

## A Proposal for Managing Glare's Effect on Tunnels: Abdoun Tunnel Case

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### Abstract

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This paper describes a new method to address glaring effects that drivers face when entering or leaving road tunnels due to the huge difference between luminance inside and outside the tunnels, in particular during sunny days. The outside luminance of the direct sun is more than 200 Klux with more than 10000 Lux as the indirect luminance of the sky, while the luminance inside tunnels is less than 20 Lux at 50m from the entrances of the tunnel. This huge difference causes disability glare for a few seconds and could cause major accidents at the entrances of the tunnels. In many recorded cases in Amman City, artificial lighting in tunnels isn't sufficiently maintained, and many lighting units are off or covered with dust. This research measures luminance inside Abdoun Tunnel in Amman City and proposes reflecting devices to light the entrances of the tunnel and allow a sufficient distance for the drivers to adapt with the less illuminated areas. The measured luminance in front of the tunnels varied between (10,000 to 40,000) Lux during March, which represents the average lighting of the year. On the other hand, luminance inside the tunnels after 50 m is less than 20 Lux. If the permitted speed inside the tunnels is 50 km/hours, then the timing required to reach this point is less than 6 seconds. Therefore, the eyes need to adapt with that difference within this time. A 1:20 scale model was constructed to simulate Abdoun Tunnel, and luminance is measured using 12 cell daylight factor meters inside the tunnel, 50m outside the entrance to 40m deep where the lighting is uniform. Sky and ceiling louvers were used to reduce external lighting 30m prior to the entrance, and special reflecting devices were used in the ceiling above the entrance of the tunnel, these devices are called the Anidolic system, which is used as shading device and to reflect daylight to the ceiling of the tunnel and increase the lighting level in the tunnel for a long distance; up to 100 m. Both arrangements decreased lighting level outside the tunnel from (65500 - 23150) Lux during December, and increased lighting levels luminance from (95 – 285) Lux at a distance of 40 m from the tunnel entrance, serving long distance inside the tunnel.

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**Keywords:** Tunnels, Glare effect, Amman, daylight, Anabolic System, Louver design.

### 1. Introduction:

Glare is a phenomenon that faces drivers when entering or leaving road tunnels due to the huge difference between luminance inside and outside the tunnels, in particular during sunny days, which causes vehicles to slow down as they approach the tunnel entrance. In order to address this issue, this paper focused on one of Amman's tunnels (Abdoun Tunnel), which represents one of the major tunnels in Amman. Although there are various methods that maximize utilization of daylight at the tunnel's entrance, this paper is aimed to select two of these methods for investigation; the Anidolic Day lighting System, and the use of the Sky and ceiling louvers, by applying them on a scale model to evaluate the efficiency and preference of these methods, and eventually choose the most adequate method.

A tunnel is a closed or roofed structure carrying a road through, or under an obstacle. This obstacle may be anything in the path of a preferred road alignment such as a mountain, a body of water, a building or a complete development. A short tunnel is also termed an underpass, but in general any covered length of road over 90 meters long should be treated as a tunnel. [1]

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Tunnels are used in a wide range of physical infrastructure systems, such as aquatic systems, wastewater systems, and passenger and freight transportation, to directly connect destinations and reduce surface impacts. High-speed rail construction projects frequently required long tunnels to reduce travel time and distance. With advances in tunneling technology, the many long tunnels in use around the world today hold valuable lessons, particularly with respect to minimization of ground disturbance and improved passenger and operator safety. [2]

In addition, road tunnels are viable means to minimize potential environmental impact such as traffic congestion, pedestrian movement, air quality, noise pollution, or visual intrusion; to protect areas of special cultural or historical value such as conservation of districts, buildings or private properties; or for other sustainability reasons such as to avoid the impact on natural habitats or reduce disturbance to surface land. [3]

The modern world's longest railway tunnels which identified 31 longer than 4.4 miles. The longest is the Gotthard Base Tunnel in 2016, a high-speed rail tunnel in Switzerland that runs for 57 Km under the Alps, Seikan Tunnel in Japan in 1988 for 53 Km, and English Channel Tunnel in 1994, for 50 Km between United Kingdom and France. [4] As mentioned above, there are a lot of benefits to using road tunnels, such as reduced travel times and length of travel (for both passenger and commercial vehicles) offset by any toll charges (if any); reduced number of accidents; and reduced traffic flow on other roads.

