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An Exploratory Study on the Effect of Indoor Lighting for Buildings on Light Pollution

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Abstract

This study aims to identify the role of interior lighting in buildings in increasing light pollution, defined as the excessive use of artificial lighting that negatively affects humans, wildlife and clear astronomical vision. The research question is what aspects of interior lighting are the causes of external light pollution. In order to answer the research question, a qualitative approach was followed, by interviewing six lighting specialists, and using a questionnaire to ascertain the views of twenty-one interior designers interested in designing interior lighting. The data collection employed two axes: the first related to the characteristics of the indoor lighting unit, and the second related to factors affecting the interior lighting. The study concluded that interior lighting has a role in light pollution, which depends on its characteristics and the nature of the interior space, through the infiltration of lighting from the interior space to the outside of the building through the architectural openings, due to the lack of consideration of the following determinants of lighting installation in the space, such as the angle of illumination and the number of lighting units and the characteristics of the space in terms of colour, material and openings. We hope that the results of the study will benefit designers in helping to maintain environmental sustainability and reducing the increase in light pollution.

Keywords

Interior Lighting, Light Pollution, Types of Lighting, Residential Buildings

1. Introduction

With the increase in world population, the use of artificial lighting in housing

has increased, which has led to the phenomenon of light pollution. Light pollution has been defined as the excessive use of artificial lighting that overshadows the light of the stars and the moon and causes changes in natural lighting at night (Falchi et al., 2011; Kamel et al., 2020). Light pollution is concentrated in cities with high population densities, as a result of the excessive use of lighting whose rays are reflected and refracted in the air and increase light pollution, which affects the residents quality of life, while uninhabited areas are the least polluted (Czarnecka et al., 2021; Posudin, 2014). Examples of lighting that cause this form of pollution include street lighting, indoor and outdoor building lighting, and billboards (Posudin, 2014).

Studies have also shown that light pollution is increasing due to the use of artificial lighting at night, which covers about 83% of the population on earth (Czarnecka et al., 2021; Falchi et al., 2016). Specifically, by 2016 83% of the populated areas in the Kingdom of Saudi Arabia are polluted by light, and this percentage is increasing and growing rapidly (Falchi et al., 2016). For this reason, people have grown away from the experience of enjoying a clear sky from which to observe and stargaze. In contrast to humans in the past, the sky was the main resource for them, as it was the way to be aware of the time and seasons of planting and harvesting (Collison & Poe, 2013; Malville & Malville, 2008).

Light pollution also affects humans, their quality of life, and ecosystem stability (Du et al., 2018; Kamel et al., 2020). According to scientific evidence, the human biological clock is affected when exposed to excessive lighting at night. This leads to sleep disorder (Ahmed et al., 2017), which causes a weaker secretion of the hormone melatonin. It may also cause high blood pressure, headaches, insomnia, and depression and may cause children to experience increased stress and anxiety (Posudin, 2014; Revell et al., 2006). Moreover, artificial lighting may negatively affect other living creatures, such as causing some animals to lose their ability to navigate, thus affecting their migration, or disrupting the flowering dates of some plants (Posudin, 2014). Unlike some resources that have been destroyed and will not be recovered, the sky is one of the natural resources that can be recovered with some effort to allow us to enjoy the beauty of the sky decorated with stars and planets (Collison & Poe, 2013; Duriscoe, 2001).

1.1. Types of Light Pollution

Light pollution can be divided into three main categories: sky glow, glare, and trespassing light (Du et al., 2018; Kamel et al., 2020). Each of these types has its own concept, causes and effects, as will be clarified. Kamel et al. defines sky glow as an increase in the illumination of the sky due to the vertically upward waste of light (Kamel et al., 2020), which is usually caused by reflections and refractions of light and its diffusion in the lower layers of the atmosphere (Du et al., 2018; Kamel et al., 2020; Posudin, 2014). This type has a great effect, extending to tens of kilometres from the point of illumination itself (Gaston et al., 2012), as it destroys the view of the night sky and makes astronomical observations difficult (Gaston et al., 2012; Kamel et al., 2020). These negative effects can be seen when

observing a light-polluted city from a far dark area, and the sky above the city appears to glow (Kamel et al., 2020).

