A SIMULATION OF DAYLIGHT LEVELS FOR THE DETERMINATION OF VISUAL COMFORT IN LARGE SPACES

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ABSTRACT

In sizable environments, such as the collective areas of a big university building, characterised by very long corridors, large hallways and broad glazed surfaces, the daytime illumination factor is often only excellent near to the latter, due to their predominantly horizontal, rather than vertical, nature.
His study, which has been carried out thanks to a simulation software, shows the results of a correlation between light contributions, come out from the wide glass surface and those of a big skylight which cross lenghtways the main part of the building.
Such results have been compared with some instrumental measurements considering the shifting and getting from them important informations on simulations reliability.

KEYWORDS

Daylight factor, splitflux, visual comfort.

INTRODUCTION

In order to define the quality of light in a space, certain criteria need to be verified, such as the quantity of light, the absence of dazzling light sources, the maintaining of certain limits in the relationship of luminance between visible surfaces, as well as the relationship between the illumination obtained and the directional characteristics of light.
With regard to luminance in particular, it is well known that it is a function of the position of the light sources and the surfaces in relation to the eye of the observer (Moncada 2003).
This article presents the results obtained from a dynamic simulation, subsequently validated by instrumental monitoring, of the layout of spaces, characterized by long corridors with large glass surfaces at the end of them.
The building used for the study is the new building of the Faculty of Architecture of Palermo (Figure 1). This building was chosen because of the interesting and correct design solutions that it demonstrates, both in terms of orientation and layout, and in terms of the size of the glass surfaces, which are very large and able to guarantee optimum visual comfort (Baker 2002), both in the study rooms and in the rooms used for more demanding visual tasks like drawing (Windows and Daylighting).
For the dynamic simulation, Ecotect v5.20® software was used (Anonymity). This software was developed from Square One, which allows a three dimensional model to be created.

Figure 1. View from the South side of the building.

It was also necessary for the modeling of the three dimensional solid to include the buildings close to it (Figure 2), so as to reconstruct its surroundings in as detailed a way as possible.
This would be useful for the software, enabling it to include possible external reflections and obstructions, both of which are essential for determining the daylight factor inside of the building being studied.

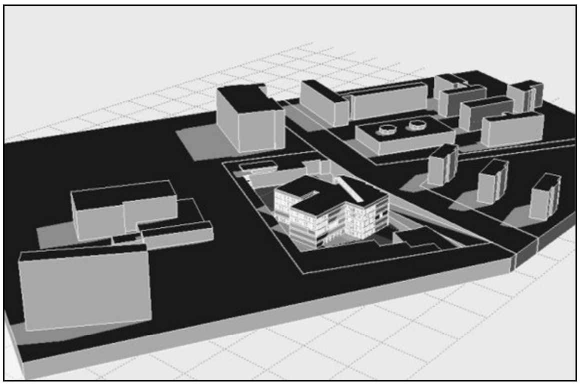

Figure 2. Three-dimensional model of the Faculty of Architecture of Palermo and of the university campus.

At the same time, for the purpose of validating the results obtained, continuous measurements were carried out using a digital instrument equipped with luxometers controlled by a multi-datalogger (Babuc/A) and interfaced to a personal computer capable of recording and processing the results obtained(Anonymity. 2005).

METODOLOGY

Along the corridors of the four storeys, which are laid out parallel to the main staircase in the building and are 32 metres long, 36 test points were distributed at equidistant intervals, nine for each of the four storeys, at a height of 10 cm from the floor(Commission). In particular, some of these test points are in line with the entrances to the study rooms.
As figure 3 shows, a large part of the corridor is illuminated by a large skylight over the main staircase, as well as the big window at the end of the corridor.

