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Research Article

Mitigating solar heat gain through windows of buildings by reflective films: A case study in Iraq

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ABSTRACT

The current work evaluates thermally the role of shading films in mitigating the heat gain through regular glazing unit, as an energy saving application. The study used experimental data collected in an actual building, and theoretical models used to calculate the heat gain and cooling load. The study served several reflective films with different colors, manners and shading rates. The measurements included the values of temperature (indoor and surface), solar radiation and light intensity. The results manifested the potential of these sheets to eliminate the solar radiation by more than 70%, and decrease the heat gain via up to 50% in comparison with the conventional clear window. A film with medium shading rate (50%) reduces the heat gain through the window up to 40%, which reduces the corresponding energy consumption by 290, 400, 480 and 540 W, in cases of using gray, red, black and retro-reflective films, respectively. This will save the energy by 3.7, 5.1, 6.2 and 6.9%. Furthermore, the use of very dark films leads to undesired rise in the internal surface temperature, as well as weak light indoor. The use of retro-films elucidates suitable light indoor and doesn't show that rise in the surface temperature owing to the ability in reflecting the rays right back without diffusion. The novelty is presenting findings of a realistic and actual investigation for the effect of shading films in the reduction of heat passed through the glass of a building in an extreme hot area. However, the study can be considered as an effective passive technique to withstand the overheating due to global warming and assigned within adaptation and mitigation policy.

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INTRODUCTION

The past few decades have seen an increase in energy consumption and related greenhouse gas emissions. Buildings are one of the main sectors with energy demand, especially air-conditioning. As an example of a very hot and dry climate, Iraq experiences harsh summers that increase the cooling energy consumption by up to 70% [1]. In order to reduce the thermal impact on buildings, effective ways, such as thermal insulation materials and adequate windows should be implemented to satisfy energy-efficient buildings. Window is a necessary element for daylight and vision, but it allows undesirable heat to let in in summer

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or wanted heat to escape in winter through its thin pane of glass or vents. Thus, it reduces the building thermal performance in comparison with the else parts of the building envelope, like the roof and the walls. Currently, many procedures are used as effective ways to reduce the solar radiation in summer, such as using windows of high thermal performance (double- or triple-glazing), overhangs, louvers and shadings [2]. Furthermore, glazing can be integrated with photovoltaic layers to compose what so-called solar windows. These windows convert incident solar radiation into electrical power, and allow for space heating or lighting. Recently, many studies have been conducted to develop building-integrated PV panels [3].

Shading is the most effective passive approach that reduces the heat gain through the window, and improves the indoor thermal comfort. It may come as reflective layers and nets or as tinted films. The basic idea of window shading is to transmit visible light as much as possible, while reflecting the heat component back to the outside [4]. On this aspect, a Low-E glass, which is layered by metallic oxides, is commonly implemented for this purpose [5]. This type of glass can reduce the emission of IR and UV rays to the inside, and keep a desired intensity of light passing through. Low-E glass is coated by a thin and transparent layer helps reflect a band of thermal rays. In the winter, low-E glass avoids the heat escaping to the outdoor, thus keep the inside warm with almost stable indoor temperature [5, 6]. The shaded low-E double-glazing window is very effective to allow the light inside while keeping the heat out. It's vital to utilize such kind of glass in combination with suitably controlled blinds, specifically blinds that allow the light to enter at a slat angle and sufficiently block the direct solar radiation component above a threshold value [7]. Glass absorbs some colors or wavelengths of light and reflects others. Even a black surface that is glossy reflects. Lighter colored objects reflect the majority of light that hits them, and darker objects absorb most of the light. There are three basic types of reflectivity: Scattered, specular, and retro [8]. Scattered or diffused reflectivity is the common way of reflectivity. In this type, when light hits the surface, it bounces off and goes in multiple directions. Specular or mirror reflectivity is when most of a beam of light reflects in another direction depending on the angle of the surface. Finally, the retro reflectivity is where the light reflects only back to the source direction. Man-made retro reflectivity is created in two ways. One is through the use of perfectly round glass spheres that take in light, bend it, and then return it. The other method is through the use of prisms that also bend light and return it. Prismatic arrays have more efficiency than glass beads. Metallizing beads or prisms enhance reflectivity by giving them a mirror finish [8, 9].

Reflective coatings can be classified as high-reflective coatings (HR-coatings) and retro-reflective coatings (RR-coatings) [10]. For HR-coatings, reflective radiation would be intercepted via adjacent buildings; therefore, HR-coatings have some drawbacks. The drawbacks appear clearly for the case of multiple buildings, where there is an accumulated heat outdoor [10]. The RR-coatings have attracted further attention owing to its capability of reflecting solar radiation back along the incident direction, which reduces the absorbed radiation amount by the closest constructions [10]. RR-coating may decrease the cooling load in summer, but it increases the heat demand during the winter months. To improve seasonal variation and achieve minimum annual energy, the best retro-reflectivity should be selected according to the specific weather characteristics of the region [11]. Therefore, a retro-reflective film has been proposed as an active method for blocking the solar radiation in summer and avoiding the overheating of indoor space. Table 1 shows some aspects of using reflective coatings [12-17].

Shading minimizes the incident solar radiation upon surfaces, especially through windows, and hence dramatically affects the building energy performance. In large buildings, it is found that the films that have suitable reflection properties are able to achieve energy savings up to 30% [18]. Technologies, such as layering low-E shading films are common recently in energy-efficient glazing units. The films with retro-reflective properties have been installed in high-rise buildings in many locations worldwide. In traditional reflective films (HR-coatings), the reflected rays from the external face of the glass surface lies toward neighboring objects and buildings, thus rises the average surrounding temperature outdoor, and helps in increasing the possibility of thermal bridging to indoor [19]. On the architectural

Table 1. Usages of some reflective coating with corresponding features

Item	HR-coating	RR-coating
1	A roof in the building with a HR-reflective layer has 10% less heat gain comparing to the conventional one [12].	When RR-coating is used for the building envelope, up to 6% heat reduction can be seen comparing to HR-coating one [15].
2	HR-coating for south wall can decrease the indoor air temperature up to 5°C comparing to that without coating [13].	The air temperature inside a tent can be decreased by 7°C as maximum using RR-coating [16].
3	A building's roof with HR-coating consumes cooling load 5-35% less than the ordinary one [14].	A model showed that the cooling demand can be decreased up to 20% using RR-coating on a large window [17].

aspects, reflective films have many advantages related to the aesthetic values. Since modern architecture utilizes curved forms, hence it is important to develop flexible films [20, 21]. Within the subject, several studies have presented some ideas upon the importance of shading the windows in controlling the indoor overheating in hot climates (or for cooling purposes) with some examples of the energy saving applications or available data. The studies focus upon various configurations for reflective shadings as films, coatings or layers. The ideas in these studies may have some developed suggestions or ability to satisfy a range of applications. They show reliable research works focusing upon the contribution of shading films in mitigating the solar rays in and corresponding overheating, as well as improving the characteristics and performance of the reflective shadings. The studies looked into the selecting of proper window films depending on the heat insulation features [22-25], or on the optical properties of the films [26, 27]. Some of the studies investigated the effect of the film on the energy saving for air-conditioning [24, 25, 28-30], or on the internal glass temperature [27, 31, 32]. However, numerous studies practiced the window films in testing rooms [29, 30, 33], in rig models [22, 31, 32], or just used computational methods [23, 34]. The retro-reflective films were the interest of some studies to enhance the indoor and outdoor thermal conditions in summer [28, 35, 36]. The current study aims to study the role of different reflective films in mitigating the solar radiation passing through regular glazed window and corresponding heat gain for a building in Iraq. The research presents the results of a realistic and actual investigation for the effect of using shading films on the heat transmitted through the glass of a building in an extreme hot area, with a thermal evaluation of multiple patterns of these films. The originality is implementing retro-reflective films beside common shading films with different shading rates. It needs to concentrate on the passive ways to reduce heat gain and reduce energy cooling for such conditions.

