VISUAL COMFORT ASSESSMENT BASED ON PERCEPTION IN TRANSITIONAL SPACES BETWEEN INSIDE AND OUTSIDE: A MEDITERRANEAN CASE STUDY

Judit López, Carlos Alonso, Isabel Crespo, Rafael Serra, Helena Coch
Architecture & Energy
School of Architecture of Barcelona. UPC
Av. Diagonal, 649, 7th floor 08028 Barcelona
e-mail: juditlb@yahoo.es

ABSTRACT

Visual comfort is usually defined in terms of illumination level, with the consequent disparity of values found in publications. However, transitional spaces have different features, such as dynamism and adaptive process, compared to other static spaces in buildings. Therefore, other factors must be considered when assessing the visual response. This study focuses on the quality of light and atmosphere and their relationship to other features such as space design. With this aim, four parameters were determined to evaluate the visual perception in a case study, namely the entrance areas of Caixaforum in Barcelona. Data collection and analytical observation were performed, and later the response to visual comfort and space design was evaluated. Although this is a single case study, the scope of this method could be all kind of entrance halls in Mediterranean climate. The results make it clear that visual comfort depends on many perceptive and spatial factors.

1. INTRODUCTION

The significance of transitional spaces between inside and outside lies in their unavoidability. There is a common feature to all kind of buildings: the continuous movement from inside to outside or vice-versa which poses an environmental gap to be solved. There are many kinds of building transitions, from simple doors and lintels to sophisticated solutions with articulated spaces. The fact is that when moving from the outdoors to an inner space or the opposite, there is a great chance for visual discomfort. In both cases, the luminous conditions in the origin and destination may be much different, causing a visual "shock". In a simple door, the transition is instantaneous, while other complex solutions offer more time for the visual system to adapt. In addition, in Mediterranean countries clear skies are present most of the time, so the horizontal illuminance level rises to more than 100,000 lx. Apart from that, the high reflectance of the surfaces on the built environment, stemming from the attempt to avoid overheating in summer, makes the visual performance worse because of the high levels of luminance reached outside. With this illuminance and high reflection, levels of up to 20,000 – 30,000 cd/m^2 can be reached. Nevertheless, in the interior of the buildings, where the light conditions are more controlled, the levels are lower, beneath 500 lx in most cases, which means luminance values of around 100 cd/m^2 for medium reflectance coefficients, making the relationship between inside and outside luminance around 300:1. The function of transitional spaces is to deal with these conditions. Traditional architecture has solved the transition in the vertical plane with solutions like the Mediterranean blind, where the proper distribution of light, moving the higher luminance out of the field of vision, is the key to making interiors comfortable (1). Another example regarding light distribution is the traditional Islamic architectural façade, where a pattern of small holes is used instead of a single window so as to reduce glare and improve the visual performance inside (2).

Nevertheless, transitional spaces are developed in a tridimensional space, and the mechanisms extend from the vertical plane to the entire space. Therefore, such spaces offer a potential for different ways of facing comfort research, which are not only visual. The reason is that, as circulation spaces, the users do not spend a lot of time in them and the expectations of comfort may not be as high as in other static spaces of the building. For example, thermal conditions in transitional spaces can be more flexible than they are in the rest of the building. In consequence, the range of temperatures accepted by the users could be wider and less energy could be used to reach thermal comfort (3). In fact, in transitional spaces the comfort depends more on the conditions of the adjacent spaces, as we said before, than on the conditions in the space itself.

Apart from thermal comfort, visual performance is also important in terms of visibility and visual comfort in transitional spaces. In general, the role of visibility has been the key to illumination design. Nevertheless, in recent years importance has also been attached to the quality of light and the atmosphere defined by the light (4). This is especially important in transitional spaces because they offer the first impression of the building and we spend little time there to adapt our visual system. The elements composing the space and the time spent covering it are also important (5) because they are directly related to the luminance contrast generated and the adaptation time. Some studies have focused on quality parameters such as the modeling factor index or MF. This index portrays the tridimensional performance of the space (6). The modeling factor index establishes the relationship between cylindrical and horizontal illuminance so as to provide an idea of the direction of light. Low MF values reflect higher light verticality while high MF values reflect the opposite, a variety on the distribution of light (reflection of surrounding surfaces).

