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Iluminación en viviendas, la habitación. Estudio comparativo y simulaciones
Lighting in houses, The rooms. Comparative study and simulations.

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Resumen—**El presente documento aborda el estudio de un nuevo material compuesto principalmente por una matriz de yeso (proveniente de un conglomerante industrial) cuyo uso es la construcción, al que se le han añadido fibras naturales, como la madera y artificiales, como la fibra de basalto y la de vidrio, además un compuesto polimérico a base de 3 elementos cotidianos, polivinilo de acetato, bicarbonato sódico y una disolución de ácido bórico, el comúnmente conocido "SLIME". Se confeccionaron probetas con porcentajes de 7.5% y 10% del peso del yeso, siguiendo la proporción con los otros componentes. Las fibras se añadieron en base al volumen. Como referencia se confeccionaron probetas sin adición de los componentes poliméricos y sin fibras. Fueron ensayadas en laboratorio y se determinaron las características físicas y mecánicas de estas. Tras el análisis comparativo se evidencia que la adición del SLIME reduce la densidad del material, mejora la resistencia térmica y mantiene unas propiedades mecánicas bastante similares a la del yeso tradicional. Las fibras, además, aportan resistencia extra, lo que se traduce en una mejora de las características del nuevo material respecto al ya existente.**

Palabras clave: vivienda, eficiencia energética, prefabricados, caracterización.

***Abstract*— This document collects the results and the comparative analysis of the study of lighting in a room of a house. The study is developed using three data analysis systems, one in situ, one in a model and the other through virtual simulation. The 4 possible orientations have been studied both in the computer model and in the mock-up, making measurements at 3 different hours of the day, namely, at 9:00 a.m., 4:00 p.m. and 8:30 p.m. The tests have been carried out in the month of May with a duration of 1 week. The results showed that the current orientation of the room is not bad to achieve the required values according to the type of use. The results of the other measurements showed lack of lighting in some sections and excess lighting in others.**

Index Terms— Lighting; homes; light comfort; luminance

I. Introduction

THE PURPOSE of lighting conditioning in workstations is to promote visual perception to ensure the correct execution of tasks and the safety and well-being of those who perform them. (De las Casas ayala et al., 1991) As is known, poor lighting can lead to errors and accidents, as well as the appearance of visual fatigue and other visual and ocular disorders (Iluminación, 2005).

Despite this evidence, it is common to find workplaces that are poorly lightened or poorly maintained lighting system. On other occasions, the lighting conditioning is limited to the

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quantitative aspect (lighting level) without considering other important requirements related to the quality of this (Egan et al., 2002). Often, this situation is motivated by the difficulties presented by the analysis and evaluation of the various aspects involved in lighting workplaces, some of which are not easily approached by non-specialists (Eco, 1983). Light conditions our way of interpreting the world around us, an essential and dynamic element in our daily activity. The functional, biological, and psychological aspects are closely related (Neila González, 2004).

There are many studies carried out on lighting in rest areas, either by parts of doctoral theses, in which we find some that study how natural lighting can affect the rest and the way of life of users or experimental studies and natural modeling of the building using scale models. Regarding commercial situations, large companies in the decoration sector have specialized personnel in their ranks who offer help to achieve adequate lighting according to the types of spaces. Normally they are oriented to residential building, although there are also those who are dedicated to more specialized types of building such as offices, teaching classrooms or sanitary spaces.

Conceived mainly for relaxation, the bedroom has many other uses today, ranging from a dressing room or dressing table to a living area or private study. Hence the importance of designing lighting that adapts to all these uses, although always with the focus on comfort and creating an atmosphere that enhances relaxation (Sierra Bravo, 1986). The construction impulse of the building sector in Spain and the needs demanded by the inhabitants are what make us choose this topic as a study objective, to check, before projecting, which orientations favor more which rooms of each home.