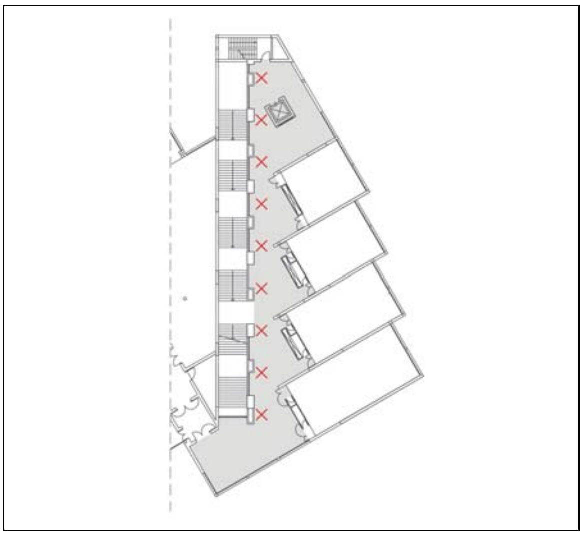

Figure 3. Positioning of the test points along the corridor on one floor.

Subsequently, these test points were positioned in the three-dimensional model, so as to identify the points where the software restores the value calculated in numerical form.
They were also marked out in the actual corridors, so that they could be easily identified, and to make it possible to take light readings on site.
As the software used needs the *sky conditions*, or rather the *sky illumination model*, as well as the *design sky luminance*, to be determined, it was necessary to monitor the value of the external illumination and to establish the type of sky for the period under consideration with another instrument.
The study was subdivided into four times of the year, each representing one of the four seasons, and a time period from 10 am to 4 pm, which corresponds to the times when the faculty is most used and when there is most daylight (British Standard Institution. 1992).
In table 1 below, the values of external illumination required for Ectotect's *Design sky luminance* are shown for the four days under consideration and in the two most representative hours.
The *Clear* model was used for the two days in summer (21st June and 21st September), but for the two days in winter (21st March and 21st December) the *Overcast* model was used, as can be seen.

Table 1. External illumination values

Time	**10.00 AM**		**4.00 PM**	
	Sky condition			
Date	**Overcast**	**Clear**	**Overcast**	**Clear**
21 Mar	41 510	- -	34 960	- -
21 Jun	- -	67 701	- -	52 410
21 Sep	- -	50 003	- -	8 260
21 Dec	33 600	- -	8 830	- -
	E Level (LUX)			

The axonometric section, with the test points distributed in the four passages, and a phase of the simulation along the corridor of the fifth level of the building, are shown in figures 4 and 5 respectively.

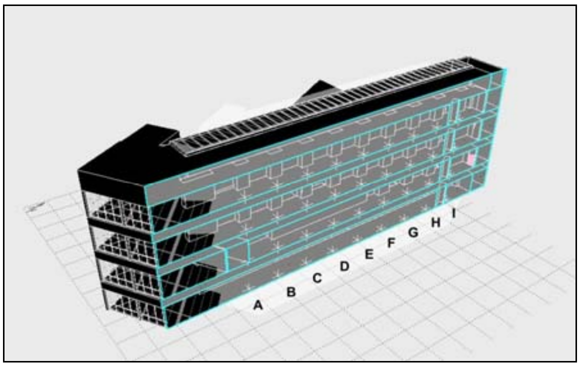

Figure 4. Axonometric section with the test points distributed on the four corridors being studied.

Particular attention was given to the examination of all the optical characteristics of the transparent materials that the glazed surfaces are made up of, and the colours of the opaque surfaces, both on the inside of the building and everywhere in the surroundings outside (Building Research Establishment 1986).
This was necessary to provide the software with the spectrophotometric characteristics of the components during the modelling phase, with an indication of the level of maintenance and cleaning required for all the glazed surfaces (Predicting Daylight 1960).
For the level of maintenance the *average* value was opted, to which the coefficient 0.95 corresponds.

