DECUYPERE Justine, CAPRON Jean-Luc & RENGLET Michel, "Influence of Mesopic Lighting Conditions on Pedestrian Visual Field in Urban Environment", *Lux Europa 2009 – 11th European Lighting Conference*, Istanbul, 2009, pp. 1177-1182.

# Influence of Mesopic Lighting Conditions on Pedestrian Visual Field in Urban Environment

Justine Decuypere[1], Jean-Luc Capron[2], Michel Renglet[3]

***Abstract***
*In Belgian artificially lighted urban environments like city centres and urban streets, the lighting conditions are mostly mesopic at night. In order to study the pedestrian's perception, his/her whole visual field has to be analysed. The Esterman grid has been chosen to draw luminance and attention maps. The luminance maps are provided by a per-pixel analysis of high dynamic range images whereas the attention maps are generated by a* mouse-tracking *test. The comparison of both maps reveals the luminance level impact on pedestrians' attention. Fifty-eight observers tested twelve urban scenes from the patrimonial city of Mons, Belgium. Considering the spectrum of the light source and the typology and materials of the urban environment, this work demonstrates the importance of the mesopic range of luminance in the visual field of a pedestrian. Moreover, it presents new ways of selecting efficient lighting solutions that involve the study of the human retina and the environment materials.*

**Keywords:** Urban Lighting, Visual Perception, Mesopic Vision

## 1. Introduction
In everyday life, many situations take place in mesopic lighting conditions. The main applications are night-time driving and urban lighting. For road safety purposes, the driver's point of view has recently been the topic of studies. Those works have led to task performance-based mesopic photometry: the observer was a driver and the main parameters were reaction time and contrast threshold. On the contrary, the pedestrian's point of view has been far less studied. The field of vision of a pedestrian walking in a city by night involves a large range of stimuli so that perception cannot be reduced to one type of stimulus or a part of the visual field. That is why, we'll discuss the importance of mesopic lighting conditions in the entire visual field of a pedestrian in urban environment by night in this paper.

## 2. Mesopic conditions
The human retina is made up of two types of photoreceptors, cones and rods. Cones are responsible for colour vision in light-adapted-viewing conditions (photopic conditions) whereas rods are responsible for night vision (scotopic conditions). Mesopic lighting conditions can be defined physiologically by the light levels where rods and cones are both operational. For the CIE, this range of luminance extends "from some hundredths or less of one cd/m$^2$ to at least several cd/m$^2$" [1]. These limits seem to vary hugely according to various authors (Figure 1). For example, the model of mesopic photometry developed by the MOVE consortium [2] reports results from $10^{-2}$ to 10 cd/m² while the X-model, developed at the Rensselaer Institute [3], functions from $10^{-3}$ to 0.6 cd/m².