MATERIALS AND METHODS

In this study, a set of thin colored films have been used with high reflectivity. The films have different colors, as black, red and gray, as shown in Figure 1. The films have a range of shading rates from 30 to 80% [37]. The specifications of these films are mentioned in Table 2. Furthermore, a retro-reflective film (with red color and 50% shading rate) has been served as an advanced case. The structure of the retro-reflective film surface has concentric circles. The whole films have been purchased from the local market as Chinese products.

Window under test, shown in Figure 2, was chosen to be in a room in the Lab of Materials-Mustansiriyah University, Baghdad. The dimensions of the room are 6 x 5 x 4 m^3. The window has dimensions of 1.7 m by 1.4 m of 6 mm thick, and it faced the south orientation. A glass area of 1 m^2 was confined, and the remainder was insulated using Styrofoam

Figure 1. Some shading films used in the study.

Table 2. Features of shading films [37]

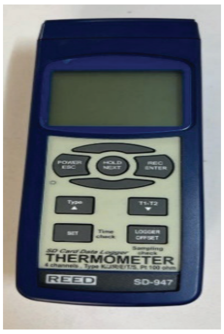
Item	Features	Values
1	Product name	Heat control film for window
2	Material	PET
3	Size	1.52 m x 30 m/roll
4	Thickness	0.1 mm
5	Shading rate	30, 50, 80 %
6	UV blocking	95-98%
7	Transparency	Clear
8	Installation	Self-adhesive

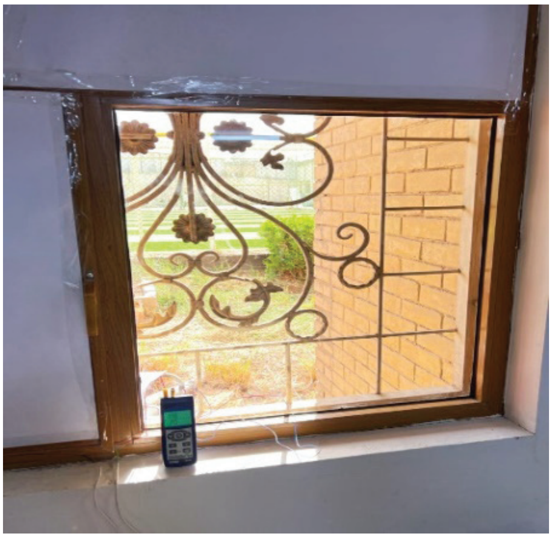
and a covering layer. The frame of the window is made of a metal (Aluminum). Note that the window faces no building except a football field 10 m away. The window has an external overhang of 0.75 m depth.

The window glass was cleaned, and then the film was glued to it using a water sprayer and wiped. The goal is to take readings of temperature, solar radiation and light throughout the daytime in summer. Internal and external temperatures of the glass as well as the ambient and indoor room temperatures have been recorded using a thermometer (Reed SD-947) provided with four Type-K

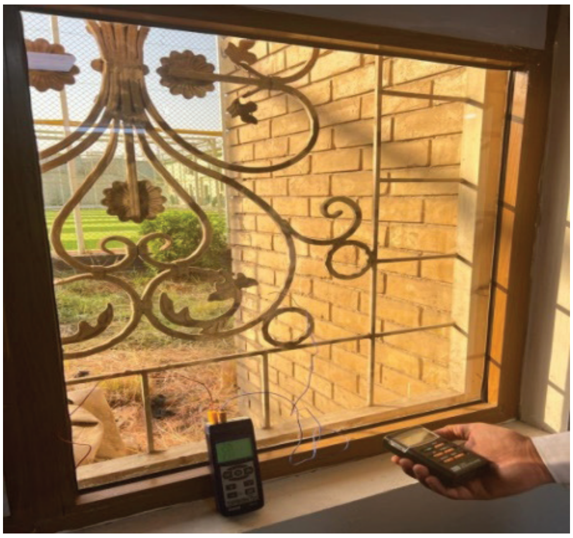
Figure 2. Views of the selected window.

Table 3. Features of the instruments used in this study

Instrument	Characteristics	Image
Thermometer	Reed SD-947 Resolution 0.1°C Accuracy ± 0.5°C Powered by batteries LCD screen SD memory	
Solar meter	TES-1333 Resolution 0.1 W/m² Accuracy ± 10 W/m² Powered by batteries LCD screen	
Light meter	Lux Light Meter Pro 2.0 (Mobile application) Resolution 1 Lux Accuracy ± 10 Lux	



A. Without shading



B. With gray film (30% shading)

C. With red film (80% shading)

D. With retro-reflective film

Figure 3. Images show the readings for some cases.

thermocouples. Note that the sensors were not attached directly to the glass surface but faraway by 5 mm to read the boundary temperature [38]. The solar radiation and the light intensity were recorded outdoor and indoor (25 cm far from the window [38]) using a solar meter (TES-1333) and a mobile program (Lux Light Meter Pro 2.0), respectively. Table 3 shows the instruments used in the study. Figure 3 depicts the samples of captured images during the readings.

RESULTS AND DISCUSSION

Ambient Conditions in Summer

Data were recorded during the summer season (August and September, 2023), where the maximum ambient temperature could reach up to 50ºC, as shown in Figure 4. The direct solar radiation during midday could reach up to 1150 W/m^2, as depicted in Figure 5. The maximum intensity of the light outdoor ranged between 120,000-160,000 Lux, as displayed in Figure 6. Note that the readings in days of dust were displaced to show reliable analysis. Data obtained reveal that the highest indoor temperature took place about 2-3 PM owing to overheating as a result of accumulation inside. The outdoor solar radiation intensity ranged between (250 W/m^2) in the early morning to (1100 W/m^2) at 11:45 AM. Also, note that the solar intensity after noon is comparatively lower than that before it owing to the usual dusty weather in evening as a result of wind movement passing through the western desert.

Collected Data

The study evaluates the contribution of reflective films in reducing the overheating indoor and corresponding effects. The study is seeking into stating the effect of film

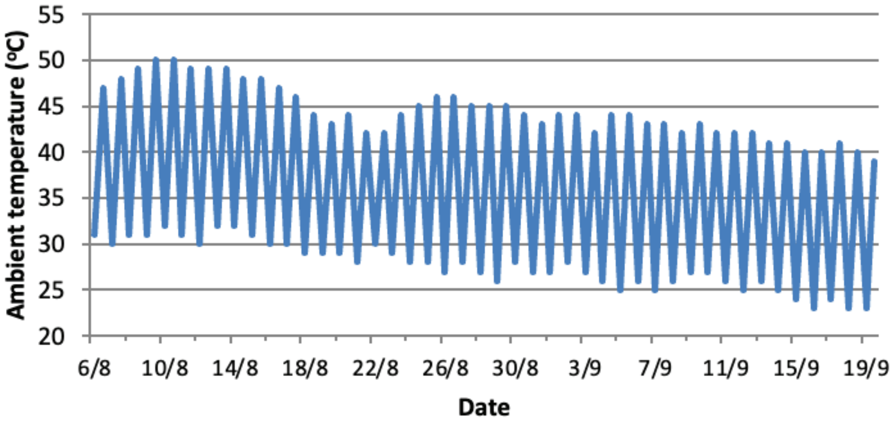


Figure 4. Variation of ambient temperature during the summer season (August and September).

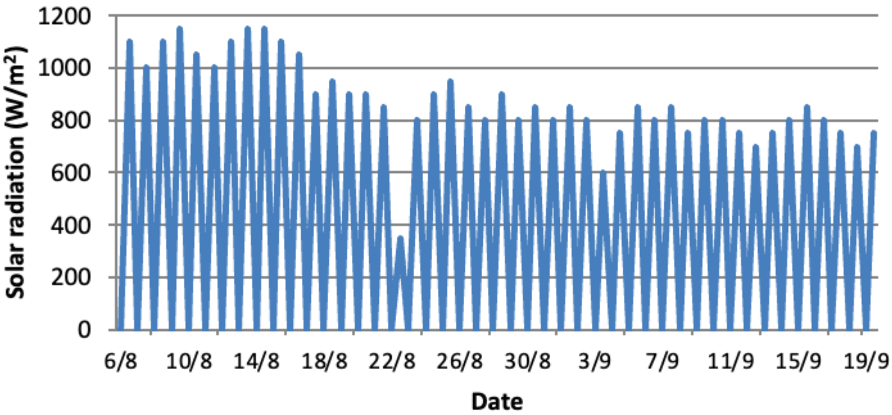


Figure 5. Variation of direct solar radiation during the summer season (August and September).