As in the rest of the rooms in the house, the lighting in the bedroom must come from an adequate general light that does not leave corners in shadow, but that at the same time is warm and not too powerful. For this, regardless of the type of lamp that we are going to use, the general lighting level recommended by the experts is 250 lux (lumens per square meter). To achieve this, it is advisable to use medium power bulbs (20 w), preferably with LED technology –which guarantee a minimum heat emission and maximum energy efficiency– and with a warm color temperature (3000 K) (Yáñez Parareda, 1982).

Ceiling panels - always with tinted shades and positioned so they don't dazzle when in bed - and indirect light wall sconces are the best sources of general lighting for a bedroom. A very functional alternative, if the bedroom has a false ceiling, is to place strategically placed recessed spotlights so that their beam of light is evenly distributed throughout the space. The downlights, which are recessed luminaires in the false ceiling so that they are flush, with LED technology offer a light very similar to natural light, they are very thin and require very little space for their installation.

Based on all these characteristics of light, as well as its importance in people's lifestyles, this research work is proposed, which will consist of the study compared between a real scale model, a virtual model, and the reality of lighting, both natural and artificial to guarantee the light comfort of those inhabitants (Comisión Europea, 2008).

Natural lighting is essential in homes, light is necessary to properly develop activities and relationships in our daily lives and provides health, both physical and mental. Characteristics such as the orientation, the size of the openings and their shape, the organization of the space and the colour of the surfaces where the light is reflected are conditioning parameters of all the above. For this reason, natural lighting, as opposed to artificial lighting, must be considered from the first moment of design, where the following aspects must be considered: - Orientation: The south orientation is the one with the greatest direct natural lighting due to its large production natural light throughout the day is recommended in winter for its great heat absorption. The most suitable is the north facade if cold white light is acceptable. This tends to be mostly quite low, which causes glare from direct sunlight. In hot climates the north orientation is recommended as opposed to the south. The worst orientations are the east and west, since they receive sunlight during the middle of the day, their light is maximum in summer as opposed to winter. The worst drawback is the height of the sun, as it is low and causes glare problems.

Architects like Alberto Campo Baeza treat light with a special sensitivity and endow it with that mysticism that surrounds it, creating especially welcoming scenes in common spaces such as their Gaspar and Guerrero houses in Zahora, Cádiz, a place that is also conducive to using this resource, natural, free, and undervalued (UE, 2010)

Lighting can be studied in two well differentiated aspects, one as an art, a set of emotions or the creation of feelings and, on the other hand, as something scientific, technology and functionality. Over the years and in the 21st century, the century of technological development, natural lighting has been losing that strength that its handling had in favour of artificial light, which we can control or tame in a much simpler way (UNE, 2010)

Once basic needs have been satisfied in developed countries, research revolves around how to improve the quality of life of people, from the use of time in day to day by monitoring buildings, thus providing remote control to Everyday actions such as raising the blinds, turning the air conditioning on and off and controlling the temperature and humidity of where we live, even controlling the lighting of the homes. That is, we talk about comfort. Comfort is comfort in a certain environment. Therefore, we must differentiate what parameters and factors are when talking about comfort. Parameters are values that can be energetically evaluated, such as architectural design, while factors are those that depend on users, such as age or type of user activity. This comfort will depend on the ability of our vision to appreciate a certain activity.

The main lighting companies, such as LLEDÓ, OSRAM, PHILLIPS, ERCO… already have integrated remote control systems on the market, with the possibility of varying intensity, colour and even programming the on and off. A wide range of resources that represent an extension of the limits of creativity of the designer (*Grupo Lledó*, n.d.)

The way we live has also changed over the years, and the development of knowledge of the needs or comforts in the home is also evident in lighting matters. The bedroom has gone from being a place where you can only rest to being a place to stay where activities as different as reading, studying, sleeping, and even playing sports are carried out. Due to this evolution, bedroom lighting trends have evolved towards the creation of different environments, from a more intimate one, with dim lights for reading or the moment before going to sleep, such as the study environment, which requires a floor plan. work well lit and a room with clarity to avoid feeling overwhelmed.