According to the above, there are two different approaches to visual comfort: from the point of view of either the quantity or the quality of light. A complete assessment of visual comfort in transitional spaces should necessarily contain other parameters apart from the amount of light in terms of illumination level to assess the quality of the light and the atmosphere generated. This study deals with other features of light closer to user perception. With this aim, four parameters were taken to assess the visual response in a transitional space. We started by measuring the levels of illuminance and their distribution in the space, then we related them to the color temperature of the light. Next we measured the illuminance levels along the entry paths and finally the luminance contrast in the visual field.

2. METHODOLOGY

As we mentioned above, four parameters were determined to assess visual response in the case study:

- Illuminance levels distributed throughout the entire space.
- Optimum color temperature related to the illuminance levels measured.
- Illuminance levels in the entry paths in order to evaluate visual adaptation.
- Luminance contrast in the visual field at different points inside and outside.

In order to evaluate the visual comfort parameters mentioned above, a series of measurements were carried out in a case study. The chosen case study is the Caixaforum building in Barcelona, a cultural center located in a restored historical building in the city center of Barcelona. The main building houses exhibition halls, conference rooms, an auditorium, a library and other services. The entrance spaces are adjacent to the main building and were designed by Arata Isozaki and Associates in 2002 to accommodate and organize all the circulation in the center. The public enters there through three stairways at street level located at the boundaries (Fig. 1) that lead to the main entrance located in the basement (Fig. 2). The main entrance is composed of a courtyard and a great hall beyond the court, where all the public circulation is articulated.

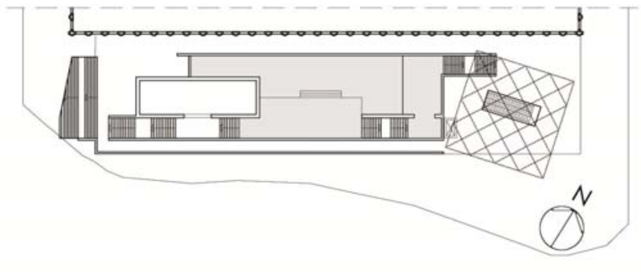

Fig. 1: Plan of ground floor (street level)

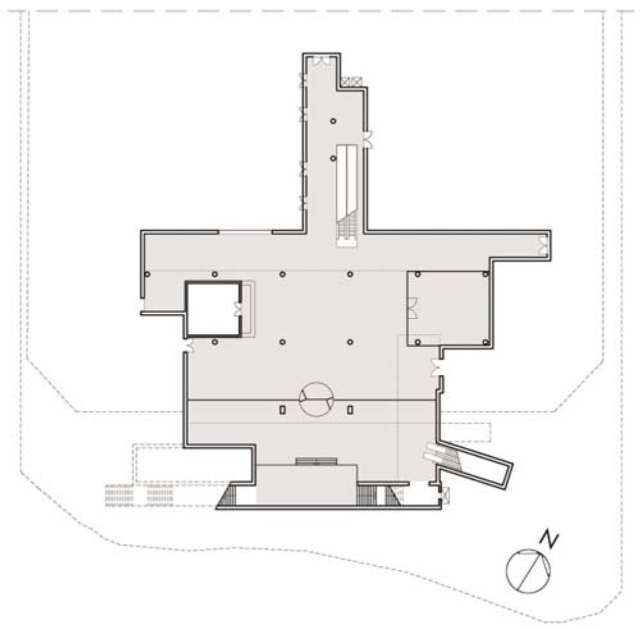

Fig. 2: Plan of basement floor (entry level)

There are several features that make up the space and influence the visual response. The whole is a perimeter-defined space with white boundary walls, especially the ones in the courtyard, which are highly illuminated during part of the day. In general, the finishes on the ceiling, floor and walls are very light. There is also a central point of attention, a sculpture used as a light fixture located at the center of the space that draws the attention. Natural light reaches the interior through a floor-to-ceiling glazed wall that separates the courtyard from the hall.