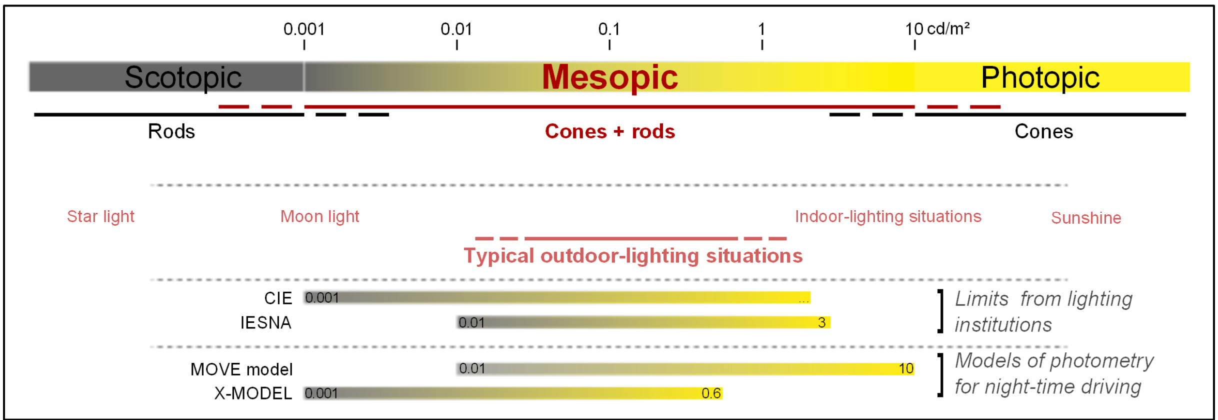

Figure 1. Mesopic range of luminance

Those models can predict the spectral luminous efficiency function at different mesopic light levels from the photopic luminance and the S/P ratio of the light source. They are mainly based on reaction time and contrast threshold tests. Models developed earlier used to consider heterochromatic

[1] Faculté Polytechnique de Mons, Service de Génie Electrique, Mons, Belgium, Justine.Decuypere@umons.ac.be
[2] Faculté Polytechnique de Mons, Service d'Architecture, Mons, Belgium, jl.capron@gmail.com
[3] Faculté Polytechnique de Mons, Service de Génie Electrique, Mons, Belgium, Michel.Renglet@umons.ac.be

brightness matching tests [4], but none of them could be chosen as the new CIE supplementary system of photometry. The elements affecting pedestrian's perception cannot be defined by simple parameters since urban scenes involve many components which interact. From a lighting aspect, the stimuli positions in the visual field can play a role in the adaptation processes, such as light spectrum or colour contrasts.

**3. Methodology**

The peripheral visual field is very important in performing tasks such as walking, keeping one's balance and building cognitive maps [5]. Since all those tasks are useful in order to move around in a city, the entire visual field has to be studied in the case of a pedestrian in urban environment. All the parts of the field of vision are obviously not equivalent. The Esterman grid provides a functional partition of the visual field. It divides the field into different-sized rectangles (Figure 2) with a proportional functional value. That means that the most divided area of the field is the most functional area. For example, the centre of the field is more important than the periphery, the horizontal meridian is more important than the other meridians and the lower part of the field is more extended than the upper one because most human activities (working, reading, eating, working) are carried out below eye level [6]. This grid was initially set up in order to quantify field loss.