Glare refers to the excessive contrast between the luminous area or the light source and the dark area around it, which causes discomfort and blurred vision (Kamel et al., 2020; Posudin, 2014). It is found that this type of light pollution is present in some road lights, where it causes accidents because the high contrast may cause temporary blindness for drivers or pedestrians, which makes it difficult for them to see the roads clearly (Posudin, 2014). Kamel et al. (2020) showed that this type of light pollution is the most difficult in terms of measurement and control. The third category, trespassing light, is defined as the illumination or unwanted light that enters and crosses certain boundaries, specifically into dark spaces. It also has several shapes, as external lighting in the streets may enter into dark buildings and houses, or it may trespass and enter the borders of external lands that are not related to it (Du et al., 2018; Gaston et al., 2012; Kamel et al., 2020; Posudin, 2014), which could lead to conflict and upset neighbours.

1.2. Causes of Light Pollution

Although light pollution is mainly caused by the presence of light itself, the extent of its impact varies according to its properties and the elements around it. Light interacts with the surrounding elements in different ways, producing different effects. The effect of light also varies according to its location, as all external lighting causes light pollution (Narisada & Schreuder, 2004; Rodrigues et al., 2015). Although 31.6% of light pollution is due to outdoor street lighting (Kamel et al., 2020). Indoor lighting is also a source of pollution, as it is exposed to reflections and refractions through windows and glass facades, and smooth and shiny materials in the space, which causes its spread and scattering (Du et al., 2018; Rodrigues et al., 2015). Directing the lighting in an unspecified way or directing it upwards causes reflections and scattering of light, thus increasing light pollution (Falchi et al., 2011; Rodrigues et al., 2015). Similarly, the originally dispersed lighting reaches the atmosphere, which increases its dispersion, and the rate of light pollution in the atmosphere increases (Kocifaj, 2011). As Falchi mentioned, the use of artificial lighting, accompanied by light pollution, expands with the urban expansion (Falchi et al., 2011).

A study by Czarnecka et al. (2021) was carried out to clarify these issues. The study was conducted to measure pollution in two different cities and the causes of pollution in each of them. It was found that lighting design was one of the biggest causes of light pollution in both cities: this included increasing the number of lighting units beyond that necessary, random distribution, and using spherical lighting units, which in turn directs 60% of the lighting in the wrong directions, which causes an unfavourable spread. In addition to not using directed lighting units so that they are covered from all sides except for the one concerned with directing the lighting. As mentioned, light pollution can be traced

back to poor lighting design (Rodrigues et al., 2015), which can be mitigated and reduced if lighting is designed in an appropriate and thoughtful manner, given the importance of light in our daily life (Du et al., 2018). Particularly, blue lights are the most polluting and affect humans and other living creatures. Thus, it is suggested to avoid the use of lights with a wavelength less than 540 nm—that is, to prevent the use of lights with cold rays (purple-green-blue) (Falchi et al., 2011).

1.3. Suggestions for Design to Reduce Light Pollution

Solutions can be provided by controlling any of the lighting characteristics, for example, the location, height, and direction of lighting, and taking into account the effect of lighting (Elsahragty & Kim, 2015; Kamel et al., 2020). In addition, new technologies are now available that enable us to control the angle, orientation, and intensity of illumination (Elsahragty & Kim, 2015). Insulators can also be used to isolate unwanted lighting and prevent it from spreading and reflecting, in addition to using lighting covers that help direct the lighting better (Falchi et al., 2011; Kamel et al., 2020).

Gaston proposes a 5-point strategy to reduce and control light pollution. First, prevent some areas from being lit, as researchers believe that preventing the problem is better than trying to solve it later. Second, reduce lighting periods. Thus, the times are arranged according to the need for lighting in certain areas, instead of having lights at unneeded times. Third, reduce light trespass, by designing barriers that prevent light from spilling outside the area requiring lighting, in addition to directing the lighting so that it is not widespread. Fourth, change the intensity of lighting, as researchers are certain that the intensity of lighting plays a major role in light pollution, and if it is reduced and controlled, this will reduce the glow and reduce the reflected light of the sky and its spread in areas and spaces. Finally, reduce the wavelength, as studies have proven that the colour of light—knowing that the colour of light is related to its wavelength—is an important factor in reducing light pollution, as the blue colour is more prevalent and contributes more to light pollution compared to yellow lighting (Gaston et al., 2012; Falchi et al., 2011).