The measurements were undertaken in the courtyard and hall of Caixaforum on August 9, 2010. They took a working day during opening hours. Three series of illuminance measurements were taken throughout the day, at 11:45 am, 5:30 pm and 9:00 pm. The points were arranged in a grid of 4 rows and 3 columns from the courtyard to the back of the hall, for a total of 12 points. The illuminance measurements corresponding to the entry paths were taken at 12:00 am at different points along the route. All the measurements of illuminance were taken in a horizontal plane at one meter off the floor with a MS 6610 digital luxmeter. The values obtained were entered into the computer for further processing. The luminance distribution in the visual field was evaluated with HDR processed pictures showing the distribution of luminance and their values in a false color mapping. The pictures were taken with a Canon EOS 350D digital camera and were processed later by the web HDR software (7), which provides the luminance values in false color images. Two series of pictures were taken: at 1:00 pm and at 5:00 pm. The field study was made in sunny conditions with clear skies and the results can be extrapolated for a Mediterranean climate.

3. RESULTS

The results obtained in the field study shown below are organized into four sections corresponding to the four parameters studied.

3.1 Illumination levels

The measurement points in the entry spaces were distributed as shown in Figure 3. The values obtained in each sequence of measurements were extrapolated to a table and a graphic, as seen in Table 1 and Figure 4.

The light distribution into the space decreases from the rows in the back of the hall (p. 10, 11, 12) to the ones in the courtyard (p. 1, 2, 3), as seen in the figures. The sequence of values taken in the morning shows the highest contrast between darker and lighter points. Simultaneous values were measured, from 109,000 lx to 356 lx, which represent over a 300:1 ratio. In the afternoon, this ratio descends to 67:1. However, at night, artificial light makes the distribution more uniform. In fact, the values range from 500 lx to 98 lx, which represent a 5:1 ratio, much lower than during the day. Furthermore, we can see that the light in the back of the hall is quite stable all day long. The values at points p.10 to p.12 range between 500 - 196 lx at any time of the day, which is a ratio of about 2,5:1. However, the first row of inner points (p.4 – p.6) shows the greatest variation in terms of absolute level, from 4,700 lx in the morning to 133 lx at night, which is a 300:1 ratio.

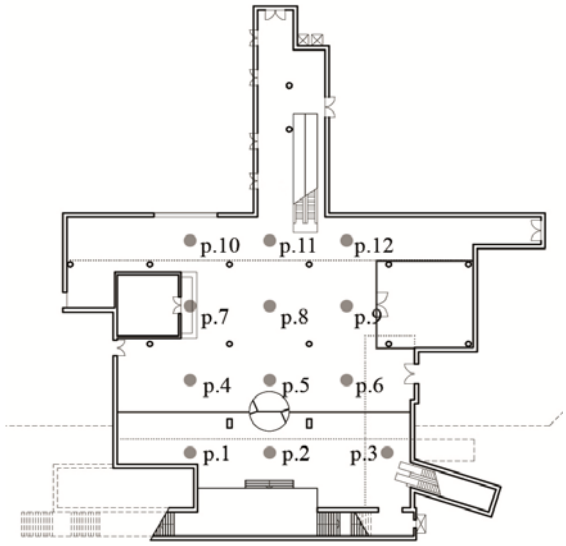

Fig. 3: Plan of basement floor with locations of measurement points

TABLE 1: ILLUMINANCE LEVELS (lx)

