

# Light Trespass from Exterior Lighting in Urban Residential Areas of Compact Cities



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## Summary

Light trespass, a kind of light pollution, occurs when unwanted light enters one's property and affects living mostly. It causes sleep deprivation, biological clock disturbance, or cancer risk. In urban residential areas, especially in compact cities of Taiwan, light trespass mainly comes from 2 sources: advertising signboard and roadway lighting. Field survey indicates that each advertising signboard increases vertical illuminance levels of 17 lux for the window. It also demonstrates that light trespass from each road lamp causes 10 lux for ground floor and affects about 4 dwellings opposite and behind it. The results show that almost all dwellings are suffered light trespass for the illuminance over the CIE recommended limit. Compared with other exterior lighting, advertising signboard influences dwellings mostly. However, roadway lighting is the main sources of light trespass due to lamps location and lighting all night. Although it is difficult to adjust the high-density living condition in Taiwan, increasing distance between lamp and dwellings, and choosing appropriate lighting devices are useful strategies to prevent light trespass. Furthermore, light trespass should be concerned for developing comfortable and sustainable living environment.

**Keywords:** light pollution, light trespass, exterior lighting, living quality, lighting simulation

## 1. Introduction

In recent years, light pollution has become an important environment issue for maintenance of night lighting quality. More and more countries have formulated relevant light pollution ordinances to reduce light pollution in outdoor lighting. Light trespass occurs when unwanted or too bright light enters one's property, and it may affect sleep quality, biological clock and even increase cancer risk. The influence of light trespass can be adjusted through number of lamps and distance, but a compact city has high population and building density and cannot escape light trespass. In Taiwan, high-density mixed residential commercial buildings, roadway lighting, advertising lighting and night life is quite different from those of residential blocks in European and American countries. Thus, influence of light trespass on the living quarters in Taiwan is more serious.

In Taiwan the source of light trespass in residential areas can be divided into two types: (1) advertising signboard in mixed residential commercial district and (2) roadway lighting. To know the light trespass in the residential areas, the field survey has been conducted, and improvement measures and suggestions are provided to ensure good environment quality at night.

## 2. Research Method

### 2.1 Definition of light trespass

Light trespass occurs when unwanted light enters one's property [1]. When unwanted light enters the houses, the nighttime environment is disturbed and the quality of life diminished. Especially in dimly-lit bedrooms, the outdoor light can affect sleep quality. In addition, too bright light can inhibit melatonin production, cause reproductive system of reproductive system [2] and increase incidence of breast cancer and colorectal cancer [3]. Thus, light trespass has adverse impact on physiology and psychology.

### 2.2 Light trespass limitation benchmark

Based on CIE150 technical report, light trespass evaluation benchmark refers to vertical illuminance of house surface or potential relevant boundary, especially location of windows [4]. The relevant boundary refers to residential property boundary potentially affected by lighting, such as building boundary line or building line. During measurement of light trespass, vertical illuminance (Ev) is calculated 1.5m above the ground or the facade or window [1] [4].

In light pollution prevention, CIE has outlined four environment zones to establish a basis for outdoor lighting regulations, from E1 to E4 [4] (Table 1). The lighting designers can determine the lighting objectives suitable to their buildings. For example, vertical illuminance of E3 zone should be lower than 10 lux during pre-curfew and lower than 2 lux during curfew.

Table 1 Maximum Ev limit of properties

Light Technical Parameter	Application Conditions	E1	E2	E3	E4
Illuminance in vertical plane (Ev) (lux)	Pre-curfew	2	5	10	25
	Post curfew, 23:00~06:00	0*	1	2	5

E1 : Natural—Intrinsically dark—National parks or protected sites

E2 : Rural—Low district brightness—Industrial or residential rural areas

E3 : Suburban—Medium district brightness—Industrial or residential suburbs

E4 : Urban—High district brightness—Town centres and commercial areas

\* NOTE : If the luminaire is for public(road) lighting then this value may be up to 1 lux