The main objective of this work is to compare by means of 3 measurement systems the results of the lighting of a room of a flat located in Pascual Rodríguez Street, 16, 3º A.

II. Experimental procedure

The choice of the specific work method has been based on the study of work possibilities and the most appropriate methodologies to achieve the established objectives.

The availability of in-situ measurement, as well as the development of a computer model were the most viable options. Finally, the elaboration of the model is an addition that will allow a third comparison value to provide reliability to the measurements.

The house under study is in the city of Madrid. The building is 50 years old, and the house has 68m2. The apartment consists of hall, corridor, 3 bedrooms, kitchen, bathroom and living room with terrace. The orientation of the space is N-S, so the window through which it naturally illuminates is oriented to the north. The points to analyse will be:

- Worktable, Height of work surface: 80 cm. Situation, by the window.
- Bed: Height of work surface: 80cm. Location, headboard on the south side of the room.

To make this comparative study in different orientations, we take as references the following degrees in the DIALux program and in the model, to specify the coordinates and incidence of the site. These are:

- NORTH = 90 °
- SOUTH = 270 °
- EAST = 360 °
- WEST = 180 °

These data were taken in this way to carry out a comparative study for the same time and date in the measurement of a model and in the virtual program DIALux. Thus, we will make a comparison with the data obtained by the two study methods carried out in the city of Madrid, seeking the analysis of the similarities and differences of the data obtained.

The measurements were scheduled, and taken for 21 days, three times a day, one in the morning, another at noon and another at sunset.

This study has been carried out using 3 different techniques: an in-situ measurement, a model measurement and a virtual simulation using DIALux software. In this way, it is intended to carry out a comparative study of the results obtained in each modality to verify the usefulness of virtual and model models when carrying out lighting projects.

Before carrying out any measurement, a detailed study of the needs to be studied was developed, the measurement points and the minimum requirements demanded according to the function. The points chosen were the study or worktable and the bed or resting place. These points are the choice of this study due to the characteristics of the person who inhabits the room. For any other room and / or person, it would be necessary to establish what situations and places in that room they occupy to focus the research on them.

Once the work planes have been defined, it is necessary to select the measurement hours. Although it could be complete to carry out a study with measurements every 20 minutes during a day, this option is meaningless since no room is used 24 hours a day without interruption. For this reason, and based on the needs of the inhabitant, it has been decided to carry out these measurements at 3 specific moments, coinciding with the main hours of use.

- 08:00 h, corresponding to the start time of the day.
- 4:00 p.m., corresponding to the time of return home and rest.
- 8:30 p.m., corresponding to the time of completion of daily tasks.

Before taking each measurement, a photograph of the sky was taken to establish similarities and show the light level. With the measurement parameters already defined, the next step is to carry out the measurements with the 3 techniques mentioned. Each of them underwent a different process, which we can observe below.

A. *In-situ measurement*

In the real model, the measurement process consisted of placing the measuring device, the PCE-170 A Luxmeter, from PCE brand, which has a measurement range of zero to 40,000 lux, with a resolution of 0.1 lux and an accuracy of ± 3% of the measurement value. During the established hours, the luxometer was placed at the indicated points and the measurements were recorded in a spreadsheet for later analysis and comparison.

B. *Measurement with model.*

For the measurement on the model, a 1:8 scale model of the room to be studied was first made. The model is made of foam cardboard, a white material, 3 mm thick glued on a base of the same material. The finish is black cardboard to the outside, to

Fig. 1. Model. Own picture.

stop the possible entry of light through the translucency of the material. The interior finishes are an imitation of the real ones, the table is black, and the bed has a white duvet cover. The closet is also white. The bed and the wardrobe have been made with the same material as the model, 3 mm cardboard-pen, while the table has been made with cardboard. Once the model was assembled, openings were made, both in its lower part and in one of the sides for the introduction of the luxmeter and its subsequent measurement.