Hour	11:45	17:30	21:00
p.1	105.000	6.420	550
p.2	109.000	14.500	490
p.3	6.700	3.600	198
p.4	2.950	1.020	139
p.5	3.100	1.050	233
p.6	4.700	1.235	133
p.7	1.088	510	168
p.8	1.240	620	435
p.9	910	570	98
p.10	456	215	196
p.11	500	315	389
p.12	356	225	226

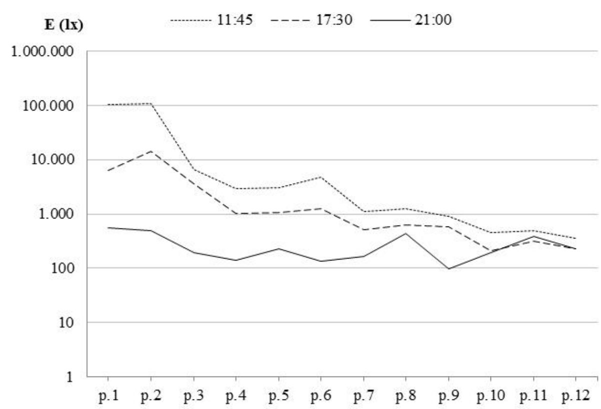

Fig. 4: Graphic with illuminance levels

3.2 Kruithof's diagram

Using the illuminance measurements obtained in the previous section, these values were entered in a Kruithof's diagram in order to deduce the most suitable values of light color temperature. In this diagram, the level of illuminance is related to the color temperature of the light, showing the comfort and discomfort zones according to the user's perception. The shaded areas beyond the lines correspond to discomfort zones, while the area in the middle corresponds to the comfort zone. The illuminance value levels obtained in the interior rows in daytime sequences are overlapped with the diagram in Figure 5, and the same operation for the sequence with artificial light is shown in Figure 6.

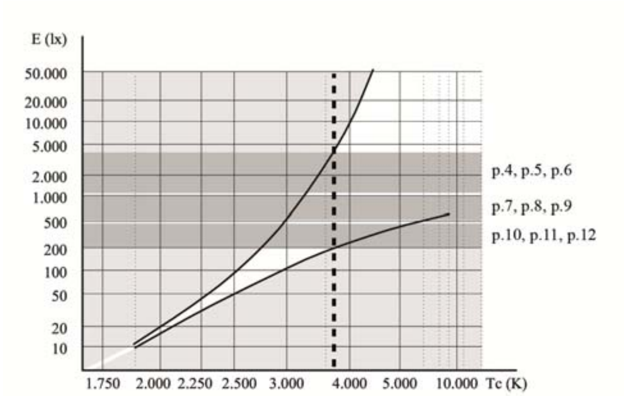

Fig. 5: Kruithof's diagram with illuminance values from points 4 to 12, at 11:45 am and 5:30 pm

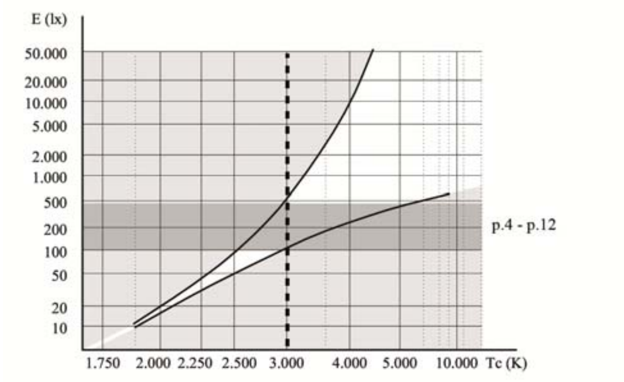

Fig. 6: Kruithof's diagram with illuminance values from points 4 to 12, at 9:00 pm

The row immediately behind the glazed wall shows a suitable color light temperature up to 4,000 K, corresponding to the higher illuminance values. But when we move to the interior, the lower levels of light correspond with lower values of color temperature. This means that the artificial lighting in the inner part of the hall should perhaps use warmer lamps to produce comfort, even less than 3,000 K. We can see also that during the daylight hours, there is a single suitable color temperature value for all the points, which is 4,000 K on average. This corresponds to a medium neutral light, in which a light with a color temperature from 3,300 to 5,300 K is regarded as neutral. However, the measurements made with artificial light show that the suitable color temperature for all the points falls to 3,000 K. however, just as in the previous case, we could use lower color temperature values at the end of the hall, even around 2,500 K.