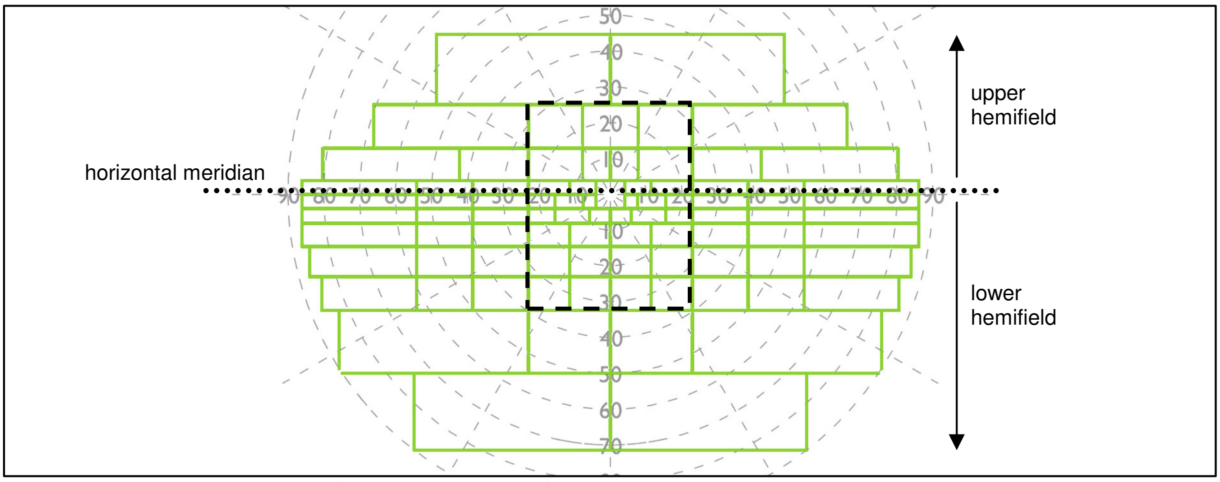


Figure 2. The Esterman grid, a functional division of the visual field

Our method consists in comparing the luminance of urban scenes and the attention of the observer when facing those scenes. Luminance and attention maps are generated using the Esterman grid. Each rectangle is weighted and coloured according to a luminance scale and an attention scale so that scenes can be compared on the basis of their spatial configuration, the spatial position or the spectrum of the light source. Scenes were selected in the patrimonial city of Mons.

**4. Luminance maps**

A per-pixel analysis of high dynamic range pictures provides luminance maps. Each rectangle of the Esterman grid is weighted and coloured according to the mean luminance of the points it encloses. The importance of the mesopic range in urban environment is emphasized and different scenes are compared in order to determine the influence of various parameters (spectrum of the light source, spatial configuration, materials…).

**4.1. Analysis of the HDR images**

High dynamic range pictures of real scenes were created on the basis of five photographs taken with incremented exposure times. The pictures were taken with a digital camera (Fuji FinePix S5000) mounted on a tripod which enabled the photograph to adjust vertical and horizontal angles to gaze direction. The aperture size was fixed (f.4) while the shutter speed varied, as it is recommended not to vary aperture size [7] [8]. Five photographs were taken at 2-stop increments from 2 seconds to 1/125 seconds. As a small ISO value reduces noise, the ISO sensibility was fixed to ISO 200, which is the minimum for the camera we used. Pictures were saved under RAW format to avoid in-camera processing that could alter the light and colour accuracy.

The five pictures are blended to an HDR image using Photomatix software. The white balance and colour primaries are defined before the blend. ProPhoto RGB is selected as colour system as it offers a larger colour gamut of other RGB systems. The white point associated to this system is the CIE Standard Illuminant $D_{50}$ (horizon light). The white balance is therefore fixed to a colour temperature of 5000 K. To measure luminance, the white balance must match the colour space instead of the lighting environment. Applying an appropriate white balance would create a better visual effect, but this would affect the luminance accuracy.


Figure 3. Transformation of photographs into luminance maps

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.7977 & 0.1352 & 0.0314 \\ 0.2880 & 0.7119 & 8.6e^{-5} \\ 0 & 0 & 0.8252 \end{bmatrix} . \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

The HDR files are read and changed into luminance maps with Matlab® (Figure 3). The RGBE format is transformed into floating point RGB values. The colorimetric system is converted to CIE XYZ colour space based on the CIE Colorimetric observer with 2° field of view. The transformation matrix (1) is calculated to achieve the unit white point balance (2-7). In the XYZ system, Y is representative of the luminance. The Y values have to be calibrated with a physical luminance measurement (8).

$$(X_r \quad Y_r \quad Z_r) = [x_r/y_r \quad 1 \quad z_r/y_r] = (0.7347/0.2653 \quad 1 \quad 0) \quad (2)$$

$$(X_g \quad Y_g \quad Z_g) = [x_g/y_g \quad 1 \quad z_g/y_g] = (0.1596/0.8404 \quad 1 \quad 0) \quad (3)$$

$$(X_b \quad Y_b \quad Z_b) = [x_b/y_b \quad 1 \quad z_b/y_b] = (0.0366/0.0001 \quad 1 \quad 0.9633/0.0001) \quad (4)$$

$$(X_W \quad Y_W \quad Z_W) = (0.96422 \quad 1 \quad 0.82521) \quad (5)$$

$$\begin{bmatrix} S_r \\ S_g \\ S_b \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix}^{-1} . \begin{bmatrix} X_W \\ Y_W \\ Z_W \end{bmatrix} \quad (6)$$

