Evaluation of Indoor HybridLight Field to Supply Wireless Sensor Network.A case study of a Simulated Enlightened Room in Tunisia.

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***Abstract*—The term iPV stands for all types of photovoltaic cell that operate under indoor conditions supplied by a mixed light.Indoor photovoltaic is a promising field specially for suppling low power electronic circuitry as wireless sensor networks.Until now, there are no international norms that define a standard test conditions for indoor photovoltaic cell.In this work, we study the characteristics of indoor natural and artificial light.This light can be transformed into electricity if it's considered as source for a PV module. The computation was made using the radiosity method to determine the light distribution inside the room taking into account the sky diffuse radiation and all surfaces reflections. We used DIALUX software to calculate the spatial distribution of incident light on all the wallsand on the ceiling to define which wall is expected to host the iPV generator.For this reason we create a surface for light intensity calculation which we will call an active surface.The simulation results showed that we can predict the amount of light under LED artificial lighting and choose the optimal position of the PV cell. One of The main issues is the nonuniformity of light distribution on the active surface which has been studied through the intensity light gradiant.**

***Index Terms*—artificial light, Dialux,gradiant, indoor Photovoltaic, light intensity, natural light, shading, wireless sensor.**

Practical Application

Utilization of low-power indoor devices such as remote sensors, supervisory and alarm systems, distributed controls, and data transfer system is on steady rise. In our case we focused on a wireless sensor node and since the node is wireless and placed in an office where the light is available , it is attractive to study the feasibility of suppling it with a photovoltaic cell in order to replace the use of batteries or to extend their lifetime.

Introduction :

In recent years, there has been a growing interest in indoor PV and more generally in autonomous indoor low energy generators for micro-power systems. The power that a PV cell can collect from indoor provides 3 orders of magnitude lower than outdoor environment [1].

The photovoltaic technology can be used as a power source in any scale, ranging from applications of mW(or even less) up to MW power plants [2].

The main researchs on iPV has focused on energy harvesting, storage and maximum power point tracking [3]. Indoor PV differs from outdoor PV in many points, e.g the inexistence of indoor standard test conditions and norms and the hybrid light spectrum is very different from solar spectrum.

The indoor PV proposes a novel power source using artificial and natural indoor light into buildings whether it was residential , commercial or industriel buildings.In our case, we will focus on an office room located in Tunisia north Africa, the present paper is far from looking to save energy and is instead oriented to recycle the existing light potential to supply a PV cell.

In this paper, we explore the possibilityto study the nature of the indoor light for many reasons specially to define the optimal position of the PV module, try to avoid the light gradiantand shading to better supply an indoor photovoltaic application like a wireless sensor network (WSN), much research on supplying WSN by iPV has been done. Recently, several authors [4-5-6-7]have studied the feasibility of satisfying WSN power need by only recycling indoor light.

I.Simulation Parameters

In this work, we used principally two software, Dialux4.12 for indoor light simulation and Origin 2016 for the graphing and data analysis.The method that Dialuxapply for the calculation is the so-called radiosity method.These calculation codes are able to predict the amount of light received by any point of a given working plane and from one or more sources installed on the ceiling of the room.

A. *The room geophysical parameters*

The case studied consiston an office room located on Tunis, Tunisia with a dimension 3.6mx5.4m, a2.800 mHeight, 36.83° on Latitudeand 10.15° on the Longitude. The Orientation is 20 degree to the north. Reflexion degreeRho (maximum value in dialux 90%): ceiling 70%,walls 50% and ground 20%. Objects in the room are two windows, a door, a table, a chair and two desks. The glass transmission factor of the window is 90%.The office is occupied from 9AM to 5PM for professional activity.The next figure shows a 3D preview of the office room

Fig.1. 3D preview of the office

Besides the room geometry, other parameters are involved as reflection coefficients of the walls and furniture.

B. *The light source technology andarrangements*

Alight-emitting diode (LED) is a semiconductor device that emits visible light when an electric current passes through it. The light is not particularly bright, but in most LEDs it is monochromatic, occurring at a single wavelength. The artificial light source used in this work is a matrix of ALTO 11200 W75 840 O2 Downlight LED, the dimensions of the LED lamp are (L x l x H): 0.065x0.065x0.08m.

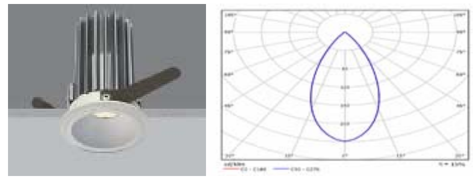

Fig.2. ALTO 11200 Light emission.

One Led power: 10 W
Luminous flow: 700 lm
The office is enlightenedby 12 ALTO led on a straight dispositionon the ceiling.
This disposition do satisfy the visual comfort for a professional activity on an office by 300 lux average light intensity on the working plan.

C. *The active surface*

The active surface is a surface on which the software will calculate either the amount of light intensity (lux) or the illuminance of the surface.The dimension, the surface origin position and the number of the calcul point are fixed by the user.In order to better study all of the office space, each wall contains an active surface.

In our case, the active surface mesure $4m^2$ and contains 20 * 50 calculation point.

D. *Tunisian Artificial Light Field evaluation*

In recent years, there have been many new developments in the lighting industries,
The Three major lamps type dominating are incandescent, fluorescent lamp and Light emitting diodes (LED).In Tunisia, in 2014 LED presents 39% of the total lamps used while incandescent represents 35% and Fluorescent 18%.