### 2.3 Light trespass measurement

To know the impact of outdoor lighting on houses, this study uses vertical illuminance (Ev) on windows as light trespass evaluation basis. Because the height of outdoor lighting fittings is limited, light trespass has greater impact on GF~2F. Thus, facade illuminance is recorded until 2F. The illuminance on window above ground is measured by using illuminance meter. Due to height and privacy of residents, for the part which cannot be measured by the illuminance meter, the measurement is replaced by measuring facade luminance, and then the luminance is converted to illuminance. First, it is assumed building facade material meets Lambert's cosine law, and luminance is equal from all directions. Under the premise, the material surface illuminance and luminance can be converted through the following equation:

$$\text{Luminance (L)} = \text{Illuminance (E)} * \text{Reflectance (}\rho\text{)} / \pi \quad (1)$$

To reach a certain degree of accuracy for the measurement results, the individual readings of photometer should be within  $\pm 20\%$  of the predictions and the average levels should be within  $\pm 10\%$  of the calculated mean [5]. Outdoor lighting measurement uses the illuminometer with 0.1 lux accuracy and cosine and colour temperature correction. Meanwhile, cloudy and rainy days should be prevented during survey. The measurement would start after discharge lamps work for 1 hour.

### 3. Light trespass caused by roadway lighting

#### 3.1 Current situations of roadway light installation

The roadway lights are basic urban lighting facilities. Most dwellings may easily be affected by the roadway lights due to adjacency to the roads, and long roadway lighting time. In Taiwan, the width of the roadway adjacent to the living quarters is 15m, 10m, 8m and 6m, and the lights are installed at each side, and distance between lamppost is around 25~35m. The lamps are usually installed between houses. 200W semi-cutoff mercury lamp is the most common style (Fig. 1).

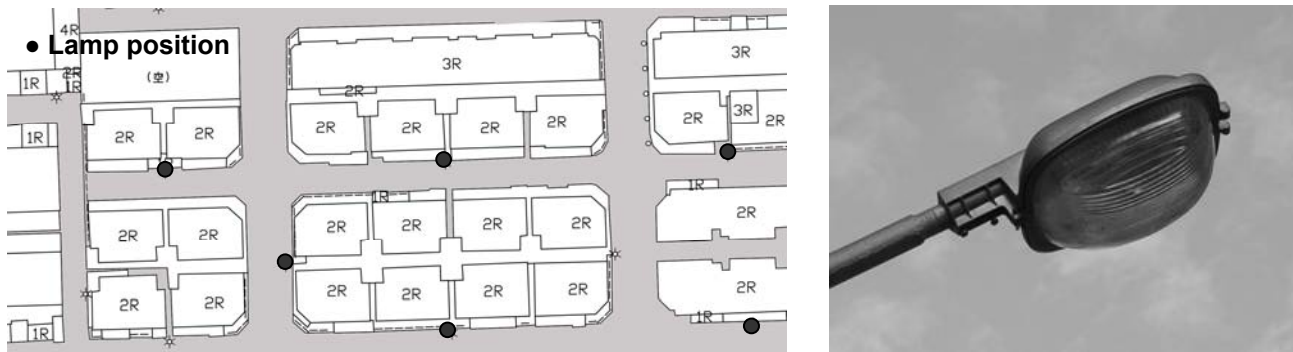


Fig. 1 Road lamp setting and style in residential areas

#### 3.2 Sample description

The study surveyed the urban attached high-rise residential buildings with the same facade style in ten 8m streets in Tainan. Considering coverage of the each road lamp, four houses at front/back of each lamp were taken as sample group, and illuminance on the windows of the houses on GF~2F is evaluated. Eight houses are divided into those at opposite side and back side of each lamp, and distant and nearby houses (Fig. 2). There were 11 sample groups at back side of the lamps, and 7 sample groups at opposite side of the lamps. The illuminance on the windows of the houses on GF~2F was measured, as well as illuminance on the windows of houses between two lamps which was used as the comparison group without light trespass.

#### 3.3 Findings of light trespass caused by roadway lighting and analysis

The findings are shown in the Fig3. The illuminance on the windows of the houses at the opposite side and nearside has the highest value of 11.5 lux. If the vertical illuminance of E3 zone in Table 1 is used as the light trespass reference benchmark, the illuminance on the windows of the houses is lower than 10 lux. However, the lights work all night. If curfew standard of 2 lux is used, the illuminance exceeds the light trespass limit. For this reason, four houses at opposite side and lamp side of each lamp to be installed may suffer light trespass, and the GF~1F are more serious. By large, the impact of light trespass can be reduced with the height of the buildings, and the impact on near side is higher than the far side, and opposite side is higher than lamp side. The illuminance on the windows is ordered as follows (1) Opposite side-- near; (2) Lamp side -- near; (3) Opposite side -- far; (4) Lamp side -- far. The value of (4) "lamp side – far" is close to or lower than 2 lux, and it is likely that no light trespass occurs (Fig. 4).