It was noted that many of the studies mentioned above deal with external lighting and its role in light pollution, while only one mentioned interior lighting, in the case of glass facades. There appears to be a scarcity of research regarding interior lighting, its characteristics and role in light pollution. Therefore, this study aims to identify the role of interior lighting in buildings in light pollution from the point of view of specialists and designers, in terms of lighting colour, intensity of lighting, location, distribution and angle within the space, the size of the lighting unit, and its relationship to space, as well as the materials and colours of the space. The research question lies in discovering what are the cases in which interior lighting cause an increase of light pollution. This is to help designers maintain environmental sustainability and reduce light pollution by de-

signing interior lighting for buildings and taking into account residents needs and requirements.

2. Methodology

To answer the research question, this study relied on a qualitative approach, collecting information through interviews with six designers specializing in lighting, from different countries, and a questionnaire involving a number of interior designers from the Kingdom of Saudi Arabia who were interested in designing lighting. The research focused on interior lighting and light pollution, and the study was conducted in the Kingdom of Saudi Arabia during the academic year 2021-2022.

2.1. The Sample

Lighting specialists and interested interior designers were selected as follows:

For the interviews:

- Six lighting designers who are members of the Architectural Lighting Division and who have published works related to lighting. This is due to the scarcity of this specialization and its lack of competence in a particular country and for the purpose of gathering of different points of view and visions, from different countries in the Arab world.

For the questionnaire:

- Twenty-one interior designers interested in interior lighting design, from the Kingdom of Saudi Arabia. They were selected according to specific criteria, which are:

- Has knowledge and familiarity with interior lighting and its characteristics.
- He/she has a scientific degree, not less than a Bachelor's degree, in (interior design—interior engineering—interior architecture—architecture—architecture—civil planning).
- Has at least one year of experience in one of the following fields (professional practice of interior design—teaching lighting curricula—designing interior lighting for a number of projects).

2.2. Study Tools

The interview questions and questionnaire questions were judged by three faculty members in the Department of Interior Design and Furniture at King Abdulaziz University. All the designers agreed to answer the questions and agreed for us to make use of their answers in the published study results.

The following tools were used:

Remote interviews were conducted via electronic communication platforms with six designers specialized in lighting from different countries in the Arab world. According to two axes, lighting characteristics and factors affecting interior lighting, they were asked questions in the following areas:

The first axis: the characteristics of the interior lighting unit. These questions

focused on how each characteristic of the light unit affects light pollution. The interview began with a general question (What is the concept of light pollution from your point of view?) to find out the ideas of the sample regarding the term light pollution. Then we moved to questions related to the characteristics of the lighting unit, including: 1) Do types of indoor lighting have different effects on light pollution? 2) How is the intensity of indoor lighting related to light pollution? 3) How does the size of the indoor lighting unit affect light pollution? 4) How does the angle of spread and orientation of the indoor lighting unit affect light pollution? 5) How does the colour of indoor lighting affect light pollution? 6) How does the temperature of indoor lighting affect light pollution?

The second axis: factors affecting interior lighting. The questions on this axis focused on studying how the external influences surrounding the lighting unit affect the interior lighting and its relationship to light pollution. We started with questions related to the lit interior space, such as: 1) What is the relationship between the colours of the space and interior lighting with light pollution? 2) What is the relationship between the number and area of indoor lighting units in the space and light pollution? 3) What is the relationship between the materials of the interior space and its interior lighting and light pollution? Then we moved to questions related to the architectural openings of the interior space, such as: How do the materials of external facades and architectural openings affect light pollution? 4) How does the location of the lighting unit in relation to architectural openings affect light pollution? 5) What is the relationship of architectural openings and their size to light pollution? Finally, the interviewees were asked about the effect of the height of the ceiling in the space: how is the height of the lit interior space related to light pollution?