Two holes were made, one in the bed and one in the table for the placement of the light meter sensor, as well as the corresponding openings in the walls to be able to insert the meter. The finishes of the walls and the ceiling were simulated with pale yellow and white cardboard, to give verisimilitude to the representation.

The scale model, as well as the computer model, allow the modification of its orientation, therefore, for its later comparison, measurements were taken in all possible orientations at the 3 selected moments. Eventually, measurements were made on the model in the same way as in situ measurement.

C. Measurement using a computer model.

In the current market there is a great variety of virtual programs for calculating natural lighting, among which we find them for free and others with a cost to pay. These range from a simple to a more complex use, but for the most part they have one factor in common and that is that they allow access to commercial house catalogs, which offer a large library of lighting fixtures, furniture, among others.

Virtual simulation programs have different complexity of use, depending on the level of depth and detail that the analysis is intended to reach, but for the most part they have a common factor and that is that they allow access to commercial house catalogues. They offer a large library of luminaires and furniture, among others. Among all the existing ones, the DIALux software has been selected for the following reasons:

- The program is free and can be downloaded from the same official DIALux website, it always keeps an update periodically.
- The results are very easy to obtain.
- It has a great ease of use of the software.
- The program provides us with data from different commercial houses of a very updated manufacturer.
- You can carry out a study of natural light in different orientations and even more, you can select the countries that are in the list, giving you different latitudes, to make comparisons and deepen the study or analysis.
- The quality of the software in terms of renderings, obtains adequate quality of images.
- You can take 3D scenes with good image quality; you can also create animations and take a tour of the entire modeled space.
- A file can be imported directly from autoCAD.
- It has a library of blocks, where the required space can be conditioned.
- The software shows you the analysis of the lighting behavior, whether natural or artificial.
- Offers a virtual space with sufficient image quality.
- It is a complete software that allows you to create both natural and artificial lighting projects and can perform energy evaluations.
- It can be applied in: Interior, exterior, roads, open spaces,

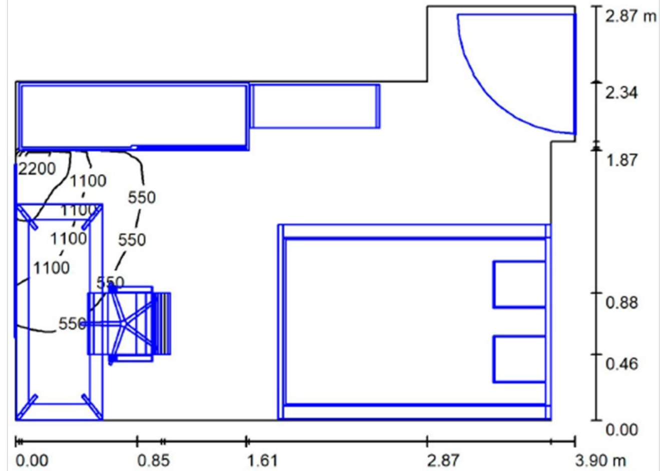

Fig. 2. Picture of the Room studied from DIALux. Own elaboration.

and energy evaluation.

To carry out the computer simulation, first a virtual model of the chosen room was made (Fig.1), adding furniture, lighting, and finishes. Next, and as explained in the scale model, the orientations, schedules, and dates of the simulation are defined. Finally, the lighting simulation, both natural and artificial, of all defined views and orientations is carried out.

III. Results

The results obtained are shown according to the type of study. First, Table 1 lists the results of the in situ measurement.