Despite the many benefits for tunnels, it has some problems in the access zone of the tunnels, because the driver's pupils can't immediately adapt to the darker area when the driver enters the tunnel. When this happens, the driver can't see any obstacles in front of him/ her. So proper lighting must be installed in the access zone to help the driver adapt to the darker zone. [5]

This huge difference causes disability glare for a few seconds and could cause major accidents in the entrances of tunnels. In many recorded cases in Amman City, artificial lighting in the tunnels is not sufficiently maintained, and many lighting units are off or covered with dust. To ensure the benefit of road tunnels, there are some design considerations to maintain safety standards, and one of the most important standards is lighting. Lighting models and conditions have been mentioned in a lot of references and research papers, they will be mentioned in the literature review below.

## 2. Literature Review

Several studies for the tunnel glare phenomenon addressed the intensity of light and its differences, and attempted to solve it by controlling the amount of artificial lighting in the tunnel.

When there is a strong light source in the field of view, it appears as a veil of light that is thrown over the world outside. Close to the light source, human eyes might be completely blinded, but further away, visual performance can also be notably hampered. This experience is well known to drivers and it is usually called glare, precisely it is called disability glare. Disability glare is the subject of this review paper. However, there are other types of glare; discomfort glare and dazzling glare that is of a different nature. Discomfort glare is the visual annoyance that is produced by distraction due to light sources off the line of sight, while dazzling glare is the hindrance of vision through the actual bright visual scenes such as a sunny beach, presumably due to papillary spasm by over-contraction. These two types of glare will not be considered as they are outside the scope of this review. [6]

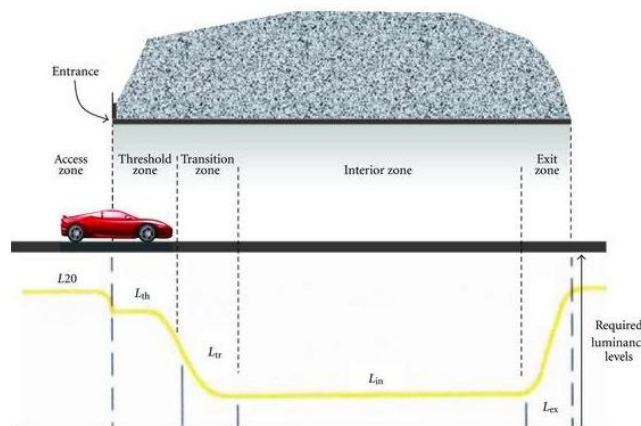
The black-hole effect (glare) refers to the perception that from the distance at which a driver needs to be able to see vehicles and obstructions at the entrance to the tunnel, the entrance is seen as a black hole. Previous studies of tunnel lighting assumed that miss-adaptation was the major cause of the black-hole effect [7]. However, Narisada (1974) showed that drivers typically start to fixate on the tunnel entrance about 90 meters from the entrance, at a speed of 60km/h. [8]

In order to avoid encountering the black-hole effect when approaching the portal of a tunnel and to help drivers adapt to the lighting environment in a tunnel, there are six lighting zones distributed throughout a tunnel. In this section we will discuss each zone's characteristic and particular type of vision problems. [5]

Access Zone: this is located in the front of the tunnel portal; the brightness around this portal will affect the driver's eyes in adapting to the level of lighting in the tunnel and his recognition of an obstacle when approaching the tunnel portal, the length of this zone is usually within stopping distance of maximum speed and the luminance is represented by L20.