$$[M] = \begin{bmatrix} S_r X_r & S_g X_g & S_b X_b \\ S_r Y_r & S_g Y_g & S_b Y_b \\ S_r Z_r & S_g Z_g & S_b Z_b \end{bmatrix} = \begin{bmatrix} 0.7977 & 0.1352 & 0.0314 \\ 0.2880 & 0.7119 & 8.6e^{-5} \\ 0 & 0 & 0.8252 \end{bmatrix} \quad (7)$$

$$L = k.Y = k.(0.2880 * R + 0.7119 * G + 0.000086 * B) \quad (8)$$

The luminance maps are generated from the calibrated Y values. Two types of scales were used. The first one is absolute: the pixel is weighted and coloured according a divided luminance scale. For instance, the luminance levels can be divided into six ranges: scotopic, 0.001-0.01, 0.01-0.1, 0.1-1, 1-10 cd/m² and photopic. The second scale depends on each scene: it divides the luminance scale into eight equally-wide ranges from the minimum to the maximum luminance of the picture. As one picture cannot fill the entire visual field, seven HDR images are created with different angles. That means that for each visual scene, 35 photographs were taken.

### 4.2. Proportion of mesopic luminance

Mesopic luminance is omnipresent in the visual field of a pedestrian walking in an urban environment at night. Our results show that more than 95 per cent of the scenes are in mesopic conditions. The luminance distribution ranges mainly between 0.001 and 10 cd/m² in the case of streets illuminated by metal halide (MH) lamps and between 0.01 and 10 cd/m² when high pressure sodium (HPS) lamps are used (Figure 4). The scenes lighted by mercury lamps (HPM) are much darker than the others, their luminance levels are mostly under 0.1 cd/m² and a significant part of the scenes is scotopic. This can be partially explained because these scenes are not located in the urban city centre contrary to the scenes lighted by HPS and MH lamps. The mercury lamps will be removed in the near future.

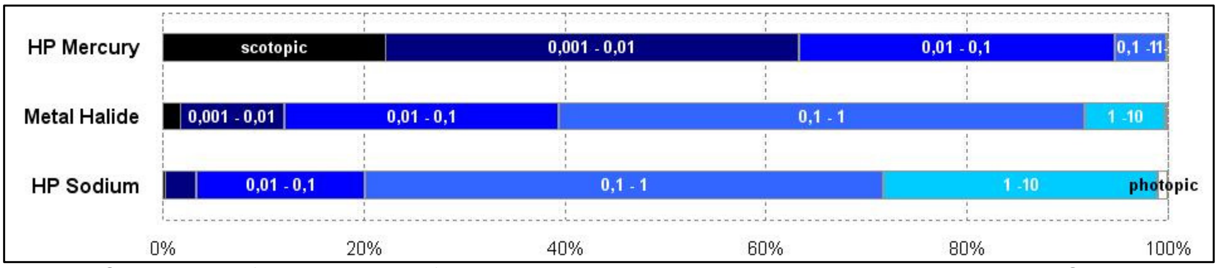

Figure 4. Comparison of the proportion of mesopic luminance in scenes lighted by HPM, MH and HPS lamps.

On figure 4, we can see that the range 0.1-1cd/m² is equally important for scenes illuminated by HPS and MH lamps. Furthermore, it is the largest range of luminance for both kinds of light sources with about 50 % of the points of the scenes. The other ranges are not spread out identically for both lamps. With HPS lamps, 30% of the scene is above 1 cd/m², whereas only 10% are above this limit with MH lamps.

### 4.3. Comparison of different visual scenes

The comparison of scenes illuminated by high pressure sodium and metal halide lamps can come down to the comparison of a spectrum centred on yellow or a spectrum with light rays of different wavelengths in the whole visible domain. The sodium lamps seem to produce higher levels of luminance, but they also seem to create uniform scenes. All the elements of the scene have the same value whereas the white lamps appear to generate better contrasts between the different parts of the visual field (Figure 5). Space configuration is better defined by the light contrasts so that the pedestrian can build a mental image of his/her environment more easily.