The questionnaire was designed according to the five-point Likert scale which is used in questionnaires to measure people's attitudes and opinions towards topics and themes, where selection is made through the specific responses: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree (Jamieson, 2017). The questionnaire was published electronically and twenty-one responses were collected from people interested in designing interior lighting, who were selected according to specific criteria, in order to collect different opinions and trends. They were also asked about several points related to lighting. The questionnaire consisted of two main axes:

The first axis: the characteristics of the interior lighting unit. In this axis, respondents' views were collected regarding whether or not they agreed with statements about the effect of the characteristics of the interior lighting unit. It started with the statement: I know what light pollution is. To see how well the sample understood the term light pollution. Then we moved to phrases related to the characteristics of the indoor lighting unit to find out if respondents considered they had an effect on light pollution or not. These statements included: Indoor lighting causes different effects on light pollution. 1) The intensity of the indoor lighting unit causes an increase in light pollution. 2) The size of the indoor lighting unit affects the amount of light pollution. 3) The angles of diffusion and

direction of indoor lighting affect light pollution in different forms. 4) The colour of indoor lighting affects the amount of light pollution. 5) The temperature of indoor lighting causes an increase in light pollution.

The second axis: factors affecting interior lighting. This axis focused on collecting views, regarding whether or not they agree with the link between the surroundings of the lighting unit and the effect of indoor lighting on light pollution. The questionnaire began with statements related to the lit indoor space, such as: (The colours of the interior space affect the degree of light pollution. 1) The number of indoor lighting units in the indoor space and its area affects the amount of light pollution. 2) The amount of lighting in the indoor space affects the light pollution. 3) The materials of the interior space affect illumination and can increase light pollution. Then we moved to statements related to the architectural openings, such as: the raw materials of the facades and the architectural openings of the lit interior space affect the amount of light pollution. 4) The location of the interior lighting unit relative to the architectural openings affects the amount of light pollution. The final statement related to the effect of the height of the ceiling in the lit interior space affects the indoor pollution.).

3. Results

The results of each of the interviews with lighting specialists and the questionnaire sent to those interested in lighting design revealed the views of the sample, based on their technical information, experiences and expectations, and helped to identify the role of interior lighting in light pollution.

3.1. Interviews

- The first axis: the characteristics of the interior lighting unit.

All the specialists agreed that light pollution is the excessive use of light that affects work, human health, and wildlife, including the clearness of the sky. Specialist (2) mentioned four types of light pollution: light directed at the sky, reflected light from the sky, trespassing light, and glare. The specialists also agreed that the concept of light pollution is known to be more related to external lighting, while specialist (3) also stated that light pollution includes internal lighting that infiltrates from inside the building to the outside.

With regard to the different effects of types of indoor lighting on light pollution, four specialists stated that the type of indoor lighting unit has no effect on light pollution, but the effect depends on other characteristics of the lighting unit, such as diffusion and the amount of lighting. Specialist (2) suggested that the effect of the type of indoor lighting unit with diffusion may be greater than the effect of a directed indoor lighting unit. Specialist (6) added that the effect lies in the ability of the occupant to control the indoor lighting unit. This interviewee suggested that those types whose characteristics, such as the direction angle and the amount of lighting, cannot be controlled may have a greater im-

pact on light pollution.

In terms of the correlation of indoor lighting intensity with light pollution, four specialists stated that the more the intensity of the indoor lighting unit increased in a space, the greater the effect on light pollution. Specialists (2) and (4) added that the correlation of the intensity of indoor lighting with light pollution also depends on other factors, such as the direction of the lighting unit, the colours, the interior space and its materials. Specialist (1) stated that the intensity of internal lighting is related to light pollution, in the case of architectural openings that allow a large amount of light to leak into the external surroundings (outside the building). Specialist (6) argued that there is a correlation between the intensity of indoor lighting and light pollution, and pointed out that light pollution is related to the amount of lighting in the interior space (which is measured in lux): the greater the amount of lighting, the greater the effect on light pollution.