**Threshold Zone:** this zone is from the portal to a proper distance inside the tunnel and still for detecting obstacles in the threshold zone. The length of this zone is dependent upon the speed of the traffic and should be equal to the corresponding stopping distance, this is because the driver must have enough time to react and stop his vehicle when he sees an obstacle in the road in front of him. The luminance is represented by  $L_{th}$ . **Transition Zone:** this zone extends from the threshold zone. The purpose of this zone is to transition from a higher lighting level to a lower lighting level in the interior zone, which makes drivers gradually adapt to the lighting environment in the tunnel following pupil changes in the driver's eyes. The length of this zone is a function of time, and begins from  $L_{th}$  and ends at the luminance of the interior zone. The luminance is represented by  $L_{tr}$ . **Interior Zone:** basically, this zone is the farthest from the tunnel portal influenced by daylight; here, the driver's vision is controlled by the artificial lighting in the tunnel. This zone provides a fixed luminance throughout because adaptation is not necessary, the requirement for luminance is dependent upon the traffic speed and density, and it is represented by  $L_{in}$ .

**Exit Zone:** this zone is the zone at the end of the tunnel, and will be influenced by the brightness outside of the tunnel which results in changing the driver's visual adaptability when he approaches the exit area. The problem is that a larger car will block sunlight coming from the outside to the inside which will affect the driver's ability to detect a car in front of him when seen against the dark silhouette of the larger vehicle farther ahead. The luminance is represented by  $L_{ex}$ . **Conjunction Zone:** this zone extends outwards from the exit zone. It provides road lighting for connecting the tunnel to the open road at night. The problem is that when drivers leave the tunnel at night, they could encounter another black-hole effect upon entering this zone without any road lighting system installed and operational. The luminance is represented by  $L_{co}$ .

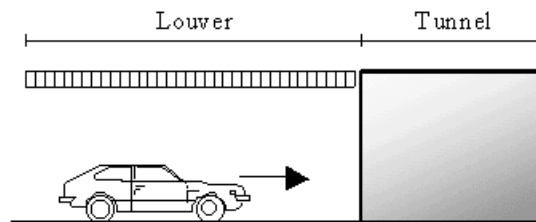


**Fig. 1. The tunnel zones defined for the purpose of lighting design [9].**

Given that the low retinal image luminance contrast of vehicles and objects in the tunnel entrance are the problem drivers experience when approaching the tunnel in the daytime; there are two possible solutions to reduce the resulting contrast:

### 1.1. Shading elements at the tunnel entrance: A proposed Louver design.

By shading the tunnel portal and the road close to the tunnel entrance with a canopy designed to exclude sunlight; this method would reduce the variation between luminance levels outside and inside the tunnel. The Aesthetic appearance of these shading structures also needs to be considered.

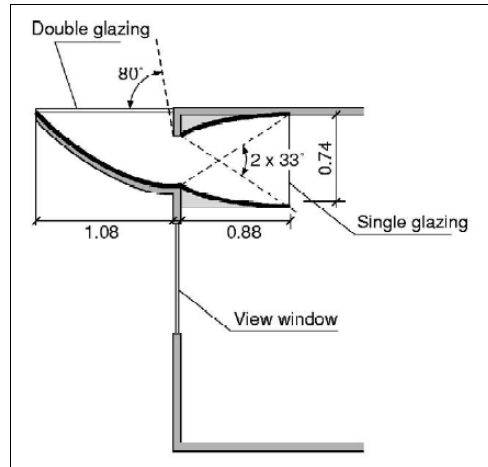


**Fig. 2. A section of the Louvers at the tunnel entrance [10]**

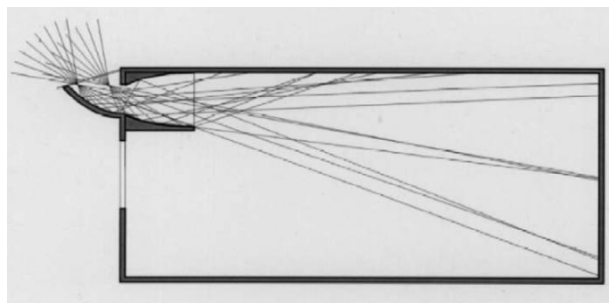
**1.2. The Anidolic System:**

Anabolic day lighting system: This system is made of certain reflectors to reflect sunlight into interior zones and manage the reflection angles. It is necessary for the light intensity to decrease gradually from daylight (outside tunnel) to the lower level (inside the tunnel) in the tunnel’s access zones in order to avoid eye blinding, known as the “Glare”[11].