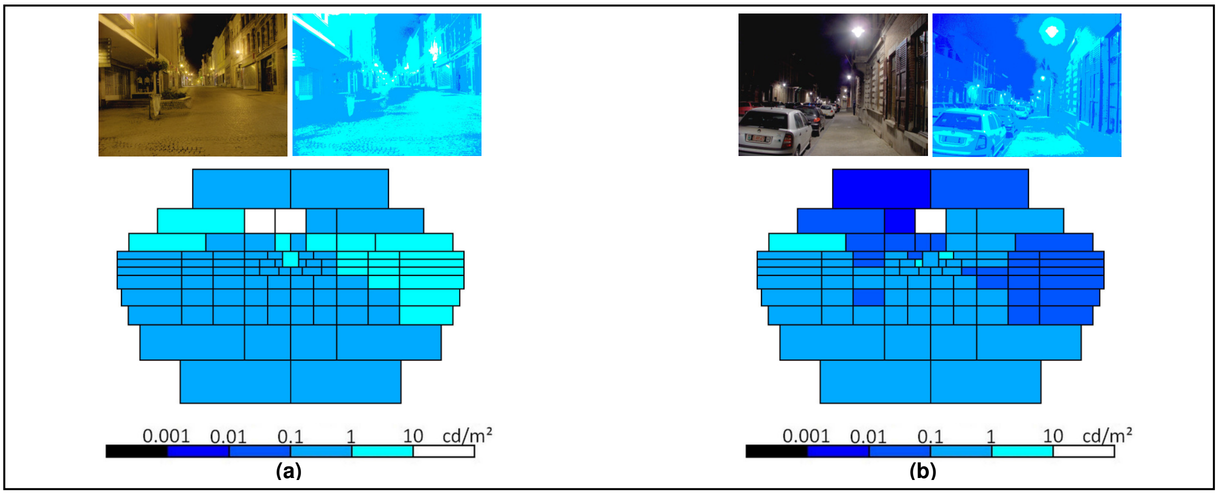

Figure 5. Comparison of scenes illuminated by HPS (a) and MH (b) lamps in urban streets.

Materials are also important considering luminance values which are calculated from reflected light rays. Figure 6 shows the impact of a reflective pavement (a) and a dark wall (b). Luminance depends on both light source and reflecting material: the source spectrum is reflected by the material reflectance spectrum. If a light source has a good mesopic efficiency, it is important that surfaces reflect its spectrum. For example, a greener light could have a good mesopic efficiency but materials of the urban environment do not reflect green so much, except trees. For those reasons, mesopic perception studies should consider not only the light source, but also the environment.

Figure 6. Influence of the materials

## 5. Attention maps

Our attention maps are based on mouse-tracking tests. While eye-tracking test consists in following the exact gaze direction of an observer with a complex device, mouse-tracking test consists in asking the observer to follow the centre of his/her attention on a screen with a mouse cursor. The second method is less reliable than the eye-tracking but is much easier to elaborate. It has far less constraints: the operator quickly gets a good command, the observer's head doesn't have to be attached and the calibration process is faster [9]. The program used to register the pointer movements was set up by M. Mancas (Service de Théorie des Circuits et de Traitement du Signal at the Faculté Polytechnique de Mons). Due to the easy implementation of this equipment, a large number of tests can be performed in a short time. Fifty-eight observers took part in our study. The results have been summarized in Esterman grids to be compared to the luminance maps.

