300 lux to 2820 lux, which was likely to produce visual (as well as thermal) discomfort.

Concerning the prediction of the discomfort glare, the DGP was found imperceptible in the four cases; DGI varied from imperceptible to perceptible; URG was perceptible in all cases expect the *mashrabiyya* with open intervals, it was intolerable and CGI was disturbing in all cases except for the *mashrabiyya* with closed intervals where it was perceptible. Based on the studies of Jakubiec and Reinhart,[29] the DGI, CGI and UGR are useful only under conditions where direct sunlight will not enter the space and where the window is a medium-sized source of contrast-based glare. However, CGI is the most robust of the three metrics as it consistently predicts a higher discomfort possibility, that is, representing a worst-case comfort scenario. VCP produces the least values and, as it was developed only for very specific, artificially lit circumstances, it is not recommended for daylit scenes; and was therefore neglected in the results of the simulation. On the other hand, DGP responds to most daylit situations, including those with many or large solid angle and direct or specular luminance sources, as it is based on contrast as well as vertical eye illuminance whereas other metrics rely wholly upon contrast. In this regard, DGP was found to be the most robust glare metric.[29]

Surprisingly, the airflow simulation showed that the *sheesh*, when closed, admitted no air at all. On the other hand, the *mashrabiyya* with closed intervals provided a favourable airflow pattern: the air covered most of the room's heights, including the lowest levels, with a velocity of 0.1–0.24 m/s, and moved upwards to be released through the upper lattice. Opening the *mashrabiyya*'s intervals would provide more room coverage and increases air movement with a velocity of 0.1–0.3 m/s. In this case, the air release through the upper part of the *mashrabiyya* is also maintained (see Table 7).

When the conventional *sheesh* was opened for ventilation purposes, the airflow pattern obtained shows air movement and room coverage was similar to the third case (*mashrabiyya* with open intervals), but with a lower velocity (0.1–0.22 m/s). However, the air was released through the entire opening and the airflow was shown to have no specific direction.

In order to increase the daylight performance of the proposed latticework device, the open intervals between the mullions of the upper part need to be increased. The sizes of the mullions of the two lattices of the part below eyelevel also need to be reduced and the intervals between them increased.

The airflow rates, ACH, fresh air rate per person and fresh air rate per square metre, for the four cases were above the minimum recommended rates. However, the closed *sheesh* had the least rates on the border line of the recommended values. It is worth noting that the *mashrabiyya* with open and closed intervals had similar rates. This means that by closing the intervals below eyelevel for privacy or intense lighting problems, the *mashrabiyya* would still provide adequate fresh air from the upper part. Also, it was logical that by entirely opening the *sheesh*, the best airflow rates would be obtained. This feature was also provided by the new *mashrabiyya*.

As mentioned earlier in the description of the proposed device, the section below eyelevel would open upwards at any angle and is equipped with a part that can be lowered. This mechanism would provide privacy and daylight while intercepting direct sunrays.

Conclusion

This paper assessed and compared between the daylight, discomfort glare indexes, airflow patterns and airflow rates of the conventional Egyptian shutter, *sheesh*, and a proposed latticework device derived from the traditional Islamic *mashrabiyya* and the traditional Japanese townhouse lattices, *machiya no kōshi*, using simulation tools. The simulations were carried out in a southward facing standard living room of a housing unit, when equipped with *sheesh* versus the new *mashrabiyya*. Ecotect, Radiance, Evalglare and WinAir simulating tools were used.

The findings show that when occupants shut the *sheesh* for shading or privacy purposes, no air was admitted at all giving a very dim interior as a result. By contrast, opening *sheesh* for ventilation purposes was likely to produce visual (and of course thermal) discomfort. On the other hand, the use of the new *mashrabiyya* was shown to provide a favourable airflow pattern whether the intervals between its vertical mullions are closed or opened. The airflow rates (air change per hour, fresh air rate per person and fresh air rate per square metre) for all cases were above the minimum recommended rates. However, the closed *sheesh* had the least rates on the border line of the recommended values. On the other hand, by closing the intervals below eyelevel for privacy or intense lighting problems, the *mashrabiyya* would still provide adequate fresh air from the upper part. Illuminance in most of the room was better than the case of when *sheesh* was used; and when adjusted, would provide comfort for the occupants. DGP was found imperceptible in all cases. For comparison and improvement purposes, further investigation in terms of thermal performances is needed.

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