For the illuminance on windows of the houses between two lamps, the illuminance on the windows of the houses on GF has the highest value of 1.9 lux, followed by 0.7 lux illuminance on windows of 1F houses, and illuminance on the windows of 2F houses has the lowest value of 0.6 lux. The findings show the illuminance on windows of the GF-2F hours is lower than 2 lux, and no light trespass problem occurs. Thus, the street lamp installation causes the illuminance on window higher than light trespass limit. Based on the principle of current position of the street lamps that distance between lamps is 35m and each house plane width is 5m, it is estimated that half residents in each street are suffering light trespass.

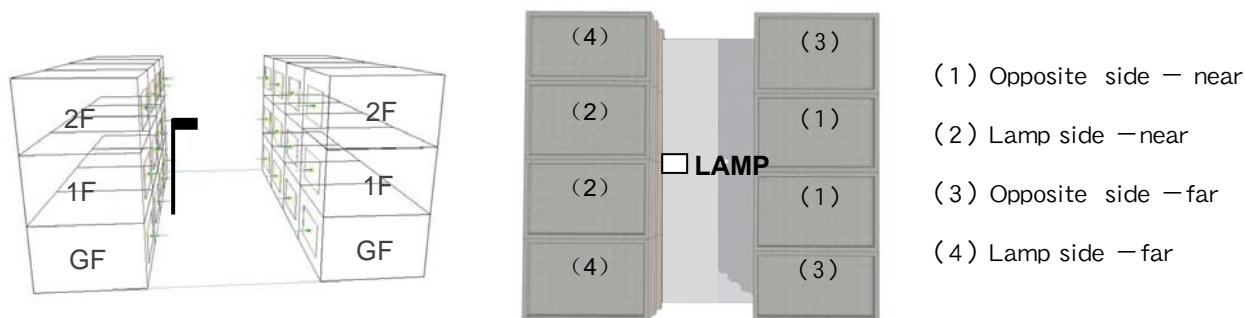


Fig. 2 Relative location of road lamp and dwellings

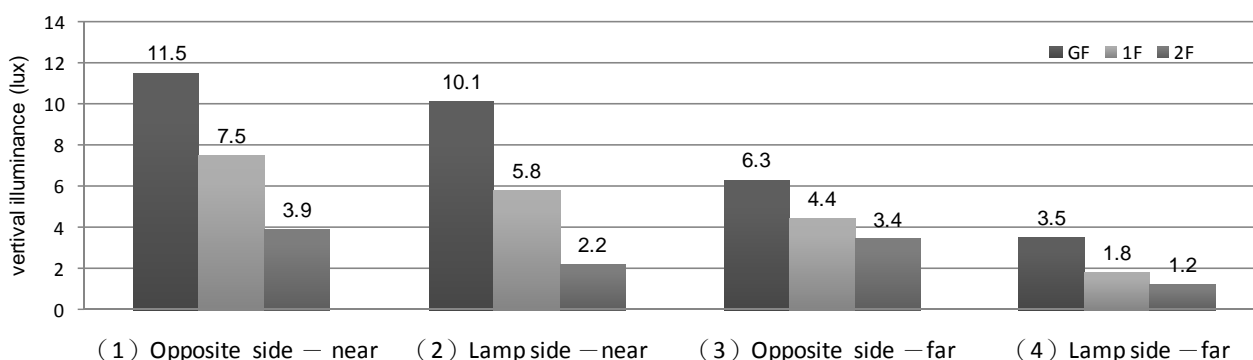


Fig. 3 Vertical illuminance ( $E_v$ ) of the dwellings

## 4. Investigation of light trespass caused by advertising light boxes

### 4.1 Current installation position of advertising light boxes

Currently, the common advertising signboard in Taiwan includes light boxes, neon light, projection lamp and large LED screen advertisings. The light box advertising features easy making, low cost and uniform distribution of the luminance. It is selected by 95% of businesses and the most common advertising way. It is used as horizontal signboard on the building surface and vertical signboard on the building facade. If there is more commercial floors, the building facade may have many light boxes. The advertising light box projecting range is subject to the building laws.

