

THERMAL AND DAYLIGHT PERFORMANCE OF TILTED GLASS AS
SHADING ALTERNATIVE IN HOT ARID CLIMATE OF BAGHDAD

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*To my beloved parents and siblings,
For their love, support and prayers.*

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ABSTRACT

Solar gain mitigation in buildings is essential to achieve thermal comfort and reduce cooling load in hot arid climate. Opaque shading is a useful strategy to block solar radiation in excessively hot locations like Baghdad. However, such shading comes at the expense of daylight illuminance and the openness of the window. A review of previous studies showed a gap in investigating the potentials of the clear glass in reducing solar gain. Solar transmittance through glass is angular dependent. The transmitted radiation decreases with bigger angles of incidence following increased reflection and reduced solar intensity. This research investigated the effects of using glass slats tilted away from the sun as an alternative to conventional horizontal shading on thermal and daylight performances of southwest rooms in commercial buildings in Baghdad. Integrated Environmental Solutions-Virtual Environment simulation tool was used to conduct the study. Six simulation cases were formulated; the base case used the common 75 centimetres overhang, the horizontal shading case had an additional three 75 centimetres horizontal shading devices, and four cases of 50°, 60°, 70° and 80° tilted glass slats in addition to the overhang. The simulation was run for seven representative days during the predominantly cooling season from April to October. Reductions in the solar gain, air temperature and mean radiant temperature using the slats were significant, especially at lower solar angles. For example, on September 21st, the solar gain of the base case was reduced by 71%, 69%, 57% and 46% with the glass slats tilted at 50°, 60°, 70° and 80° respectively compared to 61% reduction through horizontal shading. On the same day, the average air temperature was reduced between the range of 2.2–3.3°C with the slats compared to 2.7°C with the horizontal shading; the mean radiant temperature was reduced by 2.3–3.4°C with the slats compared to 2.8°C with the horizontal shading. The daylight average illuminance was decreased by around 58%, 32%, 24% and 23% by using glass slats tilted at 50°, 60°, 70° and 80° respectively compared to around 78% decrease by using horizontal shading with an average illuminance of below 100 lux in most simulated hours. However, the glass slats failed to raise the low illuminance uniformity to the acceptable threshold due to higher illuminance levels near the window and lower illuminance levels at the rear part of the room, unlike the horizontal shading that reached the acceptable to the preferable uniformity levels in most simulated hours. This study showed that replacing the conventional opaque horizontal shading with tilted glass slats, especially at an angle of 60°, can have a better impact in improving the heat mitigation by solar radiation and increasing daylight availability in the study area. Furthermore, these improvements were obtained without compromising the openness of the window.

ABSTRAK

Pengurangan penerimaan solar dalam bangunan adalah penting untuk mencapai kesejahteraan termal dan mengurangi beban penyejukan dalam iklim panas yang kering. Pelindung legap adalah strategi yang berkesan untuk menghalang radiasi solar di lokasi yang sangat panas seperti Baghdad. Walau bagaimanapun, pelindung ini memberi kesan terhadap kuantiti pencahayaan cahaya siang dan keterbukaan tingkap. Tinjauan terhadap kajian sebelum ini menunjukkan adanya jurang dalam mengkaji potensi kaca jernih untuk mengurangkan penerimaan solar. Kepancaran solar melalui kaca bergantung kepada sudut. Radiasi yang dipancarkan berkurangan dengan sudut tuju yang lebih besar berikutan peningkatan pantulan dan pengurangan intensiti solar. Kajian ini menyelidik kesan penggunaan bilah kaca condong yang dicondongkan dari matahari sebagai alternatif kepada pelindung mendatar konvensional terhadap haba dan cahaya siang di bilik barat daya dalam bangunan komersial di Baghdad. Program simulasi *Integrated Environmental Solutions-Virtual Environment* digunakan untuk menjalankan kajian ini. Enam kes simulasi telah dirumuskan; kes asas mempunyai unjuran yang biasa digunakan sebanyak 75 sentimeter; kes pelindung mendatar mempunyai tambahan tiga 75 sentimeter alat pelindung mendatar, dan empat kes bilah kaca dicondongkan sebanyak 50°, 60°, 70° dan 80° selain unjuran. Simulasi dijalankan selama tujuh hari yang mewakili musim sejuk yang dominan dari April hingga Oktober. Pengurangan penerimaan solar serta suhu udara dan min pancaran oleh bilah tersebut adalah ketara, terutamanya pada sudut matahari yang lebih rendah. Sebagai contoh, pada 21 September, penerimaan solar bagi kes asas berkurangan sebanyak 71%, 69%, 57% dan 46% oleh bilah kaca yang dicondongkan pada 50°, 60°, 70° dan 80° berbanding pengurangan 61% oleh pelindung mendatar. Pada hari yang sama, purata suhu udara berkurang antara 2.2–3.3°C bagi penggunaan bilah kaca berbanding 2.7°C oleh pelindung mendatar; suhu min pancaran berkurang antara 2.3–3.4°C bagi penggunaan bilah kaca berbanding 2.8°C oleh pelindung mendatar. Purata cahaya siang menurun sebanyak 58%, 32%, 24% dan 23% oleh bilah kaca yang dicondongkan pada 50°, 60°, 70° dan 80° berbanding dengan pengurangan 78% oleh alat pelindung mendatar dengan purata pencahayaan di bawah 100 lux dalam kebanyakan masa simulasi. Walau bagaimanapun, bilah kaca gagal untuk meningkatkan keseragaman pencahayaan yang rendah sehingga ke tahap yang dapat diterima disebabkan tahap pencahayaan yang lebih tinggi berhampiran dengan tingkap dan tahap pencahayaan yang lebih rendah di bahagian belakang bilik, berbeza dengan pelindung mendatar yang mencapai tahap keseragaman diterima hingga lebih baik dalam kebanyakan masa simulasi. Kajian ini menunjukkan bahawa dengan menggantikan pelindung mendatar legap konvensional dengan bilah kaca condong, terutamanya pada sudut 60°, boleh memberi impak yang lebih baik dalam memperbaiki pengawalan haba oleh sinaran solar dan meningkatkan cahaya siang di kawasan kajian. Tambahan itu, penambahbaikan ini diperolehi tanpa menjejaskan keterbukaan tingkap ke arah luar.