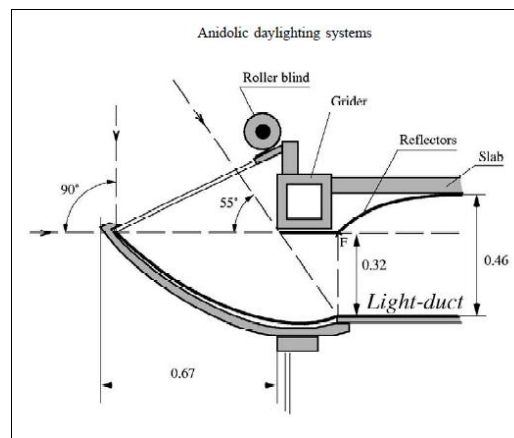
Anidolic delighting system (ADS): typically, a façade integrated collector system with an adjacent horizontal-mirror light duct inside the building that performs well in both sunny and overcast sky conditions [12]. Moreover, the anidolic ceiling uses a light duct integrated into a ceiling to guide a large flux of daylight into an office space. Its design has to meet the following requirements. [13]



**Fig. 3. Section for Anidolic system details [13]**



**Fig. 4. Ray tracing of diffused daylight component through the system (rays emitted by the sky vault). [13]**



**Fig. 5. Cross-section of Anidolic external collector.[13]**

### 1.3. Anidolic System description:

To reduce the effect of the glare which results from the vast variation between the luminance inside and outside the tunnel, several suggestions are introduced. If the entrance of the tunnel is shaded by louvers, wood, metal or concrete beams, the luminance at the entrances will be reduced gradually and help the drivers' eyes to adapt to the difference between the outside and inside of the tunnel luminance. The shaded devices or beams could be arranged to provide graduate shading and reduce the lighting gradually inwards.

The other system is using certain reflectors and aluminum tubes to capture the direct light, transfer it to the ceiling of the tunnel, and reflect it downwards to illuminate the entrance of the tunnels gradually and reduce the difference between the outside and inside lighting. This system is called the Anabolic System. It consists of light collectors exposed to the direct light, sun or sky, placed in front of the tunnel; a reflected ducting to carry the light to the tunnel, and a reflected ceiling to reflect the light downwards. [13], this system depends on the external light; therefore, the difference between the luminance outside and inside the tunnel will be acceptable.

## 2. Field Measurement

### 2.1. Actual Abdoun Tunnel Measurements:

For the purpose of this research paper, one of the longest tunnels in Jordan was chosen. It is Abdoun Tunnel south of the capital Amman with a length of 710 meters and a width of 17 meters with four lanes. This tunnel extends from the end of the Abdoun Bridge to the pursuit of traffic light towards the south of Amman (Prince Hashim Street).

Accordingly, measurements of daylight luminance in Abdoun Tunnel, at three different times (07:30AM, 10:30AM, 12:00PM) were taken. Measurements were taken by a Lux Meter model (Megatron type), on a sunny day of March. These measurements were recorded with 6 meters spacing, starting 50 meters outside the tunnel to 40 meters deep. The maximum altitude of Amman city varies between 32 degrees in the winter and 82 degrees in the summer. Drivers at the south entrance are subjected to direct sunlight from (8 – 16) hrs. After that time, the sun is blocked by the side wall of the tunnel.

This tunnel is directed north west. The sky luminance of indirect lighting, is measured in Amman to be approximately 10000 Lux. [14] The south entrance is exposed to direct sunlight during daytime, between (9-15 hrs) with a luminance of more than 200000 Lux (the maximum reading of the luxmeter). The luminance inside the tunnel is less than 20 Lux, with several lighting units burnt, and the tunnel is lacking regular maintenance.