Generally, advertising light boxes are often turned on during night operation and tuned off during closing. But some shops may turn on the light boxes during closing for publicity. In Taiwan, there are many mixed residential commercial buildings in big cities. The ground floor is used for shops and the floors above it are used for dwelling. The advertising signboards are often erected outside the windows on the higher floors. The diffuse light ray may affect residents. For this reason, it is necessary to discuss advertising signboards and light trespass.

### 4.2 Sample investigation

This study surveyed mixed residential commercial streets in Taipei and Tainan. The advertising light boxes are regarded as the major light trespass source. Type and location of advertising signboards, building height and mixture of residential commercial functions were recorded during investigation. The shops are often located on GF. Thus, this study investigated illuminance on window of the 1F~2F houses. Luminance measurement can be conducted for the place which illuminance cannot be measured. In the six commercial districts, 495 building facades were investigated.

### 4.3 Findings of light trespass of advertising light boxes and analysis

#### 4.3.1 Findings

The findings are shown in the table 2. The average facade illuminance of the windows in most commercial districts is 30~50 lux, and the average illuminance on window can reach 57 lux. If E4 25 lux is used as light trespass evaluation benchmark of the mixed residential commercial district, the value is 15~20 lux higher than the benchmark. The illuminance on window is too high. The building height is not related to the facade illuminance resulted from advertising light boxes. This is different from roadway lighting. In some sections, illuminance of 2F is higher than that of 1F. It is related to location and number of advertising light boxes. The more light boxes are, the higher vertical illuminance of the windows is.

*Table 2 Avg and MAX vertical illumination in mixed residential commercial district*






City	Road	Ev-avg (lux)		Ev-max (lux)	
		1F	2F	1F	2F
Taipei City	Hsining S Rd.	38	33	63	72
	Chengdou Rd.	45	52	181	162
	Tingzhou Rd.	43	40	129	114
	Linsen N. Rd.	43	57	72	
Tainan City	Tungning Rd.	32	21	47	58
	Shengli Rd.	35	32	63	71

#### 4.3.2 Impact of advertising light boxes on vertical illuminance of window surface

To know impact of advertising light box installation on light trespass, this section further analyses illuminance on windows under different signboard combination modes. First, it summarizes five types of advertising light box combination modes and samples, and comparison of average illuminance on the windows between 1F and 2F is made. Five types of advertising light box combination include: (a) horizontal advertising signboards; (b) one-sided vertical signboards; (c) horizontal signboards and one-sided vertical signboards (d) two-sided vertical signboards; (e) horizontal signboards and two-sided vertical signboards ( Table 3 ) .

The analysis results show horizontal or vertical signboards increase the illuminance on windows to 17 lux; erection of any two types of signboards can increase the illuminance on windows to 35 lux: three signboards can increase illuminance on window to 52 lux. The number of signboards has multiple relationships with the illuminance on windows, and one advertising light box erected on the building facade can increase the illuminance on windows to 17 lux. Based on the findings, the illuminance on windows can be estimated by using the number of signboards on building facades. In fixed commercial and residential districts, if more than 2 signboards are erected, illuminance on windows can exceed the E4 limit of 25 lux.

*Table 3 The relationship of vertical illuminance of advertising light boxes position*

style	(a)	(b)	(c)	(d)	(e)
illustration					
	only horizontal signboard	one-sided vertical signboard	horizontal and one-sided vertical signboard	two-sided vertical signboards	horizontal and two-sided vertical signboards
Ev-avg	16 lux	18 lux	35 lux	36 lux	52 lux

## 5. Light trespass in residential blocks of compact cities

### 5.1 Comparison with the Impact of light trespass from different light sources

#### 5.1.1 Roadway lighting and light trespass

Road lights are the necessary lighting facilities. However, in the compact cities, residential buildings are constructed adjacent to the streets. It is difficult to avoid light trespass, especially in narrow lanes. Roadway lighting is the major source of light trespass in residential blocks. Due to street lamp height, the floors above the street lamps will not suffer light trespass.