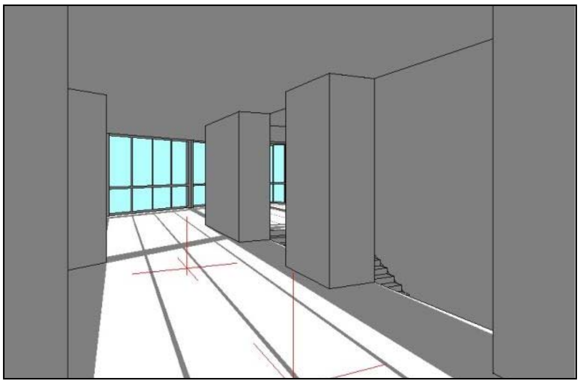

Figure 5. A phase of the simulation with the test points along the corridor of the fifth level.

DESCRIPTION OF THE MODEL

The Ectotect v 5.20 uses a calculation code based on the technique of ray tracing. Using this technique it is possible to estimate the daylight factor, starting from the most commonly used manual method called "split flux"(CIE DS 2001).

The simulation process of this method is set out in figure 6.

This method, based on an algorithm that has been validated by the international scientific community, starts from the assumption that the amount of natural light that reaches a point inside the building is determined by the sum of three factors: the Sky Component (SC), the External Reflection Component (ERC) and the Internal Reflection Component (IRC).

As far as the sky component is concerned, the software used allocates 200 points to the sky, each of which represents an SC value of 0.5.

The allocation of these 200 points obviously depends on the sky model adopted, with an increase at the zenith for the *CIE overcast model*, and an equal distribution for the *CIE uniform model*(Baker).

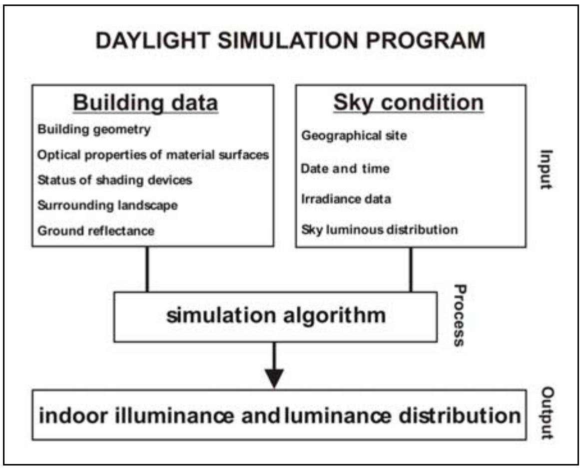

Figure 6. Elements necessary for the simulation of the Daylight.

The simulation allows a view that is in perspective to be created from any point inside the model, and from that position it also allows the points that can physically be observed through any type of opening or transparent surface to be counted.

These points represent a portion of the total luminance of the visible sky from that position.

In figure 7 the layout of the points is shown using the CIE overcast sky model, and in figure 8 a view from a point inside the building is shown.

From this view it is possible to determine the number of points that can be identified from this perspective.

The external reflection component (ERC) deals with the contribution of the rays of sunlight that reach the inside of the rooms through the transparent surfaces after having been reflected off objects outside.

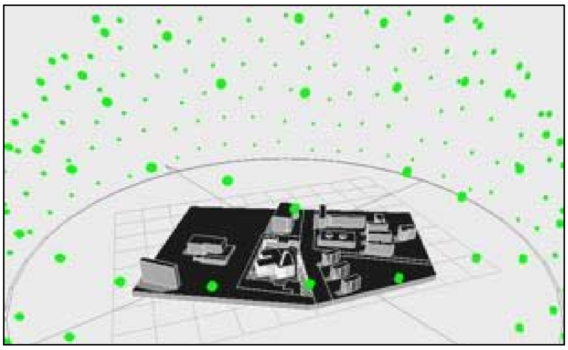

Figure 7. Layout of the 200 points with the university campus model.