**Fig. 6.** Shows some pictures of the tunnel and the conditions of the lighting and ceiling. The speed limit inside the tunnel is set to be 50km/h, and outside rush hours drivers drive over the speed limit.

Field measurements inside the tunnels are dangerous, as the tunnel has no walking paths; hence, measurement was conducted from the car. However, during rush hours, when traffic was slow, the team had a chance to walk and measure inside the tunnel.

**Fig. 7.** Shows the result of the field measurements where the luminance varied between (10000 -40000) Lux at 50m outside the tunnel and (3000 -7000) Lux at the entrance of the tunnel. The field measurements inside the tunnel are less than 20 Lux at 40m from the entrance. The drivers' eyes have to adapt to the huge difference in lighting from (40000 to 20) Lux within a 90m distance, or within 5 seconds.

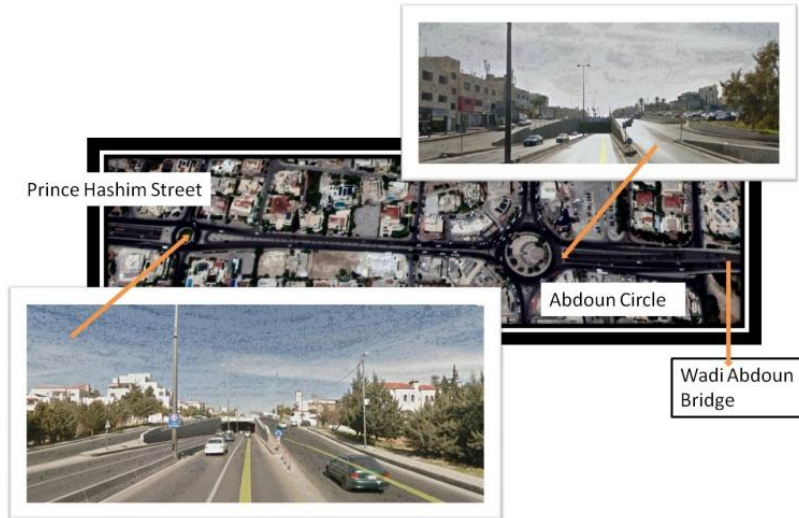


Fig. 6. A real image of the study area (source: authors by Google Earth maps, December 2018)

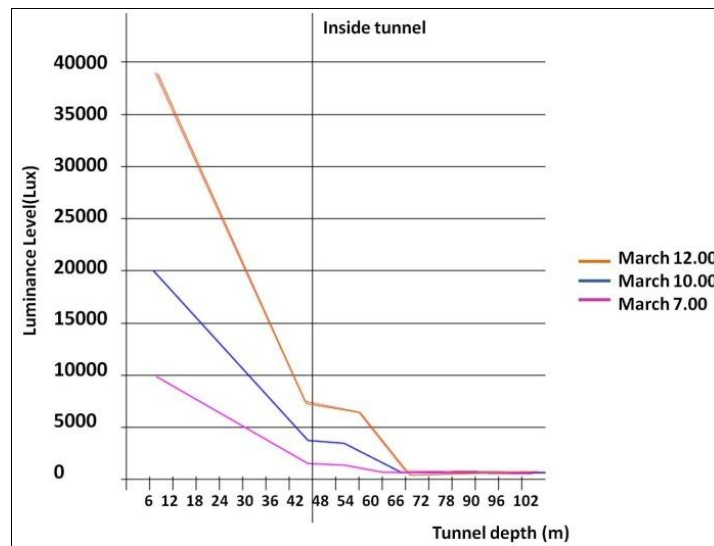


Fig. 7. Measured luminance inside and outside the tunnel

## 2.2. Measurements of the Tunnel (simulation Model):

A simulation model for Abdoun Tunnel scale (1:20) was designed, in order to apply the proposed solutions for the tunnel lighting, and test their efficiency. Measurements were taken by a daylight factor meter model, it has 12 cells daylight to be used inside and one cell to measure the outside luminance, at three different times of the year (March, June, December) at 12:00 pm (it was adopted at 12 o'clock because the amount of glare is the highest according to the result of realistic measurements refer to Fig. 7). They were recorded with 6 meters spacing, 50 meters outside the tunnel to 40 meters deep, Measurements were taken on a simulation model without any treatment systems. Results are displayed in the next three tables.