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LIST OF ABBREVIATIONS

ASHRAE	-	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
BC	-	Base case
CIBSE	-	The Chartered Institution of Building Services Engineers
COSQC	-	Central Organization for Standardization and Quality Control (Iraq)
GCB	-	General Commission of Buildings (Iraq)
GDP	-	Gross domestic product
HSD	-	Horizontal shading device
HVAC	-	Heating, ventilation, and air conditioning
ICSO	-	Iraqi Central Statistical Organization
IEA	-	International Energy Agency
IESVE	-	Integrated Environmental Solutions-Virtual Environment
IBPSA-USA	-	The United States regional affiliate of the International Building Performance Simulation Association
LBL	-	Lawrence Berkeley National Laboratory
LEED	-	Leadership in Energy and Environmental Design
MBE	-	Mean bias error
MRT	-	Mean radiant temperature
RA	-	Room area
RMSE	-	Root mean square error
SL50	-	Glass slats layer tilted at 50°
SL60	-	Glass slats layer tilted at 60°
SL70	-	Glass slats layer tilted at 70°
SL80	-	Glass slats layer tilted at 80°
UAE	-	United Arab Emirates
WA	-	Window area
WWR	-	Window-to-wall ratio

LIST OF SYMBOLS

A	-	Absorptance (dimensionless)
AT	-	Air temperature ($^{\circ}\text{C}$)
$A_{sl,wd}$	-	Combined absorptance and reflectance of the slats and window (dimensionless)
A_{total}	-	Absorptance after deduction of the slats' cosine law effect (dimensionless)
b	-	Back surface
d	-	Thickness (mm)
E	-	Atmospheric extinction coefficient (dimensionless)
f	-	Front surface
I	-	Global solar radiation (W/m^2)
I_0	-	Extraterrestrial radiant flux (W/m^2)
I_D	-	Direct solar radiation from the sun (W/m^2)
I_d	-	Diffuse solar radiation from the sky (W/m^2)
I_{dH}	-	Diffuse horizontal radiation (W/m^2)
I_{DN}	-	Direct normal radiation (W/m^2)
I_{dS}	-	Diffuse radiation for inclined surface (W/m^2)
I_{dv}	-	Diffuse radiation for vertical surface (W/m^2)
I_R	-	The reflected solar radiation (W/m^2)
I_{RS}	-	Reflected radiation for inclined surface (W/m^2)
I_{sc}	-	Solar constant (W/m^2)
k	-	Proportionality constant (dimensionless)
K	-	Kelvin
L_{im}	-	i^{th} measured value (unit of the variable)
L_{is}	-	i^{th} simulated value (unit of the variable)
lux	-	Lighting power density (lm/m^2)
N	-	Total number of data pairs

n	-	Refractive index (dimensionless)
p	-	Perpendicular polarisation of the solar wave
R	-	Reflectance (dimensionless)
R_{sl}	-	Reflectance of the slats (dimensionless)
$R_{sl,wd}$	-	Combined reflectance of the slats and window (dimensionless)
R_{total}	-	Reflectance in addition to transmittance and absorptance deducted by slats' cosine law effect (dimensionless)
R_{wd}	-	Reflectance of the window (dimensionless)
s	-	Parallel polarisation of the solar wave
T	-	Transmittance (dimensionless)
T_{out}	-	Outdoor temperature (°C)
T_{sl}	-	Transmittance of the slats (dimensionless)
$T_{sl,wd}$	-	Combined transmittance and reflectance of the slats and window (dimensionless)
T_{total}	-	Transmittance after deduction of the slats' cosine law effect (dimensionless)
T_{wd}	-	Transmittance of window (dimensionless)
x	-	Day of the year
Z	-	Solar azimuth (°)
Z_B	-	Wall normal in respect to the north
α	-	absorptivity (dimensionless)
β	-	Solar altitude (°)
δ	-	Inclination angle of the surface to the horizontal (°)
θ	-	Angle of incidence (°)
θ_{sl}	-	Angle of incidence of the slats (°)
θ_{wd}	-	Angle of incidence of the window (°)
κ	-	Glass extinction coefficient (dimensionless)
λ	-	Wavelength (μm)
μ	-	Solar wave polarisation
ρ	-	reflectivity (dimensionless)
ρ_g	-	Reflectivity of surrounding surfaces (dimensionless)
τ	-	transmissivity (dimensionless)
φ	-	Bearing angle (°)
ζ	-	Refracted angle (°)

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CHAPTER 1

INTRODUCTION

1.1 Background

Buildings consume substantial amounts of energy. The rise in world population associated with improvement in living standards leads to more energy demand. Energy savings in the building sector have high potentials in lowering carbon emissions and hence reducing the effects of global warming. By adapting technology along with energy efficiency policies in buildings, a global energy saving equivalent to the 2012 energy consumption of China, United States, Russia, Germany, France and the United Kingdom can be achieved by 2050 (IEA, 2015).

Iraq has significant growth in the gross domestic product (GDP) in recent years (World Bank, 2017). This growth, along with rising population, leads to more energy consumption as shown in Figure 1.1. Electrical appliances especially air conditioners are increasingly used with little attention to passive cooling design. Building sector is the largest consumer of the produced electric power in Iraq (Hashem, 2017). Increasing CO₂ emissions is expected because most of the electricity supplies in Iraq come from non-sustainable sources as shown in Figure 1.2 (Saeed *et al.*, 2016).

In most regions of Iraq, the cooling season extends from April until October. Summer harsh weather is featured with temperatures soaring to high levels that even exceed 50°C on some days which add huge demand for electricity (Kharrufa, 2008).

Adapting sustainability in buildings is crucial in lowering energy demand. The main goal in this aspect is heat mitigation to reduce the cooling load. This reduction could be achieved through preventing heat from solar radiation, as much as possible, from entering the buildings.