3.3 Adaptation levels in the entry paths

The level adaptation between inside and outside is likely to be one of the most important parameters for visual comfort. With this aim in mind, we took measurements in three entry paths from the street level to the interior of the hall, named r. 1, r. 2 and r. 3 (Fig. 7). The measurements were taken at various points: at street level, in the middle of the path, inside the courtyard and inside the hall.

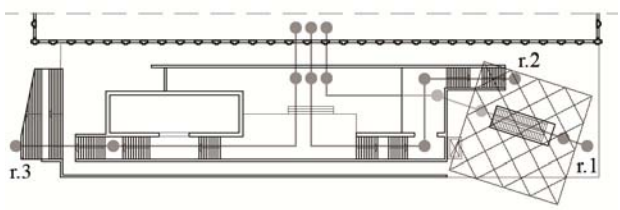

Fig. 7: Ground floor with entry paths

The measurements along r. 1 start at street level, where a half-covered escalator leads to the courtyard running through a porch. The second path, r. 2, is totally outdoors, with stairs, landings and changes of direction until reaching the courtyard. The last path, r. 3, is also outdoors, but it is characterized by a staircase that runs between two high walls.

As seen in all the figures, the most significant feature is the vast amount of light available in the courtyard in comparison with the values obtained along the rest of the path. The value obtained is somewhat similar to the value obtained at street level and very different from the immediate values in both directions. In the first case, the covered escalator yields lower levels of illuminance in the middle of the path compared to the other cases. But the influence of the obstruction of the sky until the courtyard is reached is important and offers low values in contrast to those obtained in the broad white space in front of the hall. Moreover, when we go out from the center, the level difference between inside and outside is significant in little time. Therefore, it is easy to deduce that there is a great chance for discomfort when reaching the courtyard from the street or from the interior of the cultural center. Once again, the courtyard is the most critical space in the building, and it would seem necessary to pay attention to the visual comfort in this point because of its glare potential, as we shall see in the following section.

TABLE 2: ILLUMINANCE LEVELS

	E (lx)	Distance to inner hall (m)
r.1	112.000	50
	80.000	45
	7.500	35
	5.600	25
	115.000	10
	3.800	0
r.2	76.000	55
	127.000	45
	32.500	35
	23.800	10
	115.000	5
	3.800	0
r.3	112.000	50
	33.000	40
	23.800	10
	115.000	5
	3.800	0