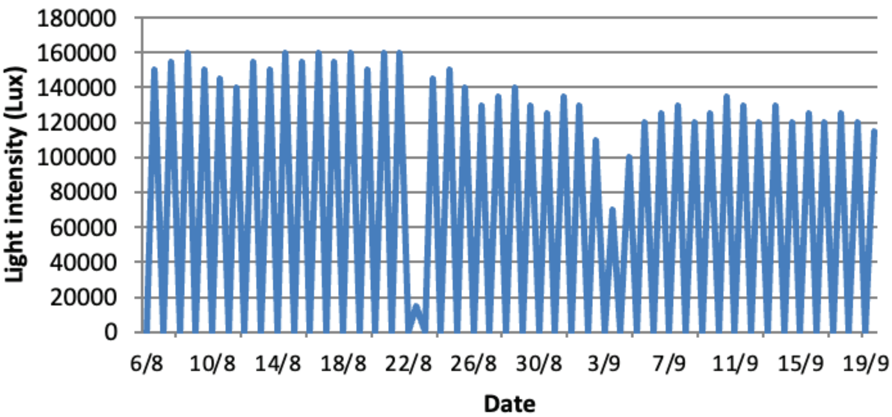


Figure 6. Variation of outdoor light intensity during the summer season (August and September).

nature, color and shading rate on the thermal conditions, internal glass temperatures and energy savings. The goal is to reconcile between the allowing of suitable amount of light to in and avoid the heat as much as possible. Therefore, the questionnaire was about evaluating which configuration of the reflective film is suitable in such hot region and climatic effects. The study followed the change in a range of parameters, as shown in Table 4.

Table 4. Parameters under study

It.	Parameter	Range
1	Type of window	With and without film
2	Type of film	High-reflected and retro-reflected
3	Colors	Black, red and gray
4	Shading rate	30-80%
5	Readings	Temperature, solar radiation and Light intensity
6	Months	August and September

The case studies include: Without film, with film (different colors and shading rates), and with retro-reflective film. These case studies covered the suggested duration (6 Aug-19 Sep), as evinced in Table 5.

The obtained data for the surface temperatures of the glass are illustrated as following: Figure 7 in case of no film is used, Figure 8 in case of using black film, Figure 9 in case of using red film, Figure 10 in case of using gray film, and Figure 11 in case of using retro-reflective red film.

Table 5. Case studies

It.	Case	Duration
1	Without film	6 Aug - 8 Aug
2	With black film (30%)	9 Aug - 10 Aug
3	With black film (50%)	13 Aug - 15 Aug
4	With black film (80%)	16 Aug - 17 Aug
5	With red film (30%)	20 Aug - 22 Aug
6	With red film (50%)	23 Aug - 24 Aug
7	With red film (80%)	27 Aug - 29 Aug
8	With gray film (30%)	30 Aug – 31 Aug
9	With gray film (50%)	3 Sep - 7 Sep
10	With gray film (80%)	10 Sep - 11 Sep
11	With retro-reflective film (Red 50%)	12 Sep - 14 Sep
12	Without film	17 Sep – 19 Sep

The obtained data for the solar radiation through the glass are shown as following: Figure 12 in case of no film is used, Figure 13 in case of using black film, Figure 14 in

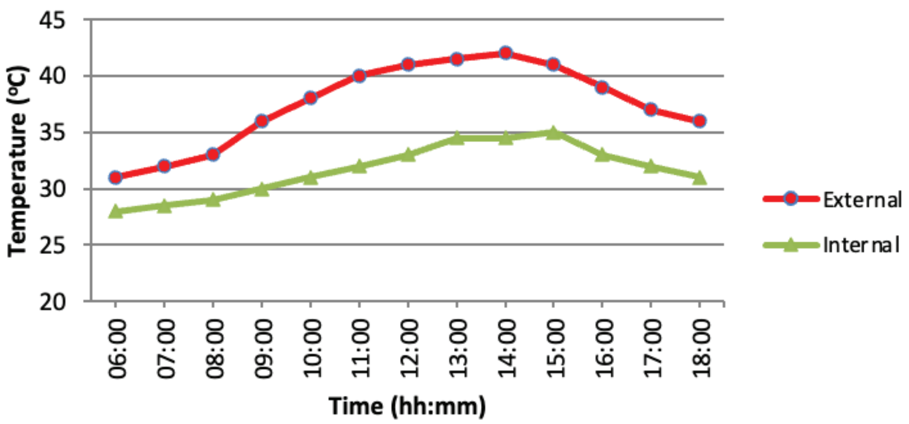


Figure 7. Surface temperature of the glass in case of no film.

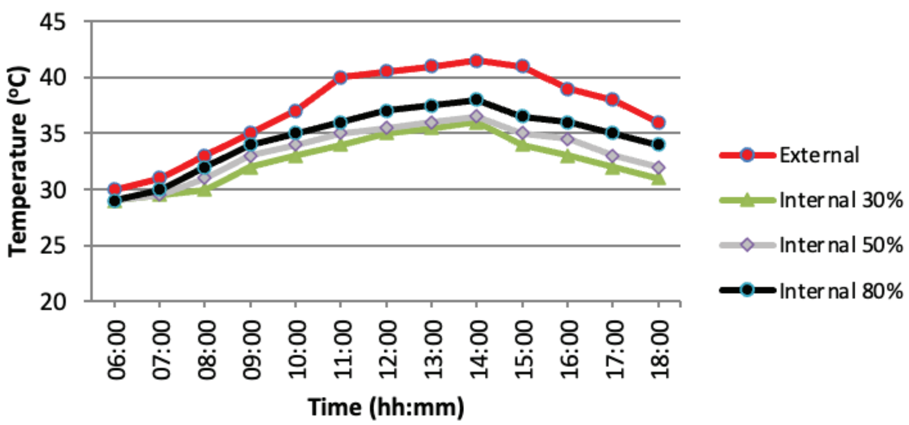


Figure 8. Surface temperature of the glass in case of using black film.

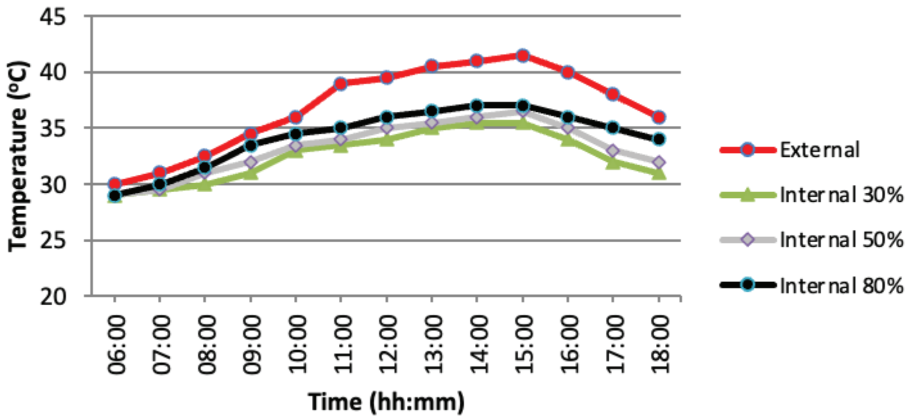


Figure 9. Surface temperature of the glass in case of using red film.