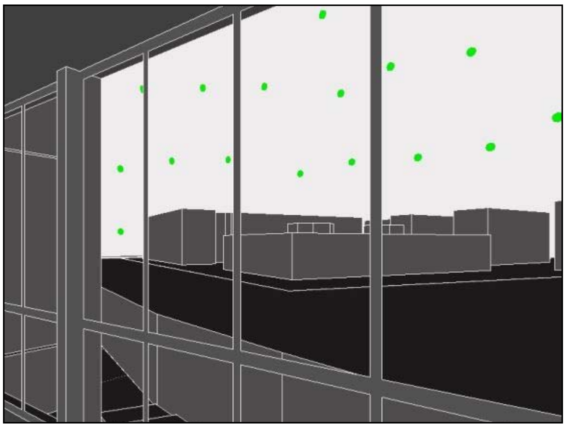

Figure 8. View from a position inside the building with selected SC points.

Therefore this contribution is determined by multiplying the illumination produced by the portion of the sky that has hit the transparent surface, by the reflection coefficient of the opaque object that it strikes (Tregenza 1989).

$$ERC=E_i \cdot r_i \qquad (1)$$

Where:

- E_i Illumination produced by the portion of sky (Lux);
- r_i Reflection coefficient of the surface.

To calculate the *internal reflection component* (IRC) the software uses an algorithm based on the following formula:

$$IRC = \frac{(0.85W)}{[A(1-p_1)]} \cdot (Cp_2 + 5p_3) \qquad (2)$$

Where:

- W area of the glazed surface (m^2);
- A total area of the internal surface (m^2);
- p_1 average reflectivity of the surfaces;
- p_2 average reflectivity of the surfaces situated below the floor that contains the point under consideration;
- p_3 average reflectivity of the surfaces situated above the floor that contains the point under consideration;
- C external obstruction coefficient, i.e. the average height of all the external objects above the opening under consideration.

SIMULATIONS AND MEASUREMENTS

The Ectotect v5.20® software allows the dynamic simulations of both the daylight factor and the lighting levels on the inside of the building to be carried out.
The results can be shown using colour mapping (figure 8) or by directly representing the numerical values on the test points already identified.

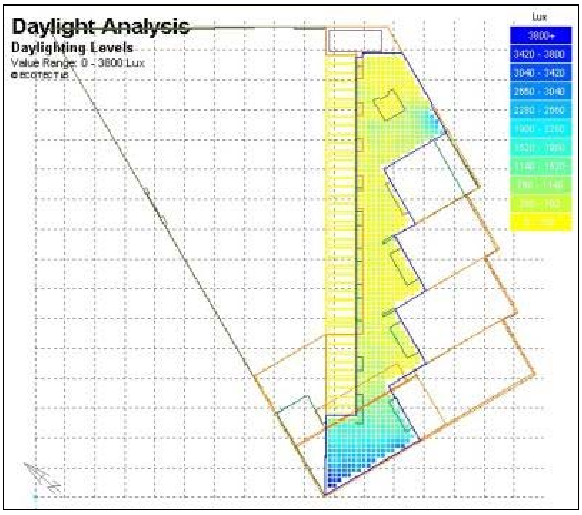

Figure 8. Representation of the levels of illumination on the second floor at 10 am on the 21st March

In this article, only the part regarding the levels of illumination is presented, as it is easier to relate this to the values measured.
As already mentioned in the introduction, the measurements were taken with a luxometers connected to a multi-datalogger.
In particular, the illumination values for the 36 test points on the four days specified during the two most representative hours were required from the multi-datalogger.
These values were shown in tables 2 and 3 to allow an immediate comparison between the simulated values and the measured values(Baiamonte 2006).
The graphs shown in figures 9-12 simplify what is shown in the tables with a direct comparison between the four floors for the 21st March and the 21st June.