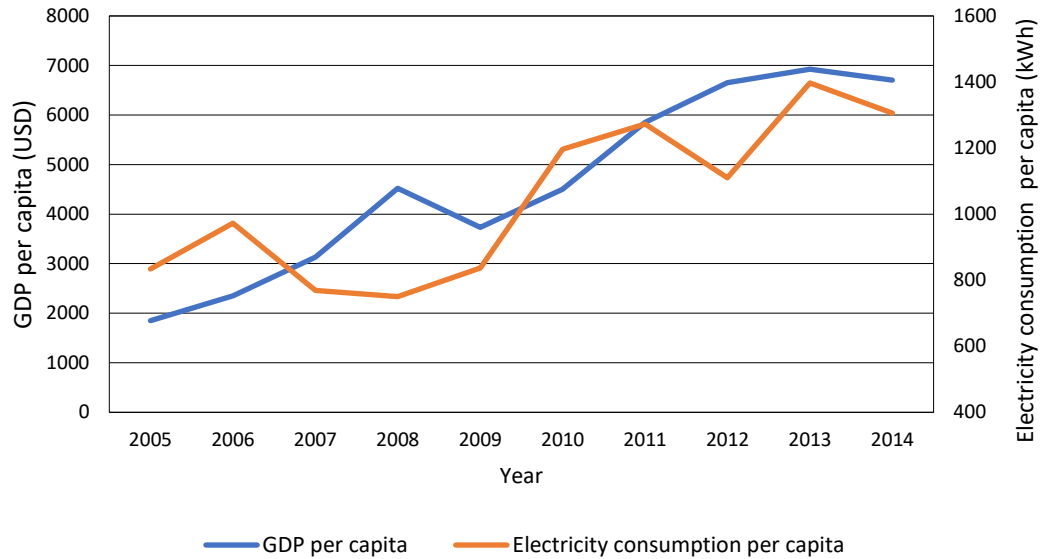


Figure 1.1 Annual electricity consumption and GDP per capita in Iraq. Data source: World Bank (2017)

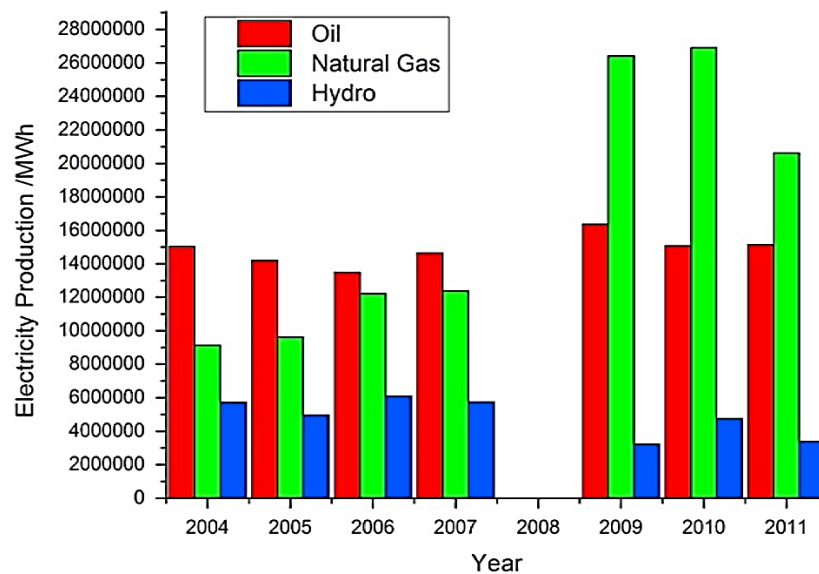


Figure 1.2 Electricity production sources in Iraq. Source: Saeed *et al.* (2016)

1.2 Problem Background

Our thermal environment is determined mainly by the sun (Harkness and Mehta, 1978). According to Lechner (2014), the top climatic design priorities for desert climate is to keep heat out and achieve protection from the sun in summer. Figure 1.3 presents the three tiers approach for building design in hot and dry climates. The best way to avoid heat gain is not by eliminating undesirable heat but by excluding it in the first place (Olgay, 1957).

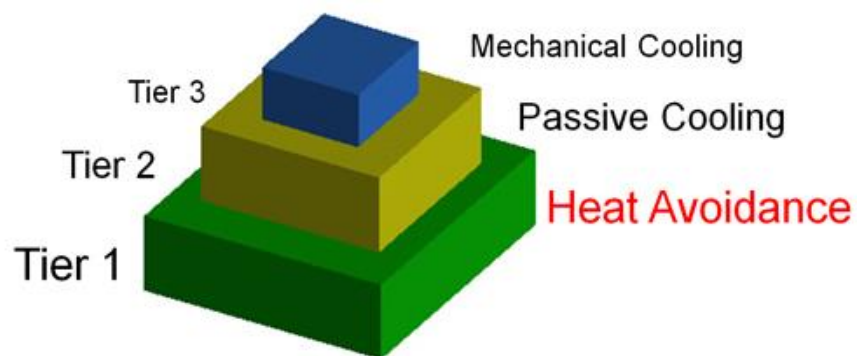


Figure 1.3 Three-tier approach for sustainable building cooling. Source: Lechner (2014)

The long summer in Baghdad means that the building facades are exposed to lower sun angles in the periods far from the maximum solar altitude of the summer solstice. Further, the prevailing direction for main streets in Baghdad is northwest-southeast which makes the buildings located on their sides face southwest or northeast. The southwest buildings, in particular, are more exposed to lower sun angles that require deep shading to cover.

The shading depth is calculated for southwestern facades according to Olgay (1957), Givoni (1998), Szokolay (2004) and Lechner (2014) from the sun path diagram (Figure 1.4). The last day of the cooling season was defined as October 31st when the sun faces the window directly at an altitude angle of 30° around 14:30. As shown in Figure 1.5, the intersection of the sun position at this altitude with window sill requires

an overhang depth of around 3 m. Shading for lower sun angles requires even deeper shading.