Regarding the effect of the size of the indoor lighting unit four specialists said that the size of the lighting unit does not affect light pollution. However, specialists (1) and (6) pointed out that the amount of lighting produced by the unit is the effect, and specialist (1) explained that if the increase in the size of the indoor lighting unit is linked to an increase in the amount of lighting, then the increase in size will indeed increase the amount of light pollution. Moreover, specialist (4) pointed out that increasing the size of the indoor lighting unit may increase the possibility of glare, thus an undesirable spread of lighting, resulting in a greater impact on the increase in light pollution.

Regarding the effect of the angle of propagation and orientation of the indoor lighting unit on light pollution, the specialists unanimously agreed that these characteristics have an effect on light pollution. Four specialists agreed on the importance of directing the lighting away from the architectural openings, and the obligation to direct the lighting units onto the necessary locations in the space to reduce their impact on light pollution. Specialists (3) and (4) added that the greater the angle of illumination, the greater the possibility of illumination in undesirable areas, and thus a greater effect. Specialist (1) also pointed out that directing the lighting unit sideways has a greater effect on pollution than directing the lighting unit downward.

In relation to the effect of the colour of indoor lighting on light pollution, three of the specialists stated that a blue colour leads to an increase in light pollution, and specialist (5) explained that blue light causes greater glare, thus a greater spread of the lighting with a greater impact on light pollution. Specialist (6) also explained that the blue colour of lighting affects wildlife negatively, and that this is a form of light pollution. Although some specialists did not believe that the colour of lighting has an effect on light pollution, specialist (4) explained that the human eye is sensitive to colours, specifically red more than white, while specialist (1) mentioned that white lighting is more effective in increasing light pollution.

In terms of the effect of indoor lighting temperature on light pollution, four of

the specialists agreed that lighting temperature has little effect compared to other properties. However, the specialists did agree that the temperature of low (cold) lighting has a greater impact on the increase in light pollution, and specialist (6) explained that lighting with a high temperature (warm) spreads less, and therefore its impact on light pollution is less.

The second axis: factors affecting interior lighting

Regarding the relationship between the colours of a space and its interior lighting and light pollution, the specialists agreed that the lighter colours of the space generate many reflections of the light, and thus may increase the light pollution, while dark colours absorb light, reducing the impact of lighting on light pollution. In terms of the relationship between the number of indoor lighting units in the void and its area and light pollution, five of the specialists agreed that the number of lighting units is not an influential factor in itself, but is linked to other factors. Three specialists added that the amount of lighting has an effect, as a large increase in relation to the amount of light appropriate for the size and function of the space increases light pollution. Specialist (5) added that increasing the number of lighting units in the ceiling significantly produces glare spots, which in turn may increase light pollution.

When asked about the relationship of the materials of the interior space and interior lighting to light pollution, the specialists unanimously agreed that smooth, soft materials with a high reflection coefficient increase light reflections and thus increase light pollution, while coarse materials with a low reflection coefficient do not generate reflections.

Concerning the effect of the materials of external facades and architectural openings on light pollution, the specialists agreed that materials with a high reflection coefficient have a greater negative impact on light pollution. Specialist (1) explained that shiny materials reflect the light upwards towards the sky. Three of the specialists stated that the materials of the architectural openings with high transmittance allow light to infiltrate through them in a larger amount, thus affecting the increase in light pollution. Specialist (2) added that the colour of the raw materials has an effect, so that if they are blue, they will have a greater impact.

In terms of how the location of the lighting unit in relation to the architectural openings affects light pollution, three specialists agreed that the proximity of the lighting unit to the architectural aperture increases the possibility of light infiltration from the interior to the exterior, which negatively affects light pollution. Specialists (3) and (5) also mentioned that the location of the lighting unit is related to the direction angle and the angle of illumination spread. Specialist (4) also added that the spread of horizontal lighting is greater than the vertical lighting directed away from the architectural openings, and therefore its effect is greater.