TABLE I
RESULTS OF IN-SITU MEASUREMENT. OWN ELABORATION

Día/hora	9:00	16:00	20:30
1	380	700	450
2	365	750	*430*
3	398	732	*483*
4	348	750	*584*
5	367	743	*498*
6	358	699	*389*
7	374	785	*398*
8	400	726	*500*
9	365	728	426
10	378	719	473
11	389	730	*436*
12	395	750	*456*
13	374	746	*485*
14	385	738	*399*
15	394	735	410
16	402	746	426
17	388	729	435
18	375	735	426
19	369	746	439
20	389	735	*437*
21	363	729	*428*

Measurements in lux

The results obtained have their peak in the midday, where they reach values of up to 785 lx on the worktable and 234 lx on the bed. The maximum values obtained in the first hours of the morning are 59 lx in bed and 398 lx at the worktable. The maximum values obtained in the late afternoon are 498 lx at the worktable and 90 at the bed.

Table 2 shows the results of north orientation measurements in the model. The values obtained are significantly lower than those obtained in both in-situ and computer model. The highest value was 113 lux, and it was obtained in worktable at 16:00h. The lowest value was 19 lux, and it was obtained in bed at 9:00.

The results of the model have been collected in the 4 possible orientations to establish comparisons with respect to the virtual simulation.

TABLE II
ILLUMINANCE VALUES OBTAINED FROM THE MODEL. OWN ELABORATION.

NORTH			
Bed			
In-situ measurement		U.P. 80cm	
Day	Time	Measurement	
	9:00	24	*lx*
06/05/2019	16:00	30	*lx*
	20:30	26	*lx*
	9:00	23	*lx*
07/05/2019	16:00	28	*lx*
	20:30	25	*lx*
	9:00	19	*lx*
08/05/2019	16:00	32	*lx*
	20:30	26	*lx*
	9:00	22	*lx*
09/05/2019	16:00	29	*lx*
	20:30	21	*lx*
	9:00	24	*lx*
10/05/2019	16:00	26	*lx*
	20:30	24	*lx*
	9:00	25	*lx*
11/05/2019	16:00	31	*lx*
	20:30	24	*lx*
	9:00	23	*lx*
12/05/2019	16:00	28	*lx*
	20:30	21	*lx*

Measurements in lux

Finally, the results of DIALux model are presented. As DIALux only shows the information on the work plane, the maximum, average and minimum values obtained in the computer model are the same for the 2 chosen study points. Table 3 shows the mean results (Em) obtained from the computer simulation. This table shows the values obtained for each of the orientations studied in the 3 selected moments. The highest value obtained was at 9 o'clock in east orientation, with 4147 lux. The lowest value was obtained in east orientation at 8:30 p.m, with 136 lux.

As expected, the difference of illuminance between the 3 times studied in east orientation is significant, as well as in west and south. North orientation got the worst illuminance results in the computer model.

The rest of the values are heterogeneous and present no correlation.

TABLE III
ILLUMINANCE VALUES OBTAINED FROM THE MODEL. OWN ELABORATION.

DIALux illuminance average results					
9:00		16:00		20:30	
Em	Orientation	Em	Orientation	Em	Orientation
559	North	370	North	*266*	North
291	South	2485	South	*142*	South
4147	East	350	East	*136*	East
245	West	3381	West	*909*	West

Measurements in lux

IV. DISCUSSION

Once the values obtained separately have been analysed, we are going to compare the results obtained for the same time bands in the 3 elements that we have compared. Maximum, minimum, and average illuminances values are compared in this section.

First, values obtained for the mean illuminance (Em) at the two working points and the 3 measurement methods that we have obtained can be seen in table 4:

TABLE IV
AVERAGE ILLUMINANCE VALUES IN ALL 3 SYSTEMS ANALYSED. OWN ELABORATION

Point 1 (worktable)					
Model		DIALux		In situ	
Time	Em	Time	Em	Time	Em
9:00	*92*	9:00	*559*	9:00	*370*
16:00	*106*	16:00	*370*	16:00	*737*
20:30	*82,29*	20:30	*266*	20:30	*461*

Point 2 (bed)					
Model		DIALux		In situ	
Time	Em	Time	Em	Time	Em
9:00	*22*	9:00	*559*	9:00	*56*
16:00	*29*	16:00	*370*	16:00	*193*
20:30	*24*	20:30	*266*	20:30	*86*

Measurements in lux

The values obtained in the model have been the lowest of all measurement systems. On the worktable, the difference between values in the computer program and in situ are more homogeneous than on the bed. The model and the measurements in situ are more correlated than the computer program. The values obtained in the model on the bed are practically the same in the 3 times analysed, and very different in DIALux. This means the values are lower as smaller is the scale. These differences and similarities can be better appreciated in figure 1.