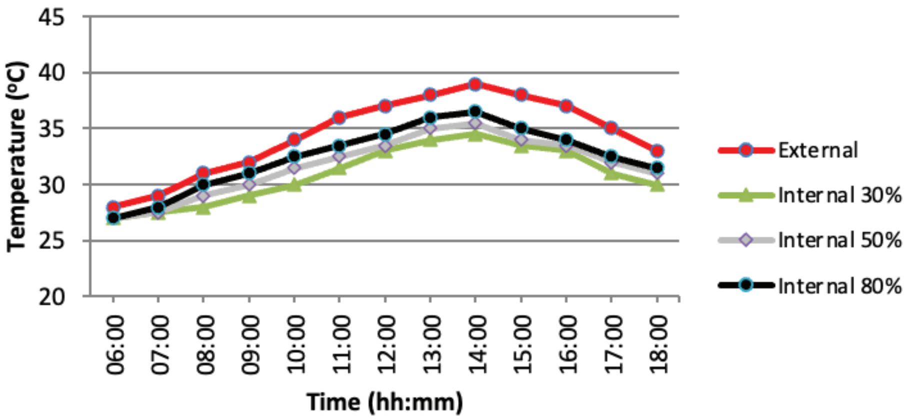


Figure 10. Surface temperature of the glass in case of using gray film.

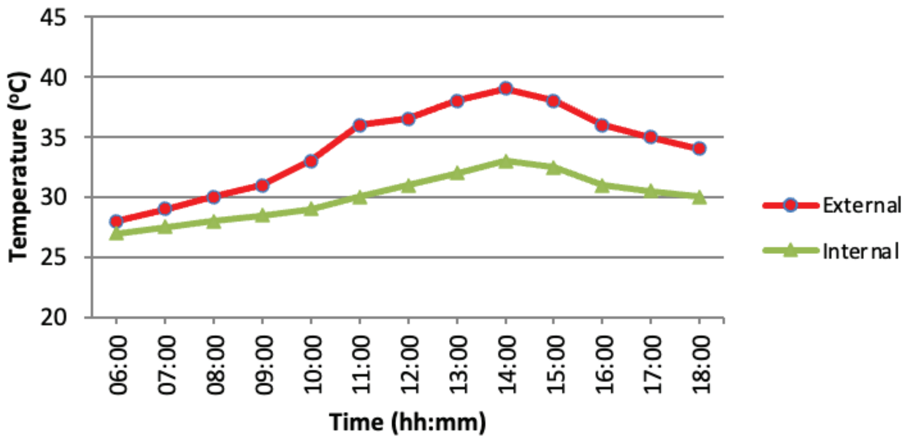


Figure 11. Surface temperature of the glass in case of using retro-reflective red film.

case of using red film, Figure 15 in case of using gray film, and Figure 16 in case of using retro-reflective red film. The results manifested the potential of black sheets to eliminate the solar radiation by more than 70%. Note that the orientation of the window is toward the south, where the sun has a high angle at the noon time. This means that the solar rays are incident on the roof. Therefore, the readings of indoor solar intensity at noon time were lower comparing to that recorded at morning or evening. Also, note that the recorded radiation is the instantaneous value.

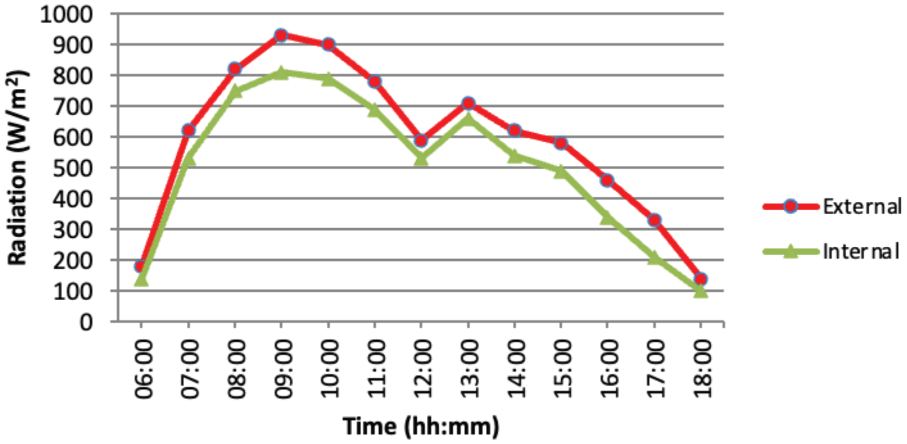


Figure 12. Solar radiation across the glass in case of no film.

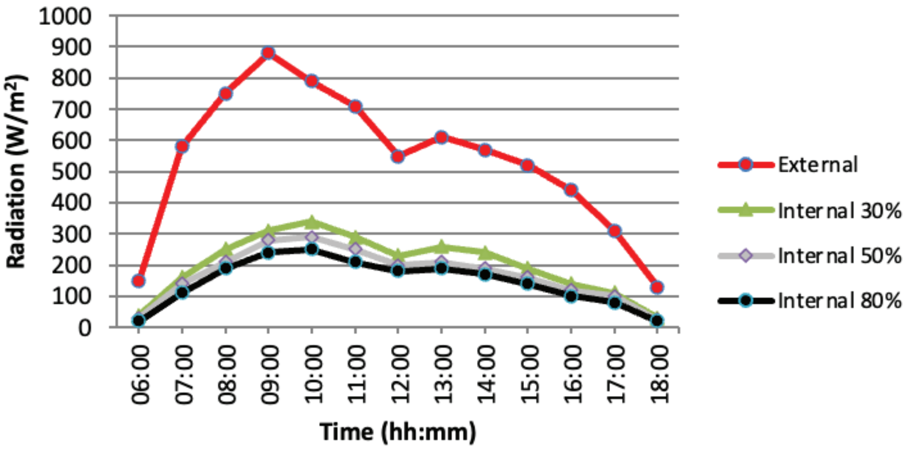


Figure 13. Solar radiation across the glass in case of using black film.

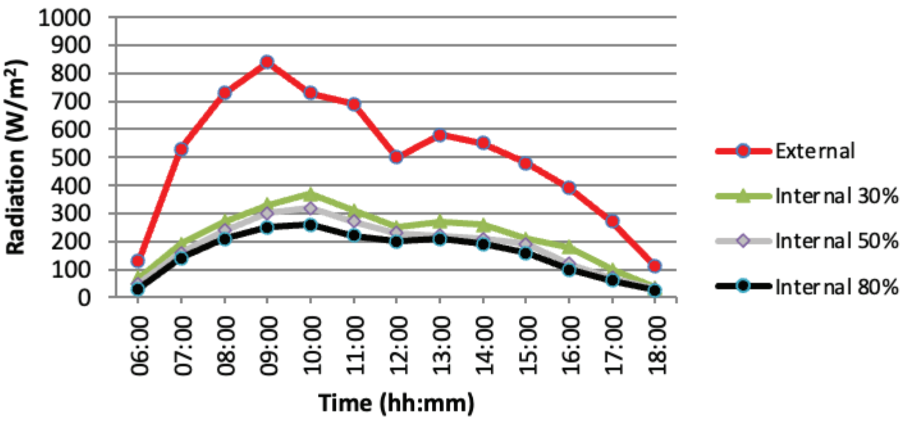


Figure 14. Solar radiation across the glass in case of using red film.

The obtained data for the light intensity through the glass are shown in the following figures: Figure 17 for the case of no film is used, Figure 18 for the case of using black film, Figure 19 for the case of using red film, Figure 20 for the case of using gray film, and Figure 21 for the case of using retro-reflective red film. Note that the external readings for the light intensity have recorded low values due to the sun shade provided by

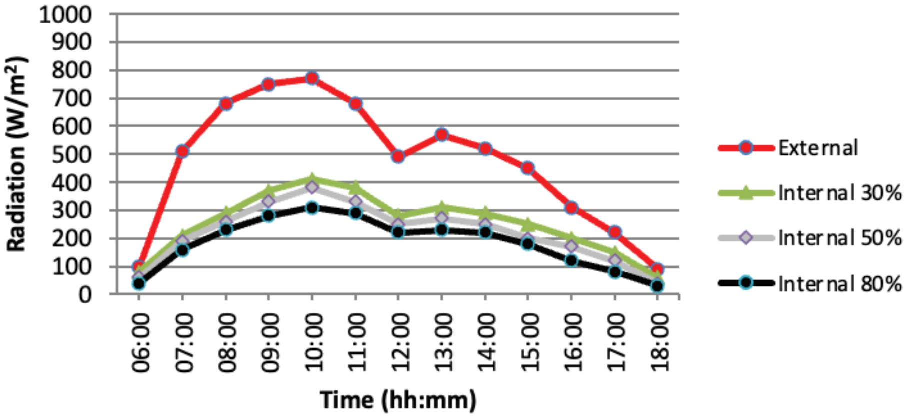


Figure 15. Solar radiation across the glass in case of using gray film.