RESULTS

An examination of the graphs shows a clear validation of the software used for the simulation dynamics; this is even more true when the Sky Component is very high.
The difference between the two values (simulated and measured) is never more than 5%, with the maximum disparity on the 21st March at 10 am on the fifth floor of the building when the illumination level measured was more than the simulated one by 150 lux, corresponding to a difference of 15%. However, this disparity is justified by the fact that the test points D and G on that floor are in line with the large openings on the staircase and therefore near the skylight that covers it.
However the results show one of the limitations of the algorithm used by the software and that is that it has difficulty demonstrating multiple reflections.
In fact, the software underestimates the values in situations where the daylight does not penetrate directly in the immediate vicinity of the space being analysed (low sky component value), but instead, undergoes multiple reflections.
This consideration is highlighted in tables 2 and 3, in which it can be seen that the simulated illuminance values on the third floor are < 10 lux, whereas the measured values are close to 100 lux.
Another limitation of the software is the fact that it does not take data about the climate or the time into consideration, but is based solely on the geometry of the building and on the optical characteristics of the materials that separate the external environment from the internal one. In any case the results have confirmed that a lot of natural light is available in the building for most of the time period under consideration.
A comparative analysis of the measurements and simulations shown in this study demonstrates that this availability of light is also present in the common areas and the distribution areas (corridors). In fact, reading the values shown, it can be seen that there is a very high level of natural illumination in all conditions and during all the time periods considered. The highest levels of illuminance are always found on the upper floors, because of the presence of the skylight over the staircase.

Table 2. 21st March lighting levels (Lux)

	Test Point	Floor							
		2		3		4		5	
		Time							
		10 am	4 pm	10 am	4 pm	10 am	4 pm	10 am	4 pm
Sim.	A	190	389	75	128	150	160	275	564
Meas.		221	409	104	164	161	179	291	580
Sim.	B	162	331	< 10	< 10	90	121	192	393
Meas.		195	383	82	71	121	131	211	441
Sim.	C	42	87	< 10	< 10	60	101	194	397
Meas.		85	112	62	70	84	109	213	483
Sim.	D	89	182	< 10	< 10	230	471	885	1 812
Meas.		111	211	59	63	249	490	1 005	1 999
Sim.	E	75	152	< 10	< 10	79	164	537	1 175
Meas.		90	179	91	84	89	183	651	1 301
Sim.	F	230	471	< 10	< 10	79	163	184	377
Meas.		245	508	95	106	90	181	222	451
Sim.	G	262	538	< 10	< 10	49	101	846	1 734
Meas.		280	604	95	102	73	119	995	1 000
Sim.	H	306	626	187	384	373	764	497	1 018
Meas.		325	641	190	412	389	198	551	1 102
Sim.	I	41	84	< 10	< 10	< 10	< 10	116	239
Meas.		61	101	63	70	69	65	204	351

Table 3. 21st June lighting levels (Lux)

	Test Point	Floor							
		2		3		4		5	
		Time							
		10 am	4 pm	10 am	4 pm	10 am	4 pm	10 am	4 pm
Sim.	A	912	1267	361	502	214	298	1 323	1 838
Meas.		1 000	1 401	441	542	326	461	1 414	1 911
Sim.	B	777	1 079	< 10	< 10	378	526	923	1 282
Meas.		781	1 211	132	143	482	553	1 012	1 403
Sim.	C	206	286	< 10	< 10	235	327	932	1 294
Meas.		215	401	122	146	333	374	999	1 411
Sim.	D	428	595	< 10	< 10	1 105	1 535	4 250	5 898
Meas.		450	651	131	187	1 211	1 609	4 003	5 998
Sim.	E	358	497	< 10	< 10	383	533	2 755	3 826
Meas.		371	580	81	161	451	581	2 806	4 011
Sim.	F	1 105	1 535	< 10	< 10	389	533	885	1 229
Meas.		1 199	1 756	94	233	474	583	920	1 402
Sim.	G	1 261	1 750	< 10	< 10	238	331	4 065	5 645
Meas.		1 404	1 980	125	341	271	384	4 104	5 698
Sim.	H	1 468	2 040	902	1 252	1 792	2 489	2 387	3 314
Meas.		1 550	2 104	939	1 354	1 798	2 511	2 404	3 504
Sim.	I	197	274	< 10	< 10	< 10	< 10	561	778
Meas.		210	299	125	185	275	277	589	820