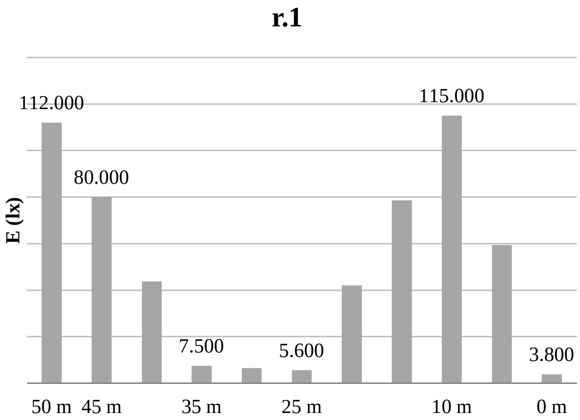

Fig. 9a: Bar chart with illuminance levels in r.1

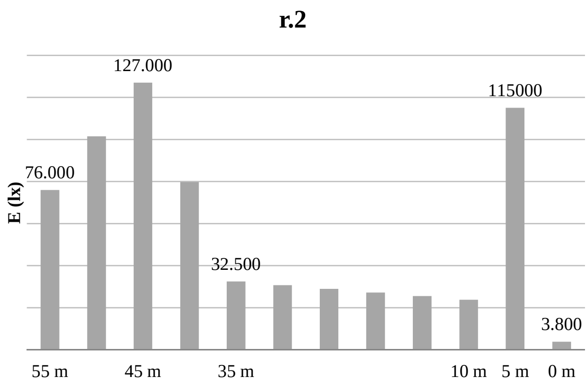

Fig. 9b: Bar chart with illuminance levels in r.2

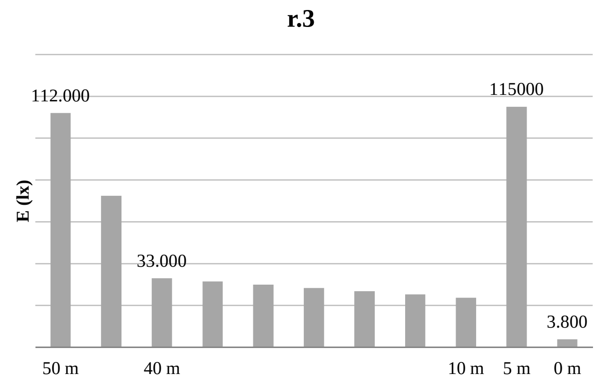

Fig. 9c: Bar chart with illuminance levels in r.3

Besides the vast amount of light in the courtyard, the time spent walking the path is also important. Considering a normal pedestrian speed, such as 1.2 m/s, and the average length of the path (50-55 m), the visitors spend less than one minute (41-46 s) to cross the space. In accordance with Figure 10, to reach full visual system adaptation we would need approximately 15 minutes from a dark to a light situation. From light to dark, the time rises to 45 minutes.

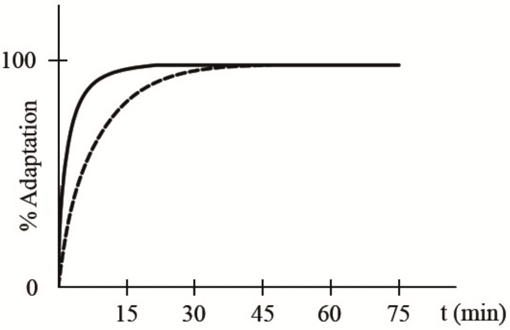

Fig. 10: Visual adaptation time

3.4 Luminance contrast

The direct consequence of high levels of illumination is the strong contrast and the consequent high levels of luminance obtained on the surfaces in the space. It is very important to assess what will happen in critical situations because of the configuration of the space and the surfaces that make it up. The position of the luminance in the visual field must be controlled because it can be critical in terms of proximity to the center of vision. High values and high contrast between higher and lower luminance have to be controlled as well. In the pictures below (Figures 11 to 13), false color images show the values and distribution of luminance in the field of view at three points in the space: looking out from the hall to the exit door, looking to the front wall of the courtyard from the door, and looking from the courtyard to the entrance door. Two sequences of pictures were taken, one at midday and another in the afternoon.