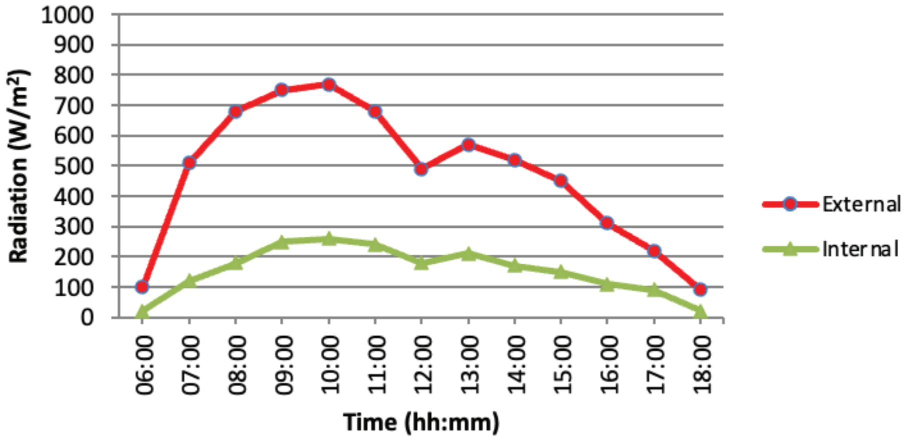


Figure 16. Solar radiation across the glass in case of using retro-reflective red film.

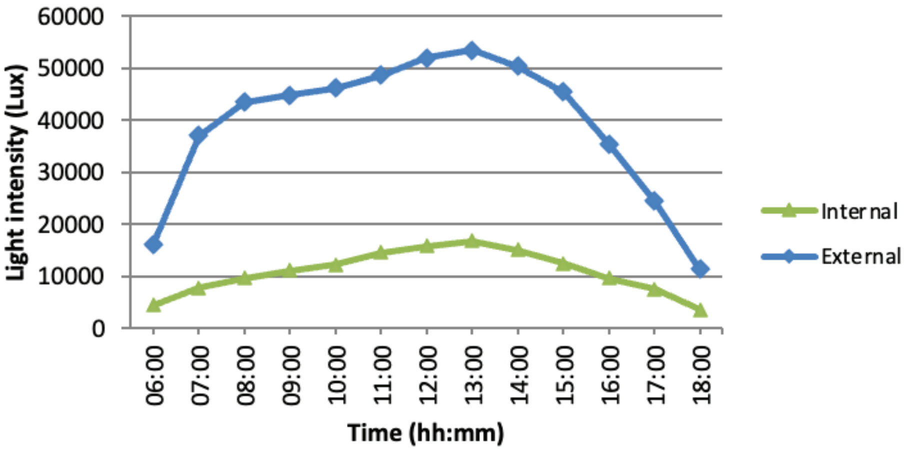


Figure 17. Light intensity across the glass in case of no film.

the overhang. However, the light intensity still higher comparing to other places or conditions. Where, the summer in Baghdad is usually clear with the absence of clouds mostly. Also, the location of the selected building and the orientation toward the sun offer high light intensity.

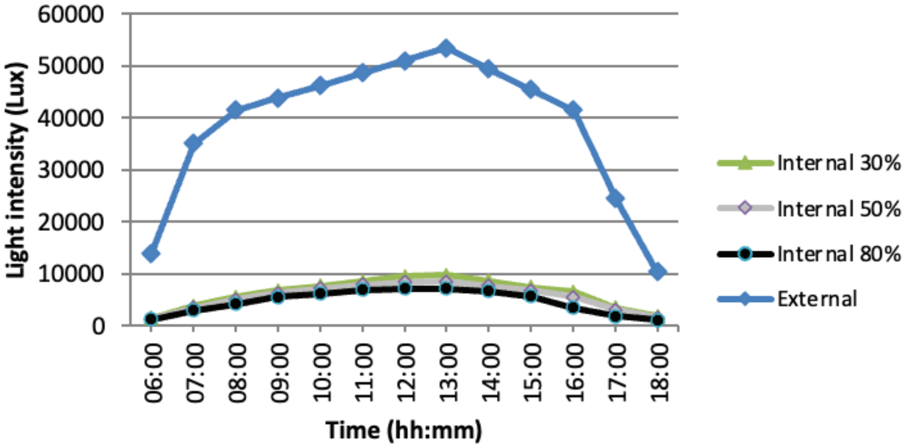


Figure 18. Light intensity across the glass in case of using black film.

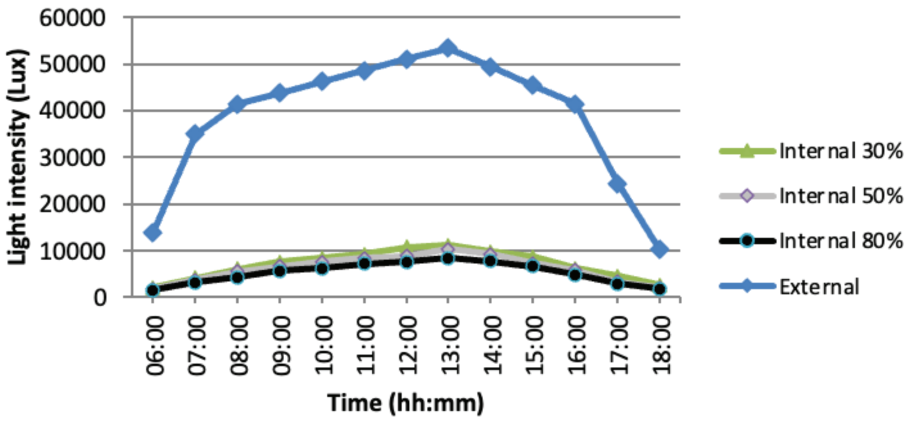


Figure 19. Light intensity across the glass in case of using red film.

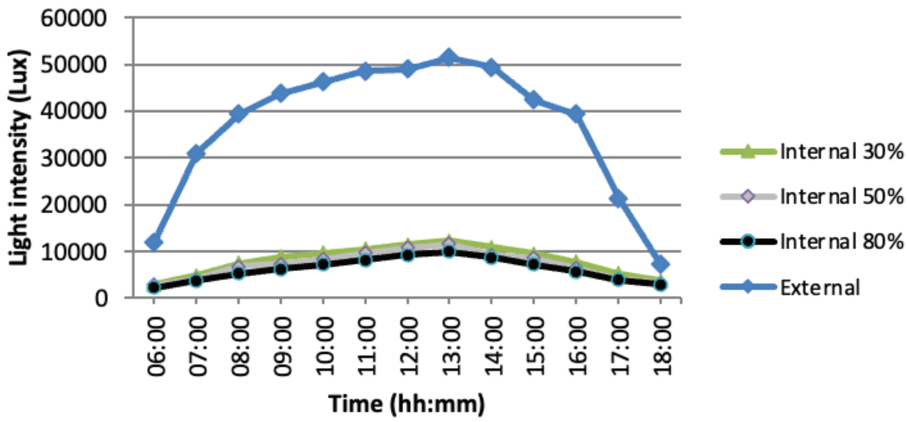


Figure 20. Light intensity across the glass in case of using gray film.