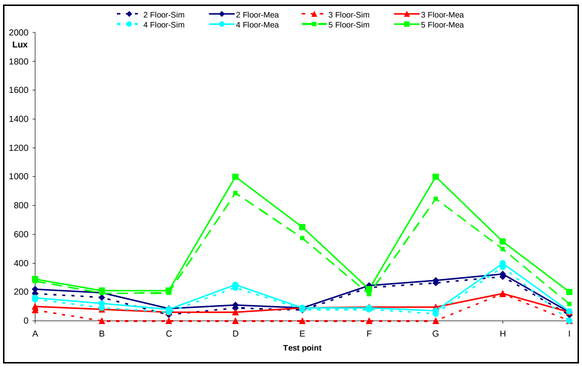

Figure 9. Comparison of measured and simulated values. 21st March, 10 am.

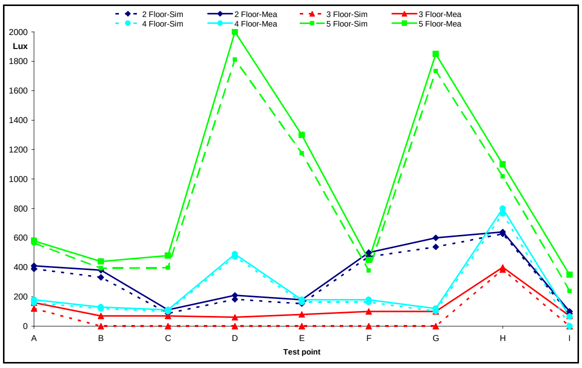

Figure 10. Comparison of measured and simulated values. 21st March, 4 pm.

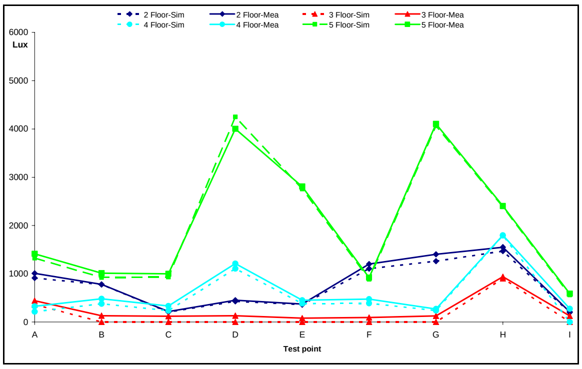

Figure 11. Comparison of measured and simulated values. 21st June, 10 am.

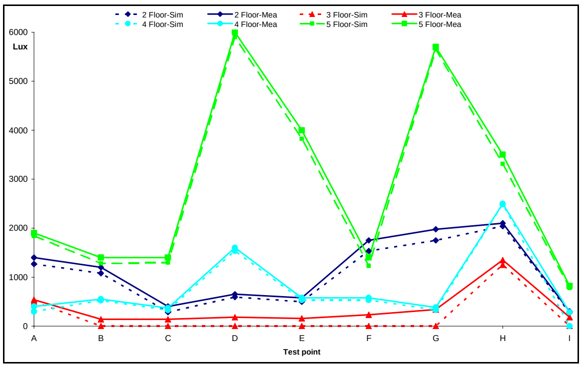

Figure 12. Comparison of measured and simulated values. 21st June, 4 pm.

CONCLUSIONS

The study made it possible to validate the use of the software in all situations and in practice for the whole year. Using colors mapping it is possible to predict, during the design phase, the performance of the glazed surfaces for the purpose of natural illumination, and consequently to evaluate the architectural choices.
It has also been demonstrated that it is always necessary to use real measurements of the external illumination to obtain more reliable results about the actual conditions than the software can produce automatically, as it uses mathematical models that are related to the Tregenza formula (Tregenza 1986) or the latitude model, which estimates illumination in relation to distance from the equator (Dresler 1962).

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