There is no correlation between the values obtained as the logic results should be a proportional relationship in the same measurement. Thus, can be a difference in scale models, and some parameters that computer model consider, and the other measurement cannot.

Average illuminances give us a general idea of how much light can we get. This is made because every day the sky looks

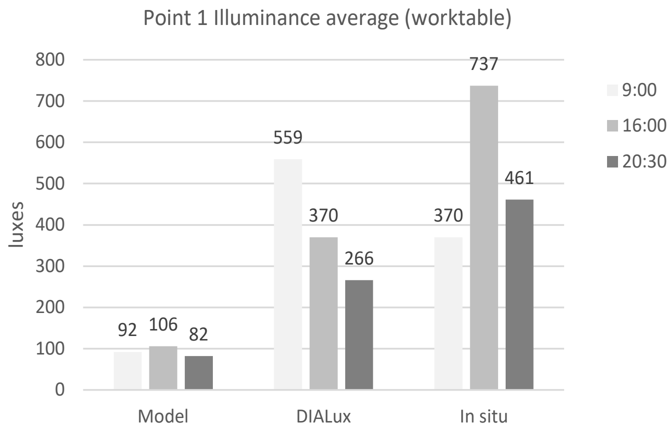

Fig. 1. Comparison of average illuminance in point 1, orientation N. lux. Own elaboration.

different and the light we get by in situ measurements can vary. Model and in situ measurements can be compared with each other, as the light they get are the same. Computer model takes an approximation and regular values of the light according to the location chosen.

In figure 2 we can see the comparison of maximum illuminance values. Model values are again the smallest of all 3 types of measurements. DIALux results at 9.00h are quite far from those given by model and in situ measurements. However, the values obtained at 16h and 20.30h are quite similar. at while the values between the last two sections in the afternoon are quite similar. In Point 2, the values are quite similar. The values obtained in bed at 20.30h are more consistent with each other, considering the scale difference.

The difference between values is consequence of the parameters that DIALux gets to analyse. Differences between in situ and model measurements are consequence of the scale.

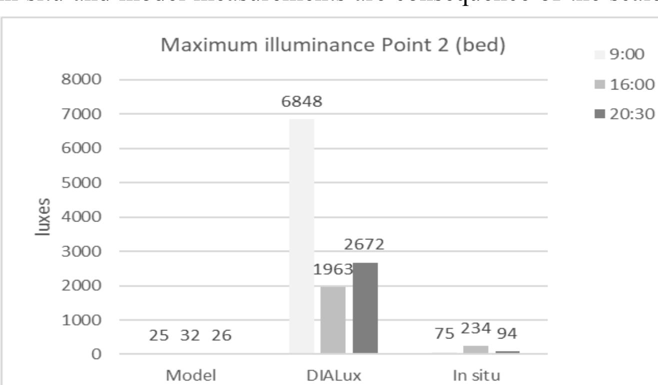

Fig. 2. Comparison of maximum illuminance in point 2, orientation N. lux. Own elaboration.

The smaller is the size of the model, the smaller the light they get.

Figure 3 shows the results of minimum illuminance in the 3 measurement techniques used. The highest values have been obtained in in-situ measurements. The lowest measurements obtained in point 1 (worktable) have been in DIALux, and the lowest measurements in point 2 (bed), were taken in the model. DIALux returns results quite far from the other systems in point 1 in the afternoon. This may be due to the lighting consideration or the difference between the chosen luminaire model and the real one. In point 2, the values are quite like each other in the different programs, while the development curve of the values remains irregular in the morning section.