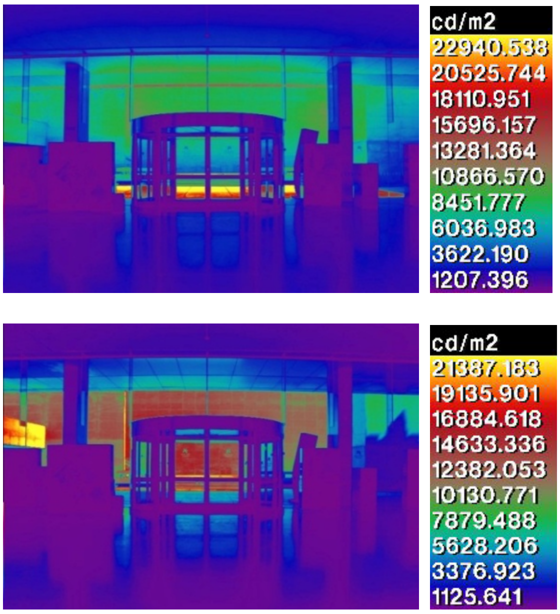

Fig. 11a, 11b: HDR photographs from hall to door at 1:00 pm and 5:00 pm

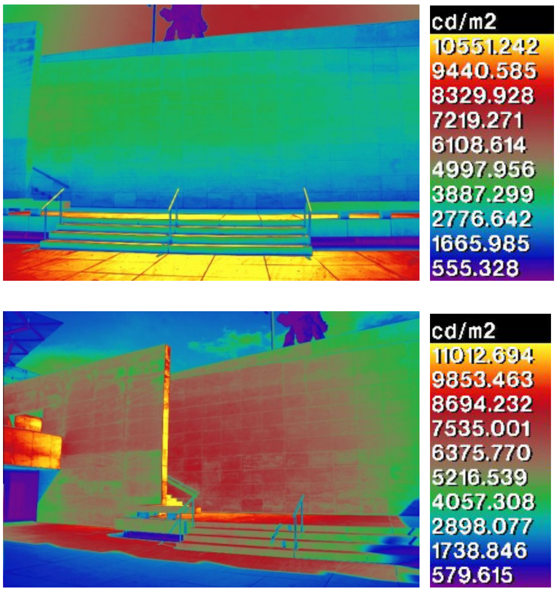

Fig. 12a, 12b: HDR photographs looking towards the courtyard wall at 1:00 pm and 5:00 pm

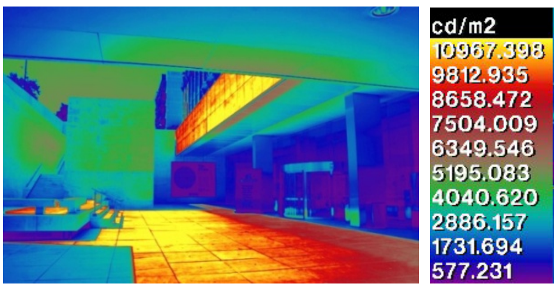

Fig. 13a, 13b: HDR photographs from courtyard to door at 1:00 pm and 5:00 pm

The first thing we should highlight is the different luminance distribution obtained in the morning and in the afternoon in the same picture due to the orientation of the building and the effects of sunlight. By looking at the points of attention in the pictures, we can see this difference. For example, in Figure 11a, the focus is on the wall in front of the door which has a luminance of around 8,500 cd/m^2 in the morning, while in Figure 11b, when the sun hits the wall, it increases to a value of around 15,000 cd/m^2, which is almost twice the former. Similar conclusions can be drawn from Figures 12 and 13. In Figure 12, the focus is on the front wall, and the relation is similar to Figure 11. In Figure 13, the focus is on the pavement and the entrance door instead. In the morning, the contrast between them is high while in the afternoon the shadow of the building improves the contrast, offering a better vision of the entrance. The position of the lighted surfaces changes from the morning to the afternoon, with the consequent changes in contrast. Another similar feature we can find in all the pictures is the contrast between the maximum and minimum luminance values. In all cases, the ratio is around 20:1. Notice as well that the maximum luminance values are distributed in the lower middle part of the space in most cases, which interferes with the central part of the visual field, causing discomfort. We can see that the sky is not always the most critical light source we have in the visual field; rather the clear surfaces are instead.