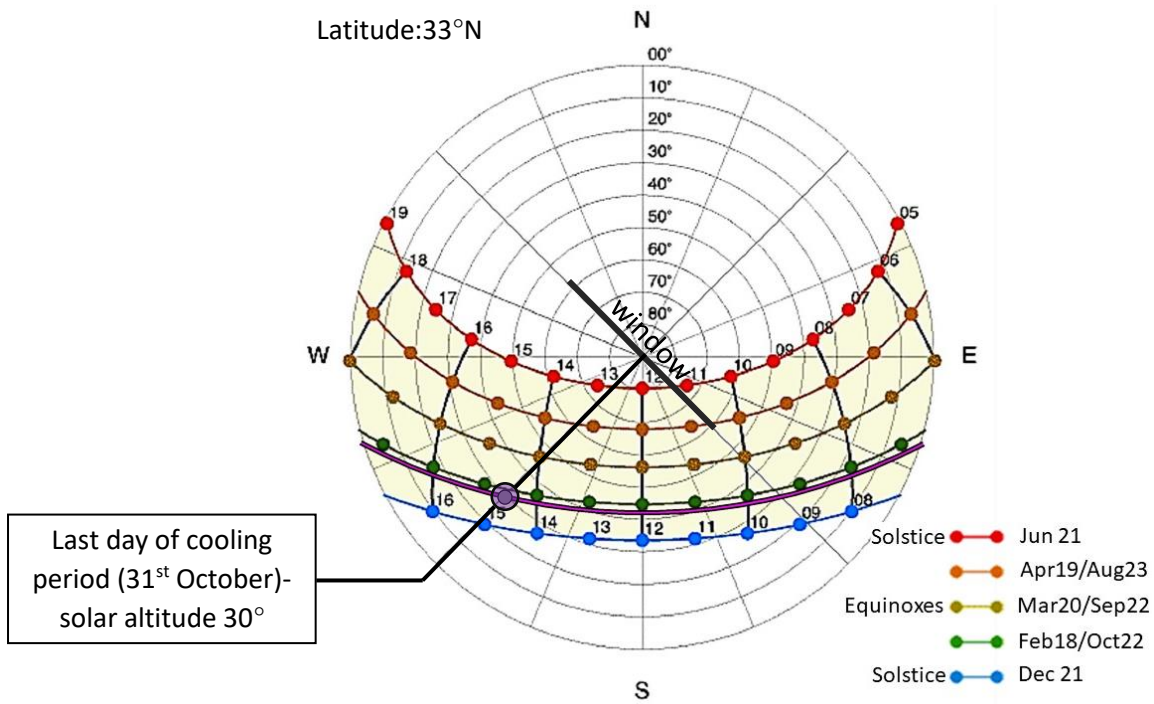


Figure 1.4 Shading angle determination for southwest windows in Baghdad (Latitude 33°N) on the stereographic sun path diagram. Diagram source: adapted from University of British Columbia (2011)

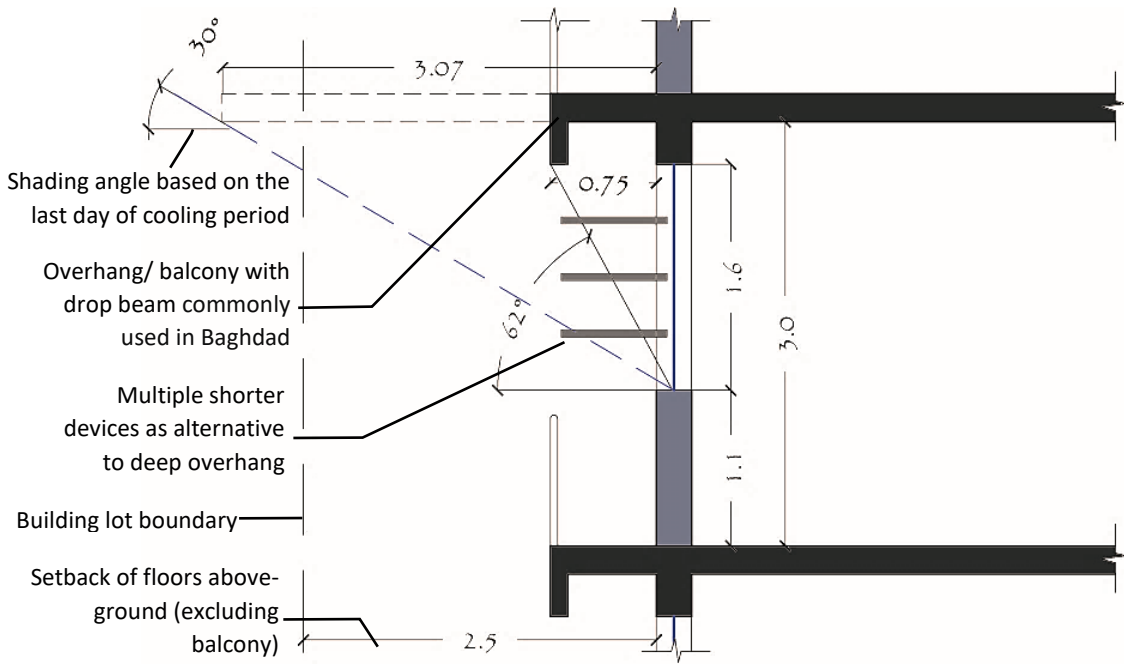


Figure 1.5 Section through a typical room in commercial buildings in Baghdad

Obviously, the deep overhang is not practical due to its size that extends outside the building lot boundary as shown in Figure 1.5. On the other hand, this overhang does not match with the local regulations of Baghdad city for commercial buildings. The building regulations issued by Design Department in Baghdad Mayorality allow only for 75 cm protrusion as open balconies on the floors above the ground floor (Baghdad Mayorality, 2007).

The overhang/balcony (75 cm) can provide relatively adequate shading for a maximum solar altitude angle of 62° (Figure 1.5) which is efficient shading according to the stated method for the period from late April until the beginning of August when the sun faces the window directly. However, this shading is not sufficient when the sun moves to lower position towards the west during this period or the rest of the cooling season when the low sun faces the window particularly in September and October (Figure 1.4).

To overcome the architectural problem created by the deep overhang, alternatives of shorter shading devices can have the equivalent solar protection effect of larger devices (Lechner, 2014; Olgyay, 1957). This could be achieved for the case of southwestern facades in this study context by dividing the deep overhang to three horizontal devices of 75 cm that make, along with the commonly used overhang, a shading effect of one deep overhang. Although the horizontal shading device has the least obstruction to outside visibility due to its minimal impact on the horizontal view (Lechner, 2014), the deep shading still has a negative effect on the daylight availability whether it is a single large piece or smaller pieces with the same performance.

Apart from the horizontal shading, other adaptations are used in Baghdad to reduce the solar radiation and its excessive heat effect, for example, using small and recessed windows, vertical shading elements and solid shading screens. Other adaptations include hanging pieces of canvas/cloth, fixing the commercial signboards in front of the window, applying frosted films to the glass or adding a layer of reflective glass to the balcony. Appendix A presents photos of some of these adaptations.

One of the main functions of windows is the visual connection between outside and inside. This function is highly emphasised in modern architecture by having bigger areas of glazed facade to provide outside visibility and natural light (Kirimtat *et al.*, 2016). Menzies and Wherrett (2005) explained that besides the interaction with outside environment and allowing more daylight, bigger windows could have better psychological effect that leads to improved productivity in work spaces.

All the above-mentioned adaptations lead to outside visibility obstruction. A smaller window results also in less daylight and less connectivity to outside. The canvasses, solid screens, signboards and frosted films have the most damaging effect on outside visibility. Even in the case of reflective glass, though transparent, it cuts a substantial amount of useful daylight (Lechner, 2014) and it can have harmful solar reflection effect on the street. Although air conditioner can bring the internal temperature down, the required cooling energy is very high that makes these adaptations necessary, particularly with frequent power failure during the hottest days.

1.3 Problem Statement

Deep shading of 3 m or its equivalent is required for southwest facades in Baghdad to reduce direct solar radiation. However, this kind of shading can obstruct visibility and eliminate useful daylight when the sun is not facing the window directly as noticed in current shading practice in commercial buildings. There is a need to find shading alternative that may overcome this problem.