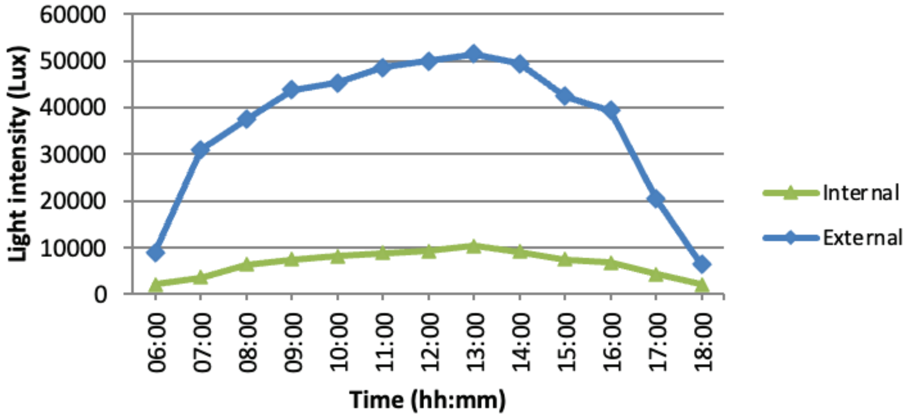


Figure 21. Light intensity across the glass in case of using retro-reflective red film.

Behavior of the Films

By looking deeply into the films, it can be recognized that both black film and retro-reflective film have shown the best reduction in the intensity of solar radiation that measured indoor (about 55% reduction), then red, and then gray. The gained radiation is the main reason for the overheating. However, the using of black film leads to undesired rise in the internal surface temperature due to the capability of black surfaces (or dark colors) in absorbing more heat [39]. Red and gray films elucidated less temperature rise. On the other hand, the retro-film didn't show that the rise in the temperature owing to the capability of retro-film in reflecting the incident rays back to the original direction they come from. Therefore, retro-films have the minimum possibility for diffusing or absorbing the radiation [8]. Regarding the light, the black film with a high shading rate reduces the intensity below 7000 Lux through the daytime, while the retro-film keeps it higher (between 7000-10000 Lux). Therefore, a (80%) shading rate is not recommended.

Heat Gain

The capacity of heat gain via a window is influenced by several factors, including types of glass and frame, orientation, shading, air leakage and heat bridge (a region in the frame conducts heat faster than nearby regions). Heat transfer across this element can be determined by [40]:

$$Q_{wind} = U\ A\ (t_o - t_i) + SHGC\ A\ I \quad (1)$$

Where:

U: The overall heat transfer coefficient (W/m^2.K) of window

A: The area of window (m^2)

t_o: the temperature of outdoor (°C)

t_i: The indoor temperature (°C)

SHGC: Solar heat gain coefficient

I: Incident radiation (W/m^2)

The overall coefficient of heat transfer through the window can be calculated as [40]:

$$U = \frac{U_g A_g + U_f A_f}{A} \quad (2)$$

Where, (g) refers to the glass, and (f) refers to the frame. By simplification this relation through neglecting the frame and conduction via glass, it yields;

$$U = \frac{h_o\, h_i}{h_o + h_i} \quad (3)$$

Where, h_o and h_i are the natural convection heat transfer coefficients for external and internal surfaces of the glass, respectively. These coefficients can be found based on Nusselt number, as following [41];

$$h = Nu\ k/l \quad (4)$$

Where, k is the thermal conductivity of air, while l is the height of glass. Nusselt number can be calculated based on outdoor and indoor air conditions as following [41];

$$Nu = 0.68 + \frac{0.67\,(Gr\ Pr)^{0.25}}{\left[1+(0.492/Pr)^{9/16}\right]^{4/9}} \quad (5)$$

Where, Gr is Grashof number, while Pr is Prandtl number. And, they can be determined depending on air properties at film temperature (average temperature between ambient and surface of glass). Solar heat gain coefficient (SHGC) of the window is the ratio of the incident solar radiation that can pass through the window to indoor [42]. Thus, it can been calculated by;

$$SHGC = I_{in} / I_{out} \quad (6)$$

Now, the average values of U-factor and SHGC for the single glazed window of various films, depending on the behavior of the films under the current study, are listed in Table 6 [See the appendix for more information].

Table 6. Thermal parameters of the glasses determined under the current study

Type of glass	U-factor (W/m².K)	SHGC
Without film	5.59	0.86
With black film (30%)	5.76	0.37
With black film (50%)	5.82	0.32
With black film (80%)	5.91	0.27
With red film (30%)	5.74	0.44
With red film (50%)	5.79	0.37
With red film (80%)	5.87	0.33
With gray film (30%)	5.63	0.54
With gray film (50%)	5.67	0.46
With gray film (80%)	5.73	0.40
With retro-reflective red film (50%)	5.51	0.31

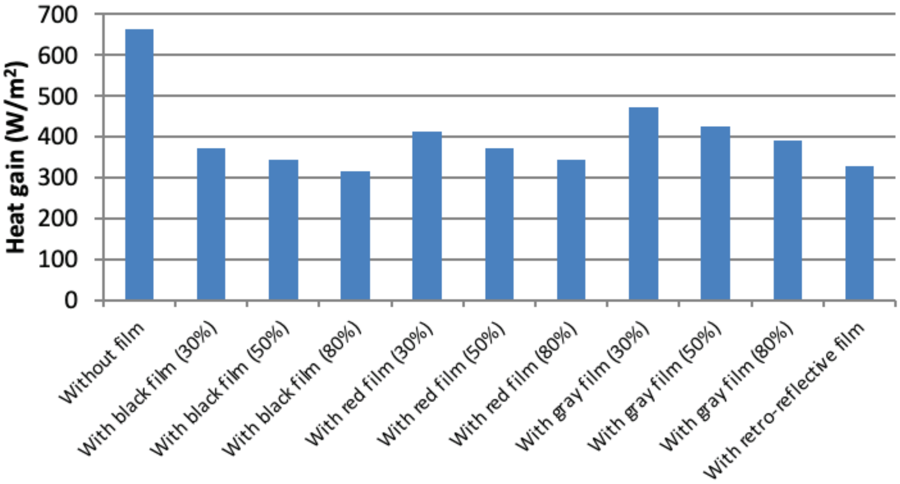


Figure 22. Average heat gain through the window for various cases at daytime.

Figure 22 shows the average heat gain through the window for different cases relying upon the resulted data. Here, the outdoor temperature is fixed at 50°C, as the maximum ambient temperature in summer. Also, consider the indoor temperature is fixed at 24°C, as the design value.

It can be observed that the conventional heat gain through the regular window without any films is about 660 W/m², which is relatively high in contrast with the cases of using the film. Where, the least heat gain is 315 W/m² (about 52% decrement) achieved by using black film of 80% shading rate, but with undesired intensity of light indoor. The case of using retro-reflective film also portrayed a low heat gain, which is 330 W/m² (about 50% decrement) with an acceptable light intensity indoor. Note that Yousif et al. [31] have mentioned in their study that a shading film can reduce the transmitted radiation by more than 50%, and makes a reduction in the heat gain up to 400 W/m², which is too close to that determined in the current study.

Cooling Load

In order to determine the air-conditioning load for a 20 m² room as a standard area for a room with various cases, a local application called "Iraq Passive Planning Package (IPPP)" [43] was employed. And, this program includes equations and relations mentioned in ASHRAE handbook [44]. The cooling load was estimated based on the transmitted heat from outside without the existence of any indoor heat. Note that the load represents a magnitude calculated for the entire day and for the whole month. Materials, elements and limits assumed during the calculation are listed in Table 7.

The total cooling load can be determined by:

$$\text{Load} = Q_{walls} + Q_{roof} + Q_{floor} + Q_{window} + Q_{door} + Q_{vent} \quad (7)$$

Where,; Q represents the heat transfer through a certain element (wall, roof, floor, window and door), and it can be found by:

$$Q = U\ A\ \Delta T \quad (8)$$

Where, U is the overall heat transfer coefficient though the element, and A is the exposed surface area, while ΔT is the temperature discrepancy across the element.