4. DISCUSSION

According to the measurements we took and a standard light assessment, we could state that there is enough light in the hall during all the day. There is no lack of visibility due to inadequate illuminance levels, thus the minimums are covered. However, the assessment based on quality reveals a different conclusion. Starting with the distribution of light, we noticed that there is a great difference in values throughout the space, especially if we compare the courtyard with the interior of the building during the day. This is even more evident when we see the vast amount of light available in the courtyard compared to the rest of the points along the entry paths. This marked difference is likely to produce discomfort. However, the key to comfort is not only the amount of light. The conversion into lighting surfaces is also critical due to the high reflectance of all the surfaces in the courtyard. When moving from a medium reflective environment such as the urban surroundings or the hall of the center to the courtyard, reflectance from the surfaces appears to be a disturbing source of light during some daytime hours. Even though the luminance in the space is right, the contrast in the transition causes discomfort. Similar considerations can be made about the color temperature of the light. The light reflected off the courtyard walls becomes the main source of light to the interior and bathes the space, tinging it with its color. In the case study, the walls are white, and the color of the light is similar to the color of daylight. However, if the walls were colored, other considerations would have to be made. Apart from natural light, the artificial sources could provide a suitable color temperature according to the needs. The Kruithof's diagram can help us to decide whether the characteristics of the lamps are appropriate depending on the most suitable color temperature, warm in the interior and cooler in the exterior.

From the parameters analyzed, we have seen the importance that the configuration of the entry spaces has on the visual response. In the case study, the courtyard appears to be the most defining characteristic of the space. Placing the entrance with a courtyard on the basement floor carries the consequence that the perimeter wall becomes the user's visual field. Thus, the material, color and reflectance of the wall are very important for visual performance because the quality of the atmosphere generated in the entrance is strongly related to it. Mediterranean countries, where high levels of illuminance are reached, are especially sensitive to this. In the case study we have noted that the materials used in the courtyard were too reflective in sunny conditions and caused discomfort at certain times of day. On the other hand, the glazed wall that separates the inside from the outside facilitates the entry of natural light in the hall but does not diminish the effects of the front wall. In parallel, it causes a gradient of light in the interior, not a regular distribution.

5. CONCLUSIONS

To summarize, to take into account the user's visual perception of a space, the illuminance assessment turns out to be too restrictive. As we have seen above, the amount of light is important, but it is even more important to determine how this light is distributed and reflected and how it works. Transitional spaces have a temporary use, and this is an advantage, because they do not have to be as restrictive as other standing spaces, but this is also a disadvantage because the visual adaptation has to be quick and there is a greater chance for discomfort. In Mediterranean countries, discomfort is likely to be produced when moving through transitional spaces because of the different conditions we find inside and outside, as we have seen in the previous sections. Therefore, special care has to be taken when designing the space and the light. A complete assessment should consider the typological analysis of the configuration of the space: the geometry and the morphology of the space, as well as a visual analysis of the light and ambient based on perception containing other parameters apart from those seen in the previous sections.

6. ACKNOWLEDGMENTS

This paper is supported by the Spanish MICINN under project ENE2009-11540.

7. REFERENCES

(1) Coch H., Serra R., Isalgué A. The Mediterranean blind: Less light, better vision, Renewable Energy 15 431-436, 1998 (2) Ruggiero F., Serra R., Dimundo A. Re-interpretation of traditional architecture for visual comfort, Building and Environment, 2009 (3) Pitts A., Bin Saleh J., Potential for energy saving in building transition spaces, Energy and Buildings, 2007 (4) Lam W., Perception and lighting as formgivers for architecture, McGraw-Hill Inc., 1977 (5) Araji M.T., Boukebri M., Chalfoun N.V., An Examination of Visual Comfort in Transitional Spaces, Architectural Science Review, 2011 (6) Lasagno C.M., Pattini A.E., Rodríguez R.G., Colombo E.M., Developing a modeling factor index for transition spaces: a case study approach, Architectural Science Review, 2011 (7) http://www.jaloxa.eu/webhdr/index.shtml