1.4 Hypothesis

This study hypothesises that tilted glass slats, when fixed in front of a window, can be an alternative to conventional opaque shading by utilising the optical properties of glass in its interaction with solar radiation to increase reflection due to bigger angles

of incidence. Furthermore, the tilt effect decreases the solar exposure on the glass surface following the cosine law (Figure 1.6). The hypothesised effects of these glass slats are:

- i. Reducing solar gain.
- ii. Improving the daylight performance.

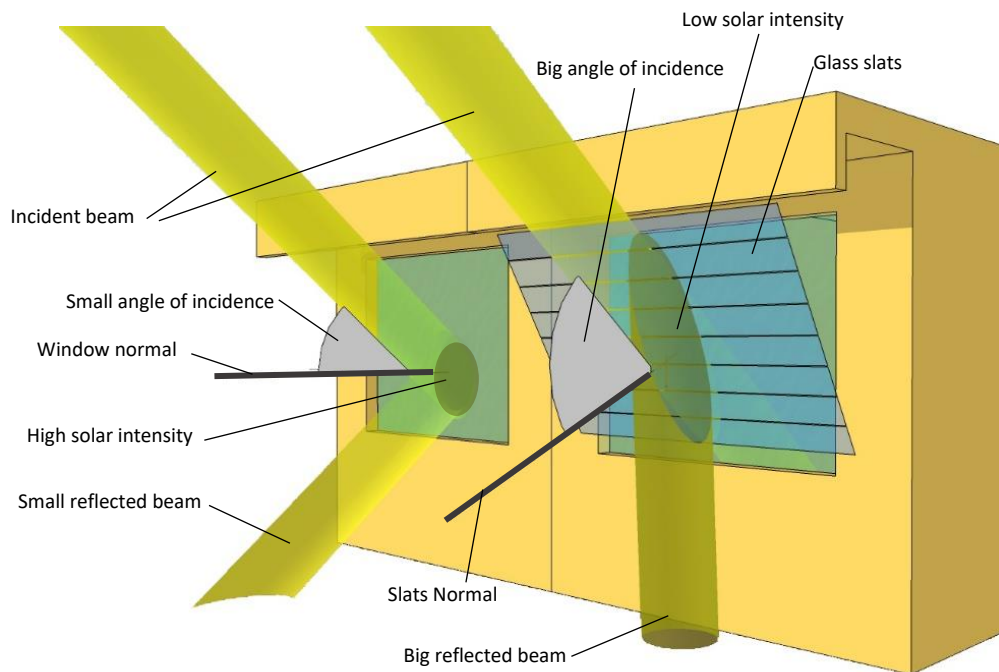


Figure 1.6 Bigger angles of incidence maximise solar reflection and reduce solar intensity by distributing radiation over a wider area

1.5 Research Aim

This research aims to investigate the effects of using tilted glass slats as an alternative to conventional horizontal shading on thermal and daylight performances of southwest rooms in commercial buildings in Baghdad.

1.6 Research Objectives

In order to achieve the research aim, the following research objectives were formulated:

1. To analyse and compare the effects of enhancing the existing 75 cm overhang with multiple horizontal shading devices (equivalent to deep shading of 3 m) and tilted glass slats at 50°, 60°, 70° and 80° angles on the solar gain and indoor temperature.
2. To examine the effects of the above-mentioned horizontal shading devices and tilted glass slats on the daylight illuminance level and uniformity.

1.7 Research Questions

1. What are the effects of the horizontal shading devices and the tilted glass slats when added to the existing overhang on the solar gain and indoor temperature?
2. What are the effects of the horizontal shading devices and the tilted glass slats when added to the existing overhang on the daylight illuminance level and uniformity?

1.8 Research Scope and Limitations

This research was based on numerical simulation that was performed for the hot arid climate of the city of Baghdad, Iraq. A full-scale field experiment was not conducted due to resources and time limitations. However, validation experiment was conducted to check the reliability of the simulation tool in predicting the thermal performance while the prediction of daylight performance by the simulation tool was

reviewed in previous studies in similar contexts. The research focuses on summer season only that requires a substantial cooling load to make buildings and spaces thermally tolerable due to the very high outdoor temperature.

The study scale is one generic room located in an above-ground floor in a commercial building. The selected orientation is the common southwest facade. Room and window dimensions, as well as the characteristics of construction materials were used as constant variables.

The glass type used for the tilted slats and the window was uncoated layer of 3 mm clear float glass fixed in front of the window at four angles with increments of 10° each. The size of the slats and the gaps between them were not calculated as ventilation is outside the scope of this research. The assumption of using smaller slats instead of one big piece of glass was to consider making the area between the glass and the window fully ventilated from the front in addition to the sides to avoid heat trap and neutralise the temperature in this area (Hashemi *et al.*, 2010). In any case, the slats were assumed to be overlapped in a way that does not allow for solar radiation to penetrate in between the slats. The suggested slats are assumed to reflect part of the radiation towards the overhang of the lower floor; the heating impact of such reflection on the room thermal performance was not considered in this study. The comparable tested shading device was the opaque horizontal type. Both of the slats and horizontal shading were external; the internal shading was not covered in this study.

The measured thermal performances were the solar gain, air temperature and mean radiant temperature in passive mode for 24 hours on one selected day of each month of the cooling season. Average illuminance and illuminance uniformity of daylight were measured in an area of interest in the middle of the room under clear sky condition. Daylight factor and glare analysis were not included in this research. The natural ventilation was not considered. Table 1.1 summarises the constant, dependent and independent variables of this research.

Table 1.1 Constant, dependent and independent variables of the research

Type of variable	Variable	Details
Constant variables	Climate	Hot dry climate of Baghdad
	Period	Cooling period (April–October)
	Orientation	Southwest
	Scale	Generic room
	Window-to-wall ratio	36%
	Constructions	Common local materials (see Table 3.2)
	Glass (window and tilted slats)	3 mm clear uncoated glass
Independent variables	Shading device	Overhang and horizontal shading devices
	Tilted glass slats angles	50°, 60°, 70° and 80°
Dependent variables	Thermal performance	Solar gain, air temperature and mean radiant temperature
	Daylight performance	Illuminance levels, average illuminance and illuminance uniformity

1.9 Research Significance

Heat gain avoidance is the primary challenge for the built environment in desert climates to achieve sustainability. A major approach in this aspect is done by controlling fenestration that can be achieved, for example, by reducing the window size or shading it densely. In both cases, this affects the building openness and the daylight potentials. In many other cases, bigger windows are associated with more solar gain and higher cooling loads. There are limited studies conducted on shading techniques specifically in Baghdad. This study is expected to give a better understanding of the effect of the commonly used overhang on building thermal and daylight performances.