Regarding the effect of the size of architectural openings, all the specialists agreed that the larger the size of the architectural openings, the more likely the

light would spread and infiltrate through them, and thus the light pollution would increase. Specialists (5) and (6) pointed out that this relationship is not fixed, as it may vary according to different other factors. Specialists (1) and (3) explained that the location of the architectural opening and the percentage of space filling is an influential factor, and specialist (3) stated that the architectural openings in the ceiling have a greater impact. Specialist (4) stated that the depth of the architectural aperture affects pollution, as architectural openings with a greater depth prevent the light leakage more effectively.

The specialists were divided regarding the association of the height of the lit interior space with light pollution. Three specialists agreed that the height of the ceiling in the space, the less the ability to control the spread of light, thus increasing the possibility of light infiltrating the external environment and affecting light pollution. This was opposed by specialists (1) and (2). They maintained that the higher the floor, the less the effect of light resulting from reflections, and therefore less impact on light pollution, while specialist (5) stated that the height of the floor is not an influencing factor where there is a control for the lighting unit.

3.2. Questionnaire

The questionnaire collected the views of interior designers interested in interior lighting design regarding the effect of interior lighting and its characteristics on increasing light pollution. In response to the first question, all the respondents were confident that they understood what light pollution is.

- The first axis: the characteristics of the interior lighting unit.

Table 1 and Figure 1 show the answers to the questionnaire regarding the first axis, the sample's opinions of which are the most influential of light pollution.

As can be seen in Table 1 and Figure 1, the majority of respondents generally agreed that all the characteristics were influential in influencing the degree of light pollution. There was particularly strong agreement that the intensity of the

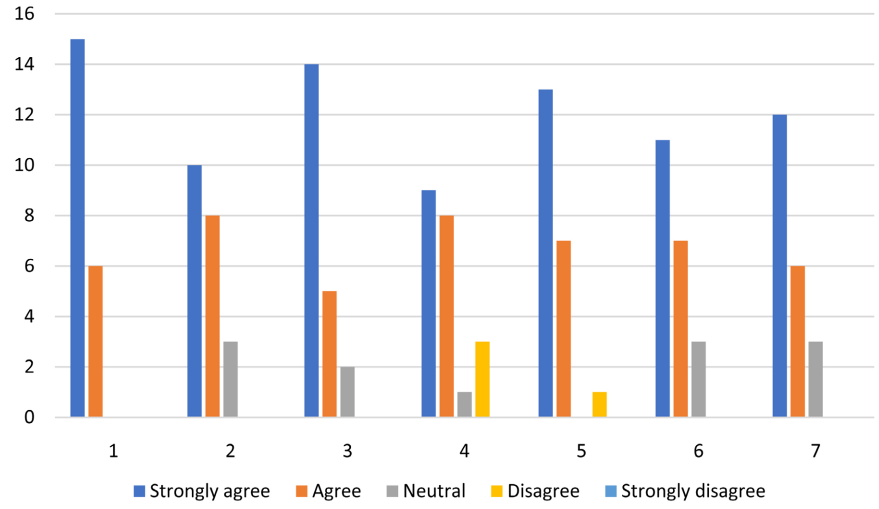

Figure 1. The characteristics of the indoor lighting unit on light pollution.

indoor lighting unit can cause an increase in light pollution (statement 3), followed by the size and angle of lighting in the interior space. Although three of the participants disagreed that these two latter characteristics would affect the amount of light pollution, it is noticeable that none of the respondents strongly disagreed with any of the statements.

- The second axis: factors affecting interior lighting.

Table 2 and Figure 2 show the answers to the questionnaire regarding the second axis, the factors affecting interior lighting which influence light pollution.