The ventilation loses is given by:

$$Q = ACH\ V\ \rho\ Cp\ \Delta T \quad (9)$$

Table 7. Features of the typical room assumed to determine the cooling load

Part	Characteristics
Construction	Typical room of 20 m^2 floor area in Baghdad.
Walls (in to out)	1 cm gypsum, 25 cm Brick and 1 cm cement plaster. There're (3) internal walls and merely one external wall.
Roof (in to out)	1.5 cm gypsum, 18 cm reinforced concrete, 8 cm soil, and 5 cm concrete tiles.
Floor	Marble tiles.
Window	1 m^2 of UPVC frame and south orientation.
Door	2.5 m^2 of wooden structure and internal.
Air quality	The indoor temperature is 24°C, and the ACH for ventilation is 0.8.
Outdoor conditions	The highest range of temperature is within 39-50°C, and the minimum range of temperature is 23-32°C. Humidity is within 20-45% with average radiation within 750-1100 W/m^2.

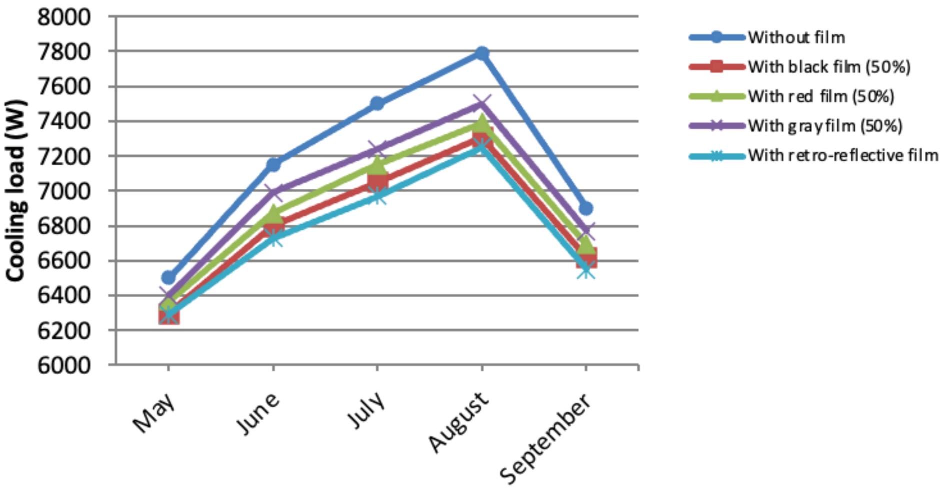


Figure 23. Comparison of cooling load for different cases.

Where, ACH is the air-change in the room per hour. V is the volume of the room. ρ and Cp are the density and the heat capacity of air, respectively [See the appendix for more information].

Hence, the energy saving can be calculated as following:

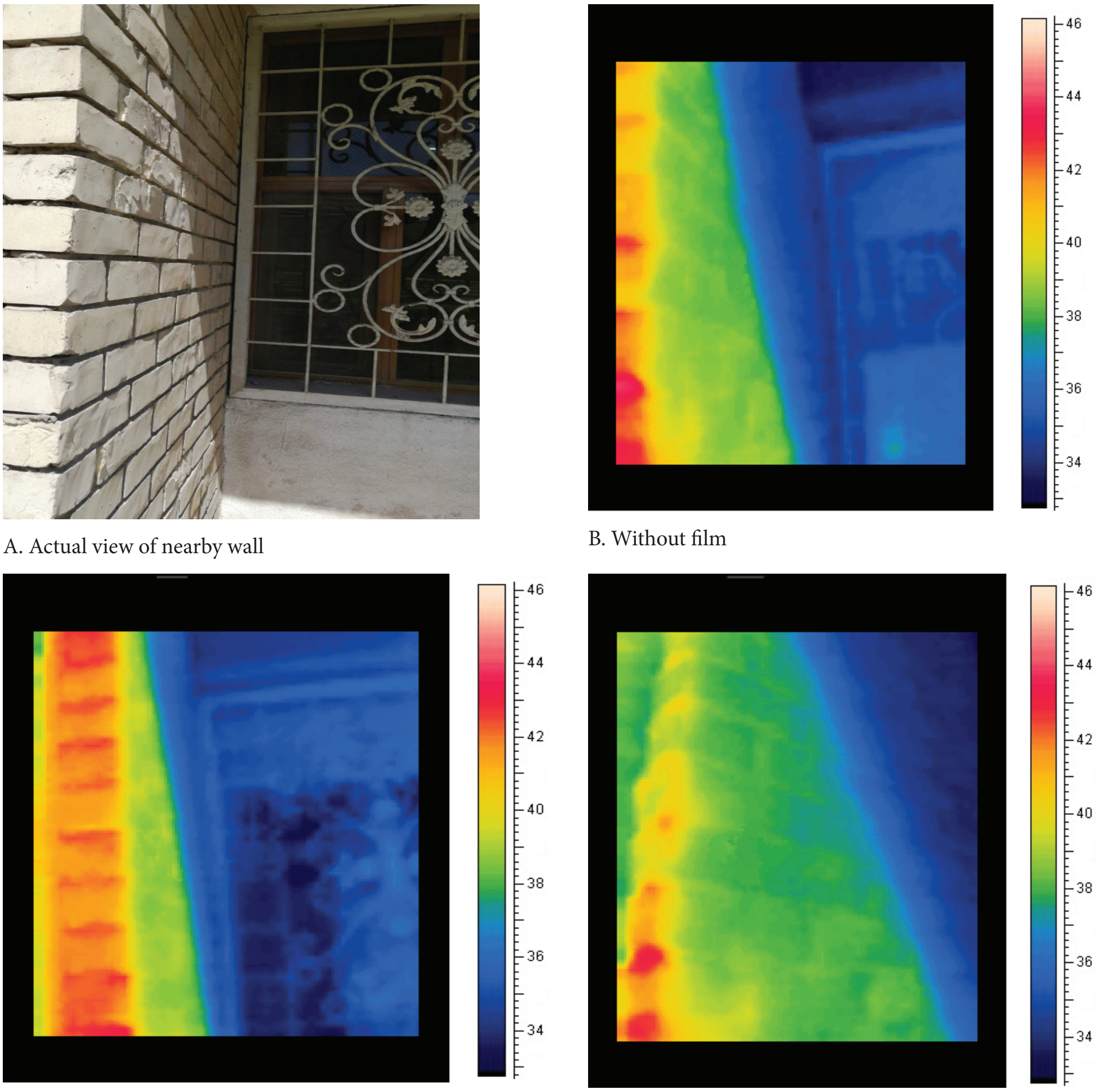
$$\text{Energy saving} = \frac{\text{Load without film} - \text{Load with film}}{\text{Load without film}} \quad (10)$$

The results, shown in Figure 23, revealed that the cooling load for a traditional building with regular single-glazing can reach up to 7800 W (2.2 TR) due to very hot weather conditions in summer, especially at July and August. The using of reflective films (50% shading) reduces the heat gain through the window, thus decreasing the corresponding energy consumption by 290, 400, 480 and 540 W, as much as possible, for the cases of using gray, red, black and retro-reflective films, respectively. Therefore, the corresponding energy savings are 3.7, 5.1, 6.2 and 6.9%, respectively, when the mentioned reflective films were added to the regular single-glazing window.

Thermal Imaging

In order to recognize the effect of the radiation reflected by the films that intercepted by nearby walls, thermal images were captured outside the building using the thermal camera (FLIR E5). The images, demonstrated in Figure 24, represent the temperature gradient on the nearby wall for three cases: Using high reflective film (black of 50% shading), using retro-reflective film, and the reference case (without film). Note that the images were taken in the last week of September 2023.