This research attempts to test enhancing the overhang with tilted slats of clear glass as an alternative to opaque horizontal shading devices. In practice, the clear glass is the most affordable type of glazing that provides maximum visible transmittance. The suggested technique is passive and focuses more on fixing geometry rather than using complex systems or materials. These slats are retrofittable to the existing buildings in addition to their ability to be integrated in new buildings.

1.10 Thesis Organization

The thesis is arranged in five chapters as illustrated below.

Chapter 1 presents the background of this research and the problem addressed in this study. The research objectives and the research questions are set in this chapter along with the research scope, limitations and research significance.

Chapter 2 focuses on the literature review by presenting a theoretical background of solar radiation and geometry, and glass optical properties. Previous studies related to shading are also presented and discussed.

Chapter 3 provides an overview of the study context and an explanation of the followed methodology in conducting this study and analysing the results. It also presents the field experiment that was performed to validate the thermal simulation software and experiments that were used by other researchers to validate the daylight simulation software.

Chapter 4 presents the simulation results with analysis of the thermal and daylight performances of the different studied cases. Furthermore, it presents a discussion on the relation between the obtained findings and the solar behaviour of the study context.

Chapter 5 concludes the research by presenting a summary of the study findings along with recommendations and possible future studies in light of this study findings.

- Ali, A. A. E.-M. M. (2012). Using simulation for studying the influence of vertical shading devices on the thermal performance of residential buildings (Case study: New Assiut City). *Ain Shams Engineering Journal*, 3(2), 163-174.
- Almaiyyah, S., and Elkadi, H. (2012). Study on the visual performance of a traditional residential neighborhood in old Cairo. *Journal of Urban Technology*, 19(4), 59-86.
- Ander, G. D. (2003). *Daylighting performance and design* (2nd ed.). Hoboken, New Jersey John Wiley & Sons.
- Aschwanden, M. (2006). *Physics of the solar corona: an introduction with problems and solutions*. Chichester, UK: Springer Science & Business Media.
- ASHRAE. (2005). *Fundamentals (SI Edition)* Atlanta: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.
- ASHRAE. (2013). *ANSI/ASHRAE Standard 55-2013: Thermal Environmental Conditions for Human Occupancy*. Atlanta: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.
- ASHRAE. (2017). *Fundamentals (SI Edition)* Atlanta: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.
- Baghdad Mayoralty. (2007). Planning and Lots Divisions Regulations in Baghdad "في مدينة بغداد مجموعة الضوابط التخطيطية للبناء وتقسيم الاراضي". Baghdad: Baghdad Mayoralty, Design Department.
- Big Ladder. (2015). Angular Properties for Uncoated Glass. Available from: <https://bigladdersoftware.com/epx/docs/8-4/engineering-reference/window-calculation-module.html#glass-optical-properties-conversion>. [02/02/2018].
- Boubekri, M. (2008). *Daylighting, architecture and health*. Oxford, UK: Routledge.
- Cho, J., Yoo, C., and Kim, Y. (2014). Viability of exterior shading devices for high-rise residential buildings: Case study for cooling energy saving and economic feasibility analysis. *Energy and Buildings*, 82, 771-785.
- CIBSE. (2004). Energy efficiency in buildings, *Guide F*. London, UK: The Chartered Institution of Building Services Engineers.
- CIBSE. (2006). Environmental design Guide A. London, UK: The Chartered Institution of Building Services Engineers.
- David, M., Donn, M., Garde, F., and Lenoir, A. (2011). Assessment of the thermal and visual efficiency of solar shades. *Building and Environment*, 46(7), 1489-1496.

- Dodo, Y. A., Kandar, M. Z., Ossen, D. R., Jibril, J. D., Bornoma, A. H., and Abubakar, A. I. (2013). *Importance of a view window in rating green office buildings*. Paper presented at the Advanced Materials Research, 180-183.
- Dubois, M.-C. (2001). *Impact of shading devices on daylight quality in offices*. Lund, Sweden: Lund Institute of Technology.
- Dubois, M.-C. (2003). Shading devices and daylight quality: an evaluation based on simple performance indicators. *Lighting Research & Technology*, 35(1), 61-74.
- El Sherif, S. K. (2012). *The Impact of Overhangs and Side-fins on Building Thermal Comfort, Visual Comfort and Energy Consumption in the Tropics*. The British University in Dubai (BUiD).
- Enteria, N., and Akbarzadeh, A. (2013). *Solar energy sciences and engineering applications*. London, UK: CRC Press.
- Estidama. (2010). *Pearl Building Rating System: Design & Construction*. Abu Dhabi, UAE: Abu Dhabi Urban Planning Council.
- Freewan, A., Shao, L., and Riffat, S. (2008). Optimizing performance of the lightshelf by modifying ceiling geometry in highly luminous climates. *Solar Energy*, 82(4), 343-353.
- Freewan, A. A. (2014). Impact of external shading devices on thermal and daylighting performance of offices in hot climate regions. *Solar Energy*, 102, 14-30.
- Furler, R. A. (1991). Angular dependence of optical properties of homogeneous glasses. *Ashrae Transactions*, 97(2), 1129-1133.
- Galasiu, A. D., and Veitch, J. A. (2006). Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review. *Energy and Buildings*, 38(7), 728-742.
- GCB, and COSQC. (2013a). Iraqi Natural Lighting Code, "مدونة الانارة الطبيعية-مدونة "بناء عراقية". Baghdad: General Commission of Buildings; Central Organization for Standardization and Quality Control الهيئة العامة للمباني; وزارة الاعمار والاسكان"- الجهاز المركزي للتقييس والسيطرة النوعية
- GCB, and COSQC. (2013b). Iraqi Internal Lighting Code, "مدونة الانارة الداخلية-مدونة "بناء عراقية". Baghdad: General Commission of Buildings; Central Organization for Standardization and Quality Control الهيئة العامة للمباني; وزارة الاعمار والاسكان"- الجهاز المركزي للتقييس والسيطرة النوعية