**Table 1. Daylight measurements recorded at constant horizontal distances inside the tunnel portal, recorded in three different months.**

Simulation model without any treatments			
Depth	Measures Lux)*95 (Simulation of sun luminance)		
	March 12:00 pm.	June 12:00 pm.	December 12:00 pm.
6	38000	26600	65550
12	38950	27550	57000
18	36100	26600	47500
24	38000	28500	46550
30	32300	24700	32300
36	30400	24700	28500
42	31350	25650	21850
48	26600	22800	17100
54	24700	21850	11400
60	20900	19000	8500
66	19000	570	6650
72	1140	285	4750
78	380	190	1900
90	190	95	95

With reference to **Table 1**, it is noted that there is a similarity in the values in this graph with values recorded in the realistic measurements at 12:00 PM in March (refer to **Fig. 7**), and this proves the validity of the simulation model and its measurements.

- The massive drop in luminance inside the tunnel, which is clarified in the graphs, causes the “Glare” phenomenon, and indicates the zones of concern.
- Applying the proposed solutions on the scale model, and measuring the daylight efficiency within each solution or system.

An investigation was conducted on possible daylight systems that can minimize the glare phenomenon in tunnels. The Anidolic system and canopy design were taken as examples of these systems.

### 2.3. The tunnel simulation model with Anidolic:

The second step was to take daylight measurements on a model with a simply designed Anidolic lighting system. The proposed system was designed and applied on the scale model using materials such as foil, arch material, etc. in order to measure luminance levels with the Lux meter.

**Table 2. Daylight measurements recorded with the use of the Anidolic system, at constant horizontal distances inside the tunnel entrance.**

Simulation Tunnel model with the Anidolic System			
Depth	Measures (Lux) (Simulation of sun luminance)		
	March 12:00 pm.	June 12:00 pm.	December 12:00 pm.
6	38000	26600	65550
12	38950	29450	61750
18	36100	28500	50350
24	38950	23750	38000
30	33250	13300	29450
36	34200	1140	21850
42	29450	760	17100
48	24700	950	3800
54	9500	855	950
60	4750	665	380
66	950	475	570
72	570	380	475
78	190	190	190
90	95	95	95

- The Anidolic system proved its efficiency in reflecting daylight to a deeper distance inside the tunnel portal. However, the massive drop in luminance levels at the tunnel entrance remains.
- The main disadvantage of this system is the variation of efficiency according to the change of sun angles during daytime or seasons.
- Another disadvantage is the height of the system that is relatively great, and decreases the total tunnel height.

#### 2.4. The tunnel simulation model with Louvers canopy:

The third step was to take daylight measurements on a model with a simply designed Louvers canopy. The proposed system was designed and applied on the scale model using arch material, in order to measure luminance levels with the luxmeter.

**Table 3. Daylight measurements recorded with the use of the Louvers, at constant horizontal distances inside the tunnel entrance, recorded in three different months.**

Simulation Tunnel model with Louvers			
Depth	Measures (Lux) (Simulation of sun luminance)		
	March 12:00 pm.	June 12:00 pm.	December 12:00 pm.
6	42750	24700	76000
12	30400	22800	70300
18	35150	20900	62700
24	32300	29450	57000
30	22800	16150	51300
36	22325	18050	44650
42	21850	26600	34200
48	13300	22800	11400
54	9500	24700	7600
60	3800	12350	3800
66	1425	7600	2850
72	950	5700	285
78	380	950	190
90	95	95	95



- The charts indicate the Louvers’ role in the gradation of luminance levels at the tunnel entrance, which results in a better eye adaptation for drivers.
- Unlike the Anidolic system, the louvers maintain a high level of efficiency regardless of the change of sun angles during daytime or seasons.
- The spacing between the proposed louvers decreases towards the tunnel in order to maximize the luminance gradation.
- Although the Louvers are able to graduate the luminance levels at the tunnel entrance, they don’t reflect daylight inside the tunnel.
- The proposed louvers are made of steel structure, which is a lightweight material and it minimizes the cost.