### 5.1. Experimental layout

Each subject was asked to look at different scenes projected for ten seconds on a screen in front of him/her (Figure 7). He/she was positioned facing the screen in order to see the image with the same angles as in the real street. He/she had to follow the centre of his/her attention with a mouse cursor. As the screen couldn't fill the entire visual field, only panoramic pictures were used. The results are therefore limited to a centre part of the Esterman grid. The observer was accustomed to the dark environment of the test room for about ten minutes. Meanwhile, the observer was shown several pictures to get used to the method. A total of 58 observers took the test. They were between 10 and 56 years old and had various professional activities. Two sets of 16 pictures were used. Each observer had to look at one set composed of six colour pictures (white balance coordinated with the colour temperature of the light source), four related views, with higher and lower white balance and six grey-scaled drawings (careful attention was drawn to the reproduction of luminous conditions).

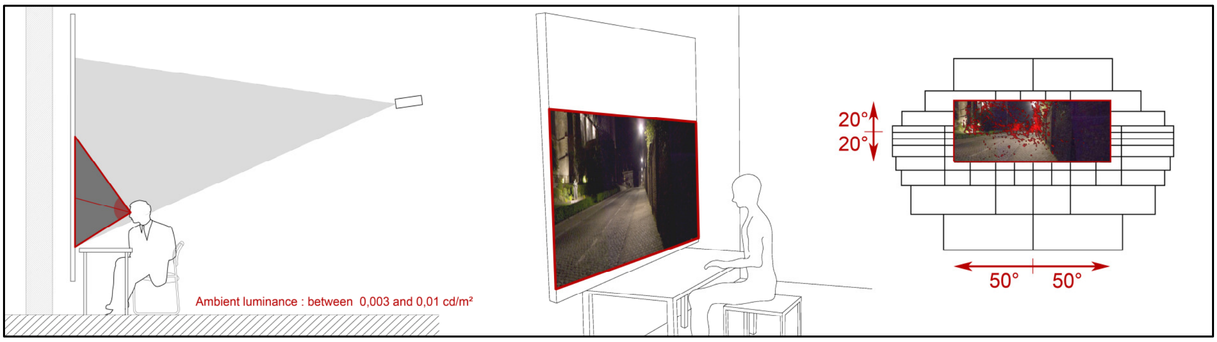


Figure 7. Experimental layout of the "mouse-tracking" test

### 5.2. Distribution of the attention in the visual field

The attention maps show that observers mainly look at the centre of their visual field. This centre is also the centre of the perspective. The observer looks where "he/she is walking to". The attention distribution widely varies among the different scenes. Noteworthy elements are especially attractive such as the belfry or other patrimonial objects. The attention paid to more functional elements like cars along the streets reveals gender differences of attention behaviour.

The use of a white balance non-conform to the reality seems to uniform the colours of the scene. As a result, the attention is a little larger in scenes with correct white balance (Figure 8). On the grey-scaled drawing of the same scene, spatial configuration is preserved so that attention remains quite similar in the spatial scan. But the erasing of elements like cars and façade textures explains that some trends in the attention maps differ.

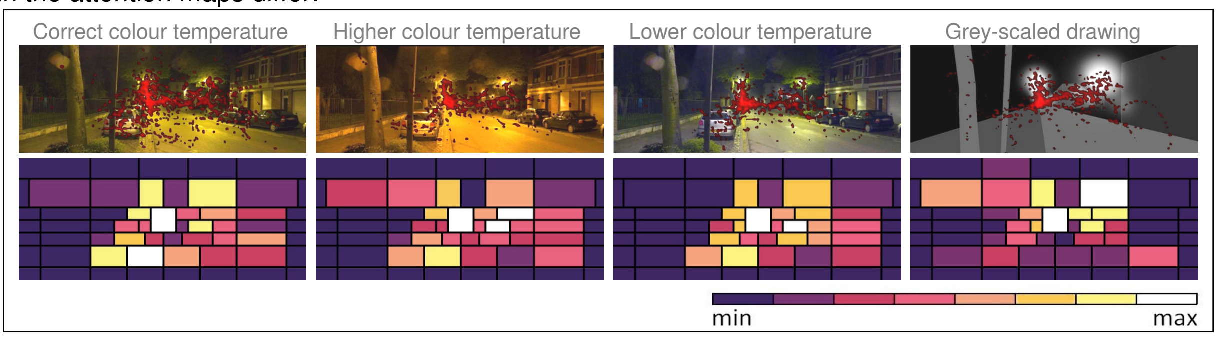


Figure 8. Attention maps. Comparison of different white balances and a grey-scaled drawing of the same scene