- GCB, and COSQC. (2013c). Iraqi Thermal Insulation Code, "مدونة العزل الحراري- مدونة
مدونة العزل الحراري- مدونة
عراقية". Baghdad: General Commission of Buildings; Central Organization
for Standardization and Quality Control الهيئة العامة
وزارة الاعمار والاسكان"-
المباني; وزارة التخطيط- "الجهاز المركزي للتقييس والسيطرة النوعية
- Givoni, B. (1981). *Man, climate and architecture* (2nd ed.). London, UK: Elsevier.
- Givoni, B. (1998). *Climate considerations in building and urban design*. New York:
Van Nostrand Reinhold.
- Google Maps. (2017). Baghdad Map. Available from:
<<https://www.google.com/maps/>>. [12/07/2017].
- Graham, S. (1999). Clouds & radiation. *Feature article published in Earth
Observatory Available from: <http://earthobservatory.nasa.gov>.*
- Haberl, J., and Bou-Saada, T. (1998). Procedures for calibrating hourly simulation
models to measured building energy and environmental data. *Journal of solar
energy engineering, 120*(3), 193-204.
- Hammad, F., and Abu-Hijleh, B. (2010). The energy savings potential of using
dynamic external louvers in an office building. *Energy and Buildings, 42*(10),
1888-1895.
- Harkness, E. L., and Mehta, M. L. (1978). *Solar radiation control in buildings*.
London, UK: Applied science publishers.
- Hashem, A. L. (2017). Assessment of embedding phase change materials in
heavyweight buildings in Iraq using ESP-r. *Al-Qadisiyah Journal for
Engineering Sciences, 8*(3), 386-397.
- Hashemi, N., Fayaz, R., and Sarshar, M. (2010). Thermal behaviour of a ventilated
double skin facade in hot arid climate. *Energy and Buildings, 42*(10), 1823-
1832.
- Heschong, L., Mahone, D., Kuttaiah, K., Stone, N., Chappell, C., McHugh, J., *et al.*
(1999). Skylighting and retail sales: an investigation into the relationship
between daylighting and human performance. *San Francisco, CA: Pacific
Gas and Electric Co, 12-13.*
- Hopkinson, R. G., Petherbridge, P., and Longmore, J. (1966). *Daylighting*. London,
UK: Heinemann.
- IBPSA-USA. BEST, Building Energy Software Tools. Available from:
<<https://www.buildingenergysoftwaretools.com/>>. [10/01/2018].

- Ibrahim, A. W. M. (2013). *New Parametric workflow based on validated day-lighting simulation Building Simulation*. Paper presented at the 1st IBPSA Conference.
- ICSO. (2011). *General Census of Buildings and Establishments and the Inventory of Houses and Households 2010, Series of Reports of Numbering and Survey Results- Report No. (1)*
- التعداد العام للمباني والمنشآت وحصر المساكن والأسر 2010، سلسلة تقارير نتائج التقييم والحصر تقرير " رقم (1) تقرير المباني والأسر- المستوى الوطني " Retrieved. from <http://cosit.gov.iq/ar/>.
- ICSO. (2014). Population Projection by Governorates and Region For 2014. 2017, Available from:
<[http://www.cosit.gov.iq/AAS2016/population/population\(8\).htm](http://www.cosit.gov.iq/AAS2016/population/population(8).htm)>.
[November 2017].
- IEA. (2015). *Building Energy Performance Metrics- Supporting Energy Efficiency Progress in Major Economies*. Paris, France: International Energy Agency
- IESVE. (2015a). ApacheSim Calculation Methods User Guide: Integrated Environmental Solutions Limited.
- IESVE. (2015b). Apache-Tables User Guide: Integrated Environmental Solutions Limited.
- IESVE. (2015c). Construction Database User Guide: Integrated Environmental Solutions Limited.
- IESVE. (2015d). ApacheCalc (CIBSE Loads) User Guide: Integrated Environmental Solutions Limited.
- IESVE. (2015e). Vista User Guide: Integrated Environmental Solutions Limited.
- Jones, W. (2001). *Air Conditioning Engineering 4th Edition* by WP, Jones: Butterworth-Heinemann Reed Educational & Professional Publishing Ltd.
- Khan, N., Su, Y., and Riffat, S. B. (2008). A review on wind driven ventilation techniques. *Energy and Buildings*, 40(8), 1586-1604.
- Kharrufa, S. N. (2008). Evaluation of Basement' s Thermal Performance in Iraq for Summer Use. *Journal of Asian Architecture and Building Engineering*, 7(2), 411-417.
- Kim, G., Lim, H. S., Lim, T. S., Schaefer, L., and Kim, J. T. (2012). Comparative advantage of an exterior shading device in thermal performance for residential buildings. *Energy and buildings*, 46, 105-111.

- Kim, J. T., and Kim, G. (2010). Advanced external shading device to maximize visual and view performance. *Indoor and Built Environment*, 19(1), 65-72.
- Kirimtat, A., Koyunbaba, B. K., Chatzikonstantinou, I., and Sariyildiz, S. (2016). Review of simulation modeling for shading devices in buildings. *Renewable and Sustainable Energy Reviews*, 53, 23-49.
- Lam, W. M. C. (1986). *Sunlight As Formgiver For Architecture*. New York: Van Nostrand Reinhold Company.
- Lau, A. K. K., Salleh, E., Lim, C. H., and Sulaiman, M. Y. (2016). Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: The case of Malaysia. *International Journal of Sustainable Built Environment*, 5(2), 387-399.
- LBNL. (2017). WINDOW v7.6.4.0: Lawrence Berkeley National Laboratory.
- Lechner, N. (2014). *Heating, cooling, lighting: Sustainable design methods for architects* (4th ed.). Hoboken, New Jersey: John Wiley & Sons.
- Lenoir, A., Cory, S., Donn, M., and Garde, F. (2013). *Optimisation methodology for the design of solar shading for thermal and visual comfort in tropical climates*. Paper presented at the Proceedings of the 13th Conference of International Building Performance Simulation Association, Chambéry, France, 25-28.
- Lim, Y.-W., and Heng, C. (2016). Dynamic internal light shelf for tropical daylighting in high-rise office buildings. *Building and Environment*, 106, 155-166.
- Markus, T. A., and Morris, E. N. (1980). *Buildings, climate, and Energy*. London, UK: Pitman Publishing Ltd.
- Marsh, W. M., and Kaufman, M. M. (2012). *Physical Geography: Great Systems and Global Environments*. Cambridge, UK: Cambridge University Press.
- Melnikova, I. N., and Vasilyev, A. V. (2005). *Short-Wave Solar Radiation in the Earth's Atmosphere*. Berlin, Germany: Springer.
- Menzies, G., and Wherrett, J. (2005). Windows in the workplace: examining issues of environmental sustainability and occupant comfort in the selection of multi-glazed windows. *Energy and Buildings*, 37(6), 623-630.
- Meteoblue. (2018). Climate Archive. Available from: <https://www.meteoblue.com/>. [02/03/2018].