**2.5. Comparing the measurements of the tunnel with/ without each system:**

For the purpose of comparison and reduction of variables, one of the three months studied in the laboratory was chosen.

**Table 4. A comparison between daylight in the tunnel with/ without with Anidolic, the Louvers, in the 21th of March, at 12:00 PM**

Comparison in March, at 12:00 PM			
Depth	Measures (Lux)*95 (Simulation of sun luminance)		
	Model without any treatments	Model with Anidolic	Model with Louvers
6	38000	38000	42750
12	38950	38950	30400
18	36100	36100	35150
24	38000	38950	32300
30	32300	33250	22800
36	30400	34200	22325
42	31350	29450	21850
48	26600	24700	13300
54	24700	9500	9500
60	20900	4750	3800
66	19000	950	1425
72	1140	570	950
78	380	190	380
90	190	95	95

- The Anidolic System: with reference to the experiment results, the main effect of this system was its capability to eliminate the luminance gap between the inside and the outside of the tunnel. However, the system allows the light to penetrate deeper inside the tunnel entrance.

Using the Anidolic system in the access zone of tunnel decreased lighting level luminance at the tunnel entrance point from (24700 to 9500) Lux during March, allowing a longer adaptation distance inside the tunnel.

- Decreasing lighting level luminance at 20m inside the tunnel from (1900 to 950) Lux (refer to Table 4).
- Louvers: with reference to the experiment results, the Louvers were capable of creating a gradation in lighting along the tunnel entrance zone.

Using the sky louver system in the access zone of the tunnel decreased lighting level luminance at the tunnel entrance point from (24700 to 9500) Lux during March, decreasing lighting level luminance from (38950 to 30400) Lux at a distance of 40 m outside the tunnel entrance and allowing a longer adaptation distance inside the tunnel (refer to Table 4).

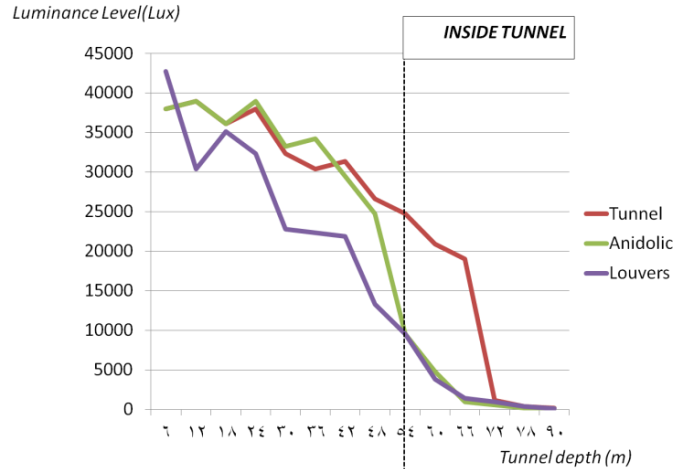


Fig. 8. A comparison between daylight in the tunnel with/ without the Anidolic system, the Louvers, in the 21th of March, at 12:00 PM