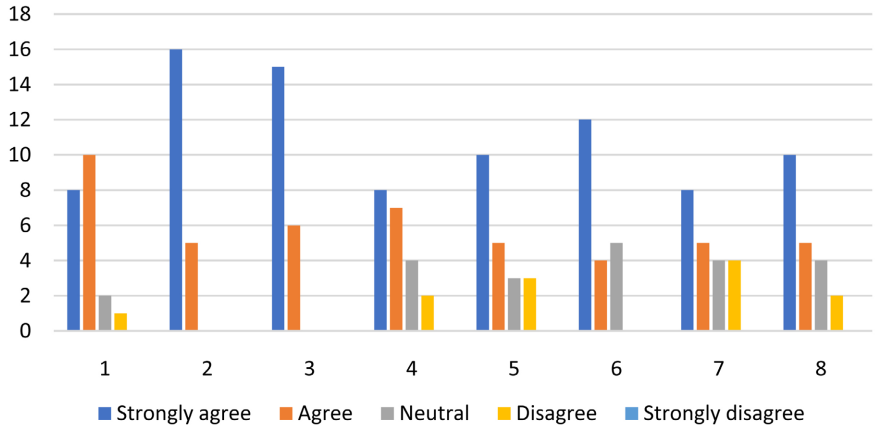

Figure 2. Factors affecting indoor lighting.

Table 1. The most influential of light pollution.

Number	Axis	Question	Answer Number of replies: 21				
			Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	Characteristics of the indoor lighting unit	Types of indoor lighting cause different effects on light pollution.	47.6%	38.1%	14.3%	-	-
			10	8	3	0	0
2		The intensity of the indoor lighting unit causes an increase in light pollution.	66.7%	23.8%	9.5%	-	-
			14	5	2	0	0
3		The size of the indoor lighting unit affects the amount of light pollution.	42.9%	38.1%	4.8%	14.3%	-
			9	8	1	3	0
4		The angles of diffusion and direction of indoor lighting affect light pollution in different ways.	61.9%	33.3%	-	4.8%	-
			13	7	0	1	0
5		The colour of indoor lighting affects the amount of light pollution.	52.4%	33.3%	14.3%	-	-
			11	7	3	0	0
6		The temperature of indoor lighting affects the amount of light pollution.	57.1%	28.6%	14.3%	-	-
			12	6	3	0	0

Table 2. Factors affecting interior lighting.

Number	Axis	Question	Answer Number of replies: 21				
			Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	Factors affecting interior lighting	The colours of the lit interior space affect the amount of light pollution.	38.1%	47.6%	9.5%	4.8%	-
			8	10	2	1	0
2		The number of indoor lighting units in the indoor space and its area affects the amount of light pollution.	76.2%	23.8%	-	-	-
			16	5	0	0	0
3		The amount of illumination in a lit indoor space affects light pollution.	71.4%	28.6%	-	-	-
			15	6	0	0	0
4		The materials of the lit interior space affect the amount of light pollution.	38.1%	33.3%	19%	9.5%	-
			8	7	4	2	0
5		The textures of the facades and the architectural openings of the lit interior space affect the amount of light pollution.	47.6%	23.8%	14.3%	14.3%	-
			10	5	3	3	0
6		The location of the indoor lighting unit in relation to the architectural openings affects the amount of light pollution.	57.1%	19%	23.8%	-	-
			12	4	5	0	0
7		The size of the architectural openings in the lit interior space affects the amount of light pollution.	38.1%	23.8%	19%	19%	-
			8	5	4	4	0
8		the height of the indoor space has an effect on light pollution.	47.6%	23.8%	19%	9.5%	-
			10	5	4	2	0

The results shown in Table 2 and Figure 2 indicate strongly agreement among the respondents that the number of indoor lighting units in the interior space and its area affect the amount of light pollution. The respondents also strongly agreed that the amount of illumination in a lit indoor space affects light pollution. The highest numbers of negative responses (I do not agree) were for the statement that the size of the architectural openings in the interior space affects the increase in light pollution, followed by the statement that the materials of the facades and the architectural openings of the interior space affect the increase in light pollution. We note that none of the respondents indicated that they strongly disagreed with any of the statements.

4. Discussion

It was clear from the interviews that the participants had a sound understanding of the concept of light pollution. The definitions of light pollution and comments provided by the specialists as the excessive use of lighting that affects human health, and wildlife, including the clarity of the sky in the literature (Posudin, 2014; Revell et al., 2006). It affects the quality of human life. However, in

line with Kamel et al. (2020), they agree that the concept of light pollution is mostly considered to be related to external lighting.