#### 5.1.2 Advertising light box and light trespass

The advertising light box is installed on the facade beside the windows and has direct impact on increasing illuminance on windows. Its impact is more serious than road lamps. As long as one advertising light box is installed on building facade, the illuminance on window can be increased to 17 lux. Being different from street lamps, advertising light box is not always set on the lower floor, if the light box is installed on higher floor, the residents may also suffer light trespass. Advertising light box has greater impact on the residents than roadway lighting. Fortunately, many businesses are closed before 11: 00 pm, and only a few of them continuously turn on their advertising light boxes to maintain commercial image.

### 5.2 Discussion of light trespass in Taiwan's residential blocks

Due to high residential density of the compact cities, installation of light fittings may cause high illuminance on facade. In Taiwan, 1F houses of the common residential houses are the principal bedrooms which are mostly affected by light trespass. If the residential houses are located in the urban residential blocks, illuminance on the windows of principal bedrooms is 6 lux due to impact of road lamps during night; if the houses in mixed residential commercial district, the light from street lamp and advertising light boxes would be received. The illuminance on window surface will increase to more than 23 lux. The more the signboards, the higher the illuminance is (Table 4).

Table 4 Comparison with light trespass from light sources

Light source	Roadway lighting	Advertising light box
Status of light trespass		
Affected time	6 : 00 pm ~ 6 : 00 am.	6 : 00 pm ~ 12 : 00 am
Affected floors	GF~2F	1F~2F, but mainly depending on the location of signboard
Ev of bedroom window (1F)	6 lux	17 lux

As compared to CIE recommended vertical illuminance limit, the investigated values are all higher than the limit. However, the feelings of the residents were not totally the same to the findings. With reference to the past survey result of the 1200 questionnaires[6], only 29% of people felt affected by light pollution. In further investigation, adverting lights box accounted for 73% of total light trespass, and light lamp account for 27%. Compared with the light trespass from advertising light box, disturbance from glittering signboard are more concerned by residents.

It's important to note that although some obtrusive light occurs, most residents are still accustomed to such strong light at night. The results are different from those in Europe and North America, and further study needs to be conducted to test if the Ev limitation is applicable in compact cities .

### 5.3 Urban light trespass improvement measures

#### 5.3.1 Improvement of light trespass caused by roadway lighting

To maintain night environment quality, it is necessary to minimize impact of outdoor light on residential areas. The most effective method of reducing vertical illuminance on window surface is to install light fittings far away from windows according to Inverse Square Law. However, location of roadway lamps is fixed, and it is difficult to change the setting rules. The better way to decrease the light emitting back to influence the dwellings is to set the lamps with light shade (Table 4). Based on the results from the software simulation, the light shade of street lamps can reduce the original vertical illuminance on window surface by 50%-60%. If controlled distribution curve of lamp is used, the Ev will be lower.

*Table 4 Vertical illuminance of different roadway lighting conditions (unit : lux)*

Lamp	(2) Lamp side – near			(4) Lamp side – far		
	GF	1F	2F	GF	1F	2F
original	12.0	7.6	1.9	3.7	4.1	1.4
with shade	6.8	2.0	1.9	2.7	1.4	1.2

#### 5.3.2 Improvement of light trespass caused by advertising light box

At present, according to Taiwan's advertising lighting regulation, glittering signboard such as neon light shall not be installed in the residential blocks. The light that enters the residential blocks cannot be controlled. Due to frequent business activities in mixed residential commercial district, adverting lighting cannot be forbidden, and it is recommended the lights should be turned off during non-business hours. The adverting lighting modes can be changed as possible. The large area of advertising light box can be reduced, as well as luminance, so as to eliminate light on windows of residential houses.

## 6. Conclusions

Light pollution has become an important concern. The Commission Internationale del 'Eclairage (CIE) has published technical report for light pollution, and light pollution is one of the evaluation items by LEED. Light pollution caused by night lighting has been included in Taiwan eco-community assessment system.

To known night residential environment quality, this study surveyed light trespass of street lamps and advertising signboards in Taiwan and conducted analysis. The results indicate that one light lamp can increase vertical illuminance by 6 lux and one advertising light box can increase illuminance by 17 lux while bedroom is on 1F. Although the light trespass caused by advertising light box is more serious than that caused by road lamps, the road lamps are turned on all the night through and are still the main source of light trespass in residential areas. Finally, this study suggested improvement measures for future lighting design and reducing unwanted light at night. In Taiwan, the compact cities have high building density, and the night life of residents is different from the countries in Europe and North American. The psychological feeling of the residents and applicable standards of light trespass evaluation will be developed in the future.

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