2.6. Comparing the measurements of the tunnel with/ without a combination of the Anidolic System and the louvers:

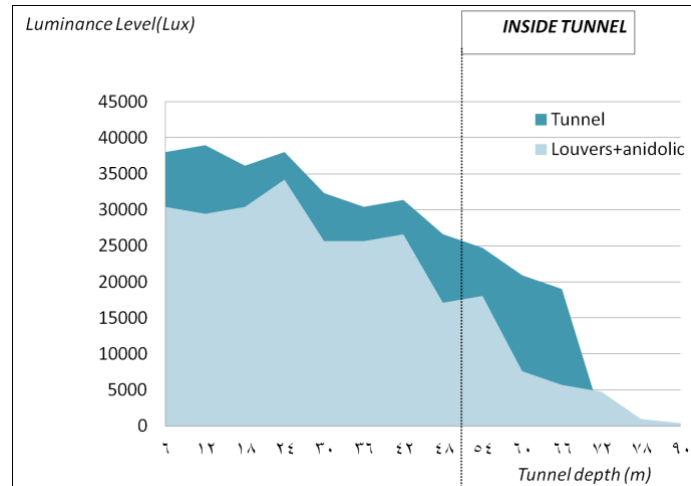
As a result of all of the above, experiments indicated that each system has its own advantages, and in order to maximize the performance of these systems, a combination of both systems was proposed. In order to obtain the most efficient solution of all solutions proposed; a combination of the Anidolic and louvers was created.

Table 5. Daylight measurements in the tunnel with the combination of Louver & Anidolic system, recorded in three different months

Comparing the measurements of the tunnel with/ without the new system (the Anidolic and louver system)						
Depth	Measures( Lux)*95 (Simulation of sun luminance)					
	March 12:00 pm.		June 12:00 pm.		December 12:00 pm.	
	Tunnel	Louvers+ Anidolic	Tunnel	Louvers+ Anidolic	Tunnel	Louvers+ Anidolic
6	38000	30400	26600	26600	<b>65550</b>	<b>23150</b>
12	38950	29450	27550	24700	57000	69350
18	36100	30400	26600	23750	47500	59850
24	38000	34200	28500	25650	46550	59850
30	32300	25650	24700	21850	32300	46550
36	30400	25650	24700	22800	28500	44650
42	31350	26600	25650	20900	21850	20900
48	26600	17100	22800	17100	17100	7600
54	24700	18050	21850	13300	11400	5700
60	20900	7600	19000	9500	8500	4750
66	19000	5700	570	5700	6650	3800
72	1140	4750	285	665	4750	950
78	380	950	190	380	1900	665
90	190	380	95	190	<b>95</b>	<b>285</b>

The comparisons above indicate that the (Anidolic/ Louvers) combination system gave the most convenient results, with the highest level of luminance gradation.

As a result of the optimum luminance gradation, the existing gap between the inside and the outside of the tunnel was eliminated to the optimum level.



**Fig. 9. A comparison between daylight in the tunnel with/ without the integration of Louvers & Anidolic system, in the 21th of March, at 12:00 PM**

### 3. Conclusion and Results

The glare's effect on tunnels is a phenomenon that causes constant traffic issues such as accidents, traffic jams and annoyance to the drivers. This study focused on addressing negligence by those responsible in applying the required criteria for tunnel lighting.

In this paper, solutions were proposed to eliminate the glare phenomenon in existing tunnels. Those solutions included the use of the Anidolic System, which is usually used in buildings to reflect daylight to the interior zones. The louver design was also proposed as a solution to eliminate the light variation between the inside and the outside of the tunnels.

In order to evaluate the systems' efficiency, an experiment was made using a scale model.

- 1 - Using the Anidolic system in the access zone of tunnel decreased lighting level luminance at the tunnel entrance point from (24700 to 9500) Lux during March and allowed a longer adaptation distance inside the tunnel (refer to **Table 4**).
- 2- Using the sky louver system in the access zone of tunnel decreased lighting level luminance at the tunnel entrance point from (24700 to 9500) Lux during March, decreased lighting level luminance from (38950 to 30400) Lux at distance 40 m outside the tunnel entrance, and allowed a longer distance inside the tunnel (refer to **Table 4**).
- 3- Furthermore, a combination between the proposed systems, that integrates both systems' advantages, led to a more convenient solution that eliminated the glare effect and improved the lighting quality in tunnels.

This combination arrangement decreased lighting level luminance outside the tunnel from (38000 to 26600) Lux during March, and increased lighting level luminance from (190 to 380) Lux at distance 40 m from the tunnel entrance, and serving longer distance inside the tunnel (refer to **Table 5**).

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