The results also showed that the type of indoor lighting unit was not considered to have an effect on light pollution, but the effect depends more on other characteristics such as the orientation angle, which is consistent with previous findings in the literature (Elsahragty & Kim, 2015; Kamel et al., 2020). This confirms what was mentioned (Falchi et al., 2011; Rodrigues et al., 2015) that directing the lighting in an unspecified way or directing it upwards causes reflections and scattering of light, thus increasing light pollution. The illumination unit and its spread was also regarded as an important characteristic affecting light pollution, which is consistent with the findings of Elsahragty & Kim (2015), as the greater the intensity of the indoor lighting unit in a space, the greater the effect on light pollution. Generally, the participants maintained that the size of the lighting unit does not affect the light pollution, but the most influential characteristic is the intensity of lighting.

Most of the participants agreed that light pollution is also affected by the elements of the interior space, that is, the colours and materials used. The results also showed that the colours of lighting were believed to have more effects on light pollution. The results showed that with regard to the temperature of illumination, the temperature of low (cold) lighting has a greater effect on increasing light pollution than lighting with a high temperature (warm), its spread is less, and therefore its impact on light pollution is less, which agreed with the findings of Falchi et al. (2011).

With regard to the second axis, factors affecting interior lighting. The interviewees pointed out that the light interior colours can generate many reflections of lighting, and thus may increase light pollution, while dark colours absorb light, reducing the effect of lighting on light pollution. This is consistent with the explanations of Du et al. (2018) and Rodrigues et al. (2015) for why reflections are one of the factors affecting the increase in light pollution.

The participants highlighted many factors explaining the reason why indoor lighting is one of the causes of light pollution, as concluded by Posudin (2014). They believed that the number of lighting units is not an influential factor in itself, but is linked to other factors, depending on the intensity of lighting. Moreover, they explained that smooth, soft materials inside and outside the space with a high reflection coefficient increase light reflections, thus increasing light pollution, while coarse materials with a low reflection coefficient do not generate reflections. This view confirms the findings in the literature (Du et al., 2018; Kamel et al., 2020; Posudin, 2014) that reflections lead to light pollution. In addition, both groups of participants agreed that the size and location of architectural openings and the materials used in them, especially those with high transmittance, can allow a larger amount of light to infiltrate through them, thus affecting the increase in light pollution, and that the height of the buildings has an effect as well.

From the foregoing discussion, it is clear that not all lighting properties are considered to have an effect on light pollution. Particularly, the participants emphasised that the type and size of the lighting unit does not affect pollution, but the effect is based mainly on the intensity of light and its direction; for example, there are lighting units in different sizes and shapes, but if the intensity of the light is weak it does not affect the light pollution. It is also possible that the lighting intensity may be high, but its direction is far from the openings that leak light to the outside. The temperature of the lighting and the interaction with the interior space in terms of colour, material, openings, the location of the openings and the height of the building were also perceived to have an effect on environmental pollution.

5. Conclusion

From this study, it can be concluded that the external light pollution resulting from internal lighting lies in the exit or leakage of lighting from the internal space (inside the building) to the external environment (outside the building). To reduce it, the amount of light infiltrating through the architectural openings must be controlled, in the same way as the amount of light entering from outside the building to the interior space, such as sunlight and street lights, is usually controlled. In order to reach this level of control, it is not enough only to reduce or close the architectural openings, but interior designers must study all the characteristics of the lighting unit and the factors with high impact to reach the appropriate lighting design for each interior space. Any one of the factors cannot be neglected, because they are linked to each other and any difference may produce a significant impact. Moreover, reducing light pollution resulting from indoor lighting means saving energy wasted when lighting infiltrates outside the space. The research recommends a future experimental study to measure the effect of indoor lighting on light pollution in the outskirts of cities and a study of design considerations and standards that can be followed in the design of interior lighting without increasing light pollution. In addition, this study will help designers to understand the impact of ill-thought-out design of interior lighting on light pollution, and the associated factors affecting this issue. During the preparation of this research, there were some difficulties, which included the lack of previous studies related to interior lighting, where the focus of existing studies was mainly on external lighting, and the scarcity of individuals for the required sample (lighting specialists and those interested in lighting design), which led to the reduction of the sample size.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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