The readings of temperatures shown by the thermal images exhibited that the range of wall surface temperature is between (34-44°C), where the lowest temperature of the wall is that closest to the window in the shading area. Note that the shading area may remain relatively cool for the whole day long due to the canopy provided by the long overhang around the window. However, a high temperature (above 40°C) can be seen around. The analysis of the images for the selected cases indicates that there is an increase in the average surface temperature by 2-3% for the case of using black reflective film, and a decrease by 1-2% for the case of using



A. Actual view of nearby wall

B. Without film

C. With black film (50% shading)

D. With retro-reflective film

Figure 24. Comparison for the effect of reflected radiation on the nearby wall.

retro-reflective film, comparing to the case without using the films. Nevertheless, these variations are not significant due to the extreme hot weather. Therefore, using either traditional films or retro films has not a pronounced contribution on the near-infrared component reflections from the window surface falling directly upon the neighboring wall in such climate. But, they were proposed as effective ways to block the solar radiation and avoid overheating the indoor space. Note that the overhang canopy is a common traditional architecture in Iraq. However, the shadow doesn't cover the whole window as can be seen from the figure. Besides, the thermal images show that the nearby wall has relatively higher temperatures in case of no-shading while for the case of retro-reflective film, the temperatures went lower due to the less heat absorbed by the walls that come directly from the reflection upon the glass. Take into considerations that the orientation of the building, the position among other buildings, and corresponding window to wall ratio are all affect the incident solar radiation, and thus may offer a natural shading, which impact the amount of heat gain [45, 46].

Comparison with Previous Works

The present work depicts the importance of reflective film as an effective method to reduce the intense radiation and corresponding heat transferred through the window. This can be a necessary step in the achievement of energy-efficient buildings in hot-arid climate. In general, the results evinced that the reflective sheets can eliminate the

Table 8. Comparison with similar works

Reference	Purpose (covering area)	Reduction in Indoor temperature	Reduction in Heat gain	Reduction in Cooling load
[Current]	Window	5-12%	40-50%	5-7%
[11]	Walls	-	-	20%
[12]	Roof	18%	10%	-
[13]	South wall	15%	60%	-
[14]	Roof	10-15%	-	5-35%
[15]	Building envelope	-	4-6% less than traditional films	-
[16]	Tent	12-18%	-	-
[17]	Window	--	-	20%
[22]	Window in a box model	6-9%	-	5-14%
[24]	Window	-	40-55%	Up to 35%
[25]	Double glazed window	-	-	8%
[27]	Smart window	5%	-	-
[28]	Window	-	-	Up to 18%
[30]	Windows of a building	Up to 16%	-	3%
[36]	Window	Up to 19%	-	-

solar radiation and decrease the heat gain via up to 50% in comparison with the conventional clear window. A film with suitable shading rate reduces the heat gain through the window up to 40%, which reduces the corresponding energy consumption up to 7%.

For validation purpose, a comparison was conducted between the results of the current study and the findings of some other works that may have some close conditions, as shown in Table 8. The comparison based upon the reduction in the following parameters: Indoor temperature, heat gain and cooling load. As can be seen, the majority of the previous works reveal a reduction in the indoor temperature by 10-20% and a high energy savings by using reflective films, while the current study illustrates relatively lower values. This is mostly due to the small dimensions of the window under consideration for the current study, as well as the extreme summer conditions in Iraq that make the passive cooling methods less pronounced.

CONCLUSION

The role of certain reflective films in mitigating the solar heat gain through regular glazed window and corresponding cooling load was investigated for a building in Iraq as an example of a hot arid climate. The study measured three parameters: Internal surface temperature of the glass, internal intensity or radiation, and internal intensity of light. The main findings of the results can be concluded as:

1. The use of reflective films (50% shading) reduces the heat gain through the window and decreases the corresponding energy consumption by 290, 400, 480 and 540 W, for the cases of using gray, red, black and retro-reflective films, respectively.
2. The corresponding energy savings comparing to the regular clear glass are 3.7, 5.1, 6.2, and 6.9%, respectively
3. The utilization of dark films leads to undesired rise in the internal surface temperature unlike light films.
4. Films with high shading rates can reduce the radiation indoor, but they have a drawback due to the weak light indoor. Therefore, they are not recommended.
5. The use of retro-films elucidates a suitable light indoor and doesn't manifest the rise in the surface temperature owing to the capability of retro-film in reflecting the incident rays right back without diffusion.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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APPENDIX: CALCULATIONS

This appendix presents a sample of calculations for the parameters under study like U, SHGC, Q_{wind} and the cooling load.

1. Calculate U-value, as following:
   - Specify average temperatures of air (outdoor and indoor) and surface of glass (external and internal) for the certain case (from Figures 4, 7-11). Note that indoor air temperature supposed to be the design temperature (24°C).
   - Specify air properties (α, β, ν, k, Pr) at film temperature (T_f);

$$T_f = \frac{T_a + T_s}{2}$$

   - Find GrPr-value;

$$GrPr = \frac{g\ \beta\ \Delta T\ l^3}{\nu\ \alpha}$$

   Note that (g) is the gravity, while (l) is the glass height.
   - Determine Nu-value (from Equation 5).
   - Determine h-value (from Equation 4). For example, in the case of (without film), the value of (ho) will be (11.98 $W/m^2.K$), and the value of (hi) will be (10.47 $W/m^2.K$).
   - Determine U-value (from Equation 3). The table below shows U-values for all cases.

It.	Case	ho	hi	U
1	Without film	11.98	10.47	5.59
2	With black film (30%)	11.86	11.06	5.75
3	With black film (50%)	11.74	11.30	5.81
4	With black film (80%)	11.61	11.64	5.90
5	With red film (30%)	11.94	11.02	5.74
6	With red film (50%)	11.89	11.21	5.79
7	With red film (80%)	11.79	11.53	5.87
8	With gray film (30%)	11.96	10.62	5.63
9	With gray film (50%)	11.91	10.76	5.67
10	With gray film (80%)	11.86	11.02	5.74
11	With retro-reflective film	12.11	10.20	5.51

2. Calculate SHGC-value, as following:
   - Specify average intensities of solar radiation (outdoor and indoor) for the certain case (from Figures 12-16). For example, in the case of (without film), the value of (Io) will be (589 W/m^2), and the value of (Ii) will be (506 W/m^2).
   - Determine SHGC-value (from Equation 6). The table below shows SHGC-values for all cases.

It.	Case	Io	Ii	SHGC
1	Without film	589	506	0.86
2	With black film (30%)	537	199	0.37
3	With black film (50%)	537	169	0.32
4	With black film (80%)	537	146	0.27
5	With red film (30%)	502	218	0.44
6	With red film (50%)	502	185	0.37
7	With red film (80%)	502	158	0.32
8	With gray film (30%)	472	252	0.54
9	With gray film (50%)	472	219	0.46
10	With gray film (80%)	472	185	0.4
11	With retro-reflective film	474	152	0.31

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3. Calculate Q_{wind}-value, as following:
   - Determine Q_{wind}-value (from Equation 1). For example, the average heat gain for the case (without film) will be 661 W/m^2. The table below shows Q_{wind}-values for all cases.

It.	Case	U	SHGC	Q_{wind}
1	Without film	589	506	661.34
2	With black film (30%)	537	199	371.76
3	With black film (50%)	537	169	343.32
4	With black film (80%)	537	146	315.66
5	With red film (30%)	502	218	413.24
6	With red film (50%)	502	185	372.54
7	With red film (80%)	502	158	344.62
8	With gray film (30%)	472	252	470.38
9	With gray film (50%)	472	219	423.42
10	With gray film (80%)	472	185	388.98
11	With retro-reflective film	474	152	329.26

4. Calculate the load (from Equation 7). Use corresponding Equations 8&9 and information in Table 7 to calculate the heat transfer through the construction elements, as following:

Case	Qwalls	Qroof	Qfloor	Qdoor	Qwind	Qvent	Qlat (10% sens)	Qtot (W)
Without film	2700	2900	350	180	661	450	750	7790
With black film (50%)	2600	2800	330	170	343	430	650	7310
With red film (50%)	2600	2800	330	170	372	440	680	7390
With gray film (50%)	2650	2800	330	170	423	440	690	7500
With retro-reflective film	2600	2750	320	160	329	430	660	7250

This is for August, and so on for other months.