### 5.3. Confrontation to luminance maps

Logically, observers pay less attention to dark parts of the scene. But luminance seems not to be the only parameter influencing gaze orientation. Attention is not distributed in a similar way in the case of scenes illuminated by MH or HPS lamps. With MH lamps, the attention maps are quite similar to luminance maps (Figure 9). The whole scene is observed. For the scenes lighted with HPS lamps, attention is mainly concentrated on the centre of the visual field. MH lamps have a good colour rendering index contrary to HPS lamps. This means that scenes with a good luminance and colour distribution are watched in their totality whereas in front of scenes that are uniform in luminance and colour, subjects tend to focus attention on the centre of the field.

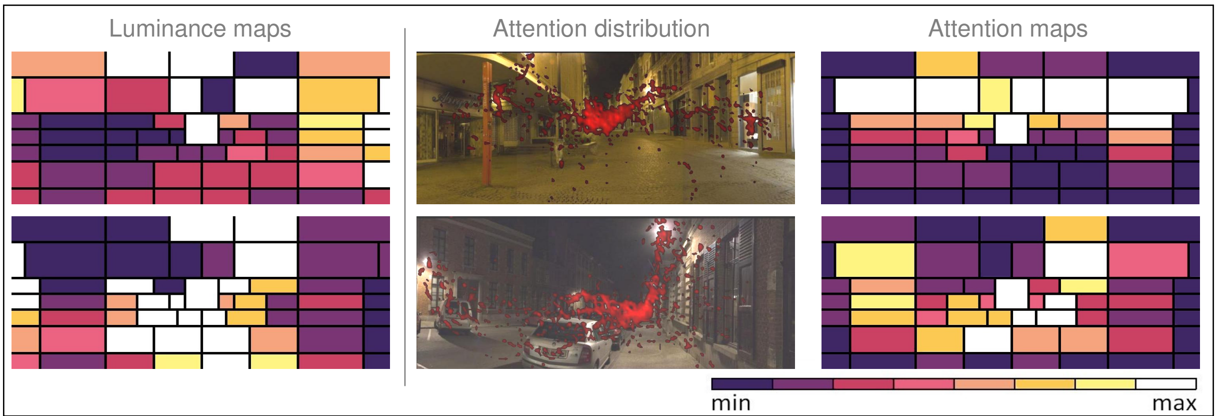


Figure 9. Comparison of scenes illuminated with HPS and MH lamps. Luminance and attention maps.

## 6. Conclusion

In urban environment, the pedestrian is mainly confronted to mesopic luminance levels. Luminance maps indicate that the mesopic range of vision is omnipresent in his/her visual field. At those levels, human vision varies according to several parameters. Visual attention was studied in order to describe these parameters. Attention maps show that it is easier for the observer to place himself/herself in space when there is a good luminance contrast between the scene elements. Lamps that have a full and continuous spectrum can generate this kind of contrasts while lamps with a low CRI tend to make the scene more uniform. The observer watches the whole scene when it is illuminated by MH lamps while he/she only pays attention to the centre of his/her field of vision when HPS lamps are used. Lighting designers should consider the real perception of observers rather than photometric values that do not stand for the entire reality. Light installations should be set up taking into account the street environment: ground and wall reflectance, position of the observers walking in the street, position of the light sources in their visual field, mesopic impact on perception… Under the present circumstances, it is important not to waste energy in a light spectrum that would not be reflected by the environment or that the human retina would not be sensitive to. That way, energy consumption and light pollution could be reduced.

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