In point 1, model get similar results in the three times measured and all of them are higher than DIALux results. There is a great difference between the values obtained in the model

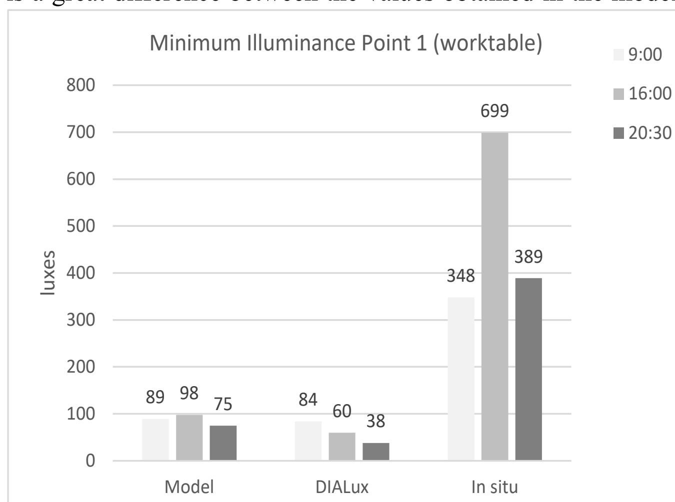

Fig. 3. Comparison of minimum illuminance in point 1, orientation N. lux. Own elaboration.

and computer model and in situ. In situ and model results make sense according to the sun path in this orientation. At 9.00h, points get lighter than at 20.30h. In situ, the values are quite different. This means that the measurement from the model and the computer system are not too representative to calculate this illuminance. In point 2 (fig. 4) there is no consistency between the results obtained. Results obtained for the same time are completely different and they have no relation. DIALux results is the farthest from the others.

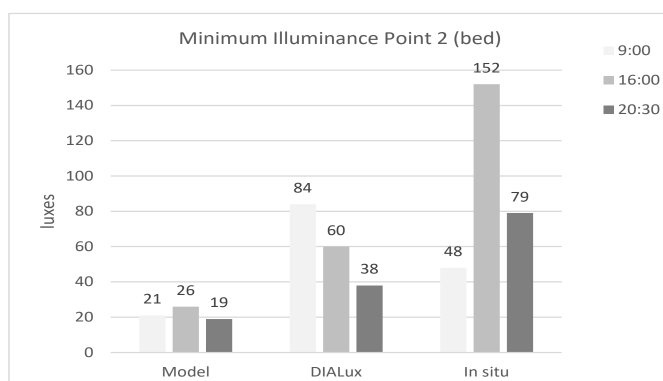

Fig. 4. Comparison of minimum illuminance in point 2, orientation N. lux. Own elaboration.

V. Conclusions

After conducting this research study to analyse the behaviour of natural lighting in a room of a house located in Madrid, the comparison between 3 different measurement systems were carried out. There were results that were expected and others, however, that have been produced by the research. For this reason, the conclusions obtained have been divided into expected and unexpected.

A. Expected

- Of the two work points studied, point 1 (worktable) presented the most favourable results due to its proximity to the natural light hole in all orientations.
- The South and West orientation have been the orientations that have received the greatest amount of medium illumination.
- Regarding the amount of light, the east and west orientations work best first thing in the morning and late in the afternoon, respectively.
- Model measurements differed significantly from actual and in-situ measurements.
- The best orientations for the space studied are the East, the South and the North.
- The south orientation would cause glare and excess lighting.

B. Unexpected

- The measurements in the model have been the ones that have thrown the least amount of light in any of the two points analysed.
- The measurements of the computer program and the real ones have been more like each other, so the results are more consistent.
- In situ measurements carried out in working point 2 have been significantly smaller than those in point 1.
- The results obtained in the west orientation have been worse than those of the east orientation.
- Despite receiving less light, the north orientation seems the best suited to work needs, in addition to having indirect and diffuse lighting throughout the day, which avoids glare and sensitive heat loads from radiation.

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