- Nabil, A., and Mardaljevic, J. (2005). Useful daylight illuminance: a new paradigm for assessing daylight in buildings. *Lighting Research & Technology*, 37(1), 41-57.
- Najim, K. B. (2014). External load-bearing walls configuration of residential buildings in Iraq and their thermal performance and dynamic thermal behaviour. *Energy and Buildings*, 84, 169-181.
- Najim, K. B., and Fadhil, O. T. (2015). Assessing and improving the thermal performance of reinforced concrete-based roofing systems in Iraq. *Energy and Buildings*, 89, 213-221.
- Nemer, T. H. (2015). *Use of Estidama Rating Tool to Assess Existing Building in Hot Dry Climate*. Universiti Teknologi Malaysia, Skudai, Malaysia.
- Nielsen, M. V., Svendsen, S., and Jensen, L. B. (2011). Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight. *Solar Energy*, 85(5), 757-768.
- Nikpour, M. (2014). *Heat gain and daylight assessment in self shading office buildings in tropical climate*. Universiti Teknologi Malaysia, Skudai, Malaysia.
- Olgyay, A. (1957). *Solar control and shading devices*. New Jersey: Princeton University Press.
- Olgyay, V., and Olgyay, A. (1963). *Design with climate*. New Jersey: Princeton University Press.
- Onset Computer Corporation. (2017). HOBOWare. Available from: <http://www.onsetcomp.com/hoboware>. [15/06/2017].
- Ossen, D. R. (2005). *Optimum Overhang Geometry for High Rise Office Building Energy Saving in Tropical Climates*. Unpublished PHD, Universiti Teknologi Malaysia.
- Owen, C., Pirie, D., and Draper, G. (2010). *Earth Lab: Exploring the Earth Sciences*. Belmont, California: Cengage Learning.
- Palmero-Marrero, A. I., and Oliveira, A. C. (2010). Effect of louver shading devices on building energy requirements. *Applied Energy*, 87(6), 2040-2049.
- Peel, M. C., Finlayson, B. L., and McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and earth system sciences discussions*, 4(2), 439-473.

- Prieto, A., Knaack, U., Klein, T., and Auer, T. (2017). 25 Years of cooling research in office buildings: Review for the integration of cooling strategies into the building façade (1990–2014). *Renewable and Sustainable Energy Reviews*, 71, 89-102.
- Quaschnig, V. (2003). The sun as an energy resource. *Renewable Energy World*, 6(5), 90-93.
- Rea, M. (1993). Lighting handbook: Reference and application (8e édition ed.). *New York*.
- Reinhart, C. F., and Wienold, J. (2011). The daylighting dashboard—A simulation-based design analysis for daylit spaces. *Building and environment*, 46(2), 386-396.
- Rubin, M. (1985). Optical properties of soda lime silica glasses. *Solar energy materials*, 12(4), 275-288.
- Ruggiero, F., Florensa, R. S., and Dimundo, A. (2009). Re-interpretation of traditional architecture for visual comfort. *Building and Environment*, 44(9), 1886-1891.
- Saeed, I. M., Ramli, A. T., and Saleh, M. A. (2016). Assessment of sustainability in energy of Iraq, and achievable opportunities in the long run. *Renewable and Sustainable Energy Reviews*, 58, 1207-1215.
- Safwat, A. (1999). *The Effect of nature on the Shaping of Residential Buildings at Nasser's Lake Zone*. Ain Shams University, Cairo.
- Saleh, S. (2011). Impact of urban expansion on surface temperature in Baghdad, Iraq using remote sensing and GIS techniques. *Canadian Journal on Environmental, Construction and Civil Engineering*, 2(8), 193-202.
- Sherif, A., El-Zafarany, A., and Arafa, R. (2012a). External perforated window Solar Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments. *Energy and Buildings*, 52, 1-10.
- Sherif, A., Sabry, H., and Rakha, T. (2012b). External perforated Solar Screens for daylighting in residential desert buildings: Identification of minimum perforation percentages. *Solar Energy*, 86(6), 1929-1940.
- Sherif, A. H., Sabry, H. M., and Gadelhak, M. I. (2012c). The impact of changing solar screen rotation angle and its opening aspect ratios on Daylight Availability in residential desert buildings. *Solar Energy*, 86(11), 3353-3363.

- Solar Radiation Monitoring Laboratory. (2013). Waldrum Sun Path Diagram 33°N. Available from: <<http://solardat.uoregon.edu/cgi-bin/SunChart.cgi>>. [18/12/2017].
- Sun Earth Tools. (2018). Sun Position. Available from: <<https://www.sunearthtools.com/>>. [01/02/2018].
- Szokolay, S. V. (2004). *Introduction to architectural science: the basis of sustainable design*. Burlington, MA: Architectural Press.
- Taleb, H. M. (2014). Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in UAE buildings. *Frontiers of Architectural Research*, 3(2), 154-165.
- Toe, D. H. C. (2013). *Application of Passive Cooling Techniques to Improve Indoor Thermal Comfort of Modern Urban Houses in Hot-Humid Climate of Malaysia*. Doctoral Dissertation, Hiroshima University, Hiroshima, Japan.
- Tutiempo Network. (2017). Climate Data. Available from: <<https://en.tutiempo.net/climate>>. [18/07/2017].
- Tzempelikos, A., and Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. *Solar Energy*, 81(3), 369-382.
- Ulpiani, G., Benedettelli, M., di Perna, C., and Naticchia, B. (2017). Overheating phenomena induced by fully-glazed facades: Investigation of a sick building in Italy and assessment of the benefits achieved via model predictive control of the AC system. *Solar Energy*, 157, 830-852.
- University of British Columbia. (2011). Stereographic Sun Path Diagram 33°N. Available from: <<http://ibis.geog.ubc.ca/courses/geob300/applets/sunpath/>>. [18/12/2017].
- Van Moeseke, G., Bruyère, I., and De Herde, A. (2007). Impact of control rules on the efficiency of shading devices and free cooling for office buildings. *Building and environment*, 42(2), 784-793.
- Weather Underground. (2017). Historical Weather Available from: <<https://www.wunderground.com/>>. [02/08/2017].
- Weber, W. (2013). *Lessons from vernacular architecture*. Oxford, UK: Routledge.
- World Bank. (2017). Iraq Data 2017. Available from: <<https://data.worldbank.org/country/iraq?view=chart>>. [28/11/2017].