TABLE I. TUNISIAN MARKET SHARE LIGHTING TECHNOLOGIES EVOLUTION FROM 1984 to 2014 [8].

Parc %	1984	1989	1994	1999	2004	2009	2014
Incandescent	83	79	76	73	68	55	35
Fluo	10	12	14	16	18	17	18
LCL*	0	0	0	0	3	19	39

LCL: low consumption lamp.

The contribution of LED lamp in the Tunisian Market due to its characteristics in energy saving do justify our choice of ALTO LED lamp in the first section.

II. RESULTS: SIMULATED ARTIFICIAL LIGHT DISTRIBUTION

i. Artificial light simulation Results

Indoor artificial Light illumination levels vary in function of the activity in the local, there is a minimum level to guaranty the visual comfort, next table illustrate those levels.

TABLE II : indoor illumination levels

	Activity
Around 500 lux	Office Classroom Conference room A shop Hotel reception Sick room
Around 1000 lux	Industrial design Jewelry Operating room

It's possible to calculate the light exchangebetween luminaires and any other surfaces (direct light) and also the light exchange between illuminated surfaces (indirect lighting)[9].

We carried out lighting simulations of an office building in order to clarify the characteristics of indoor lighting environments using Dialux.

The Led Lamp hanging on a 3.6mx5.4m area of the ceiling and oriented to the bottom.An active surface on each wall (1,2,3,4)is created to calculate the amount of light.

After the simulation, we compare the light spread on all walls, for example we present the wall n°1:

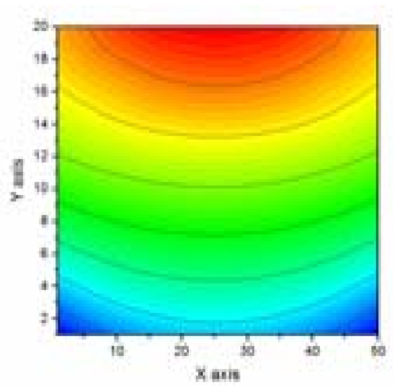

Fig.3. light intensity on a vertical active surface laid on wall n°1.

Figure 6 show that we have zones with equal intensity. Next we will compare the light intensity in different vertical active surface laid on every wall, for example we choose the wall 1 and 3.

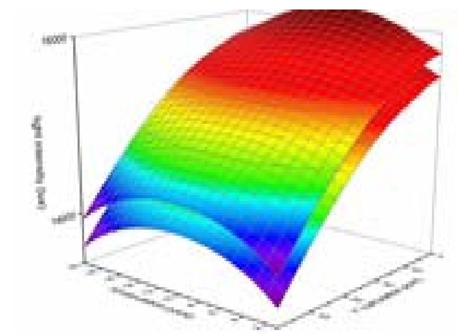

Fig.4.Stacked 3D colormap surfaces light intensity for symmetric walls

Light distribution is symmetric in wall 1 and 3. Both distributions are similar if we don't take into account the presence of any obstacle.

The nonuniformity of light intensity on the active surface is similar to the shading phenomenon for a classic photovoltaic panel.

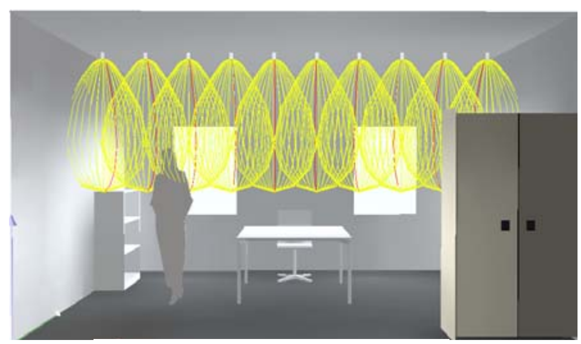

Fig.5. Artificial light lamp disposal

In table III is showing the photometric results generated by Dialux program for office considered.

TABLE III.Artificial Lighting:Photometric Results

surface	Medium luminance [lx]			Reflexing factor (%)	Medium luminaire [cd/m2]
	Direct	Indirect	Total		
Work plane	247	46	293	-	-
Floor	125	56	181	20	11
ceiling	0	55	55	70	12
Wall 1	100	36	136	50	22
Wall 2	101	48	149	50	24
Wall 3	0	63	63	50	10
Wall 4	74	49	124	50	20

ii. Characteristics of the incident light on the active surface,

The incident light depends on the position of the active surface and the distance between the light sources and to better study the characteristics of the incidental light on the active surface, we have studied the artificial light gradiant on a surface of $4m^2$ laid on the wall with a fixed origin position. We have varied the density of luminaire and keep the surface constant.

TABLE IV. GRADIANT INDICATORS

Luminaire density	Min	Max	Avg	Min/Avg	Min/max
5x5	2.51	44	82	0.08	0.06
10x10	107	580	187	0.57	0.18
20x10	214	764	372	0.58	0.28
20x20	426	906	642	0.66	0.47
30x30	958	1974	1431	0.67	0.49
50x50	2660	5493	3968	0.67	0.48
60x60	3830	7903	5711	0.67	0.48
100x60	6384	13166	9518	0.67	0.48

Table 3 shows the evolution of the minimum, maximum and the average of light intensity (lux) on the active surface of function of the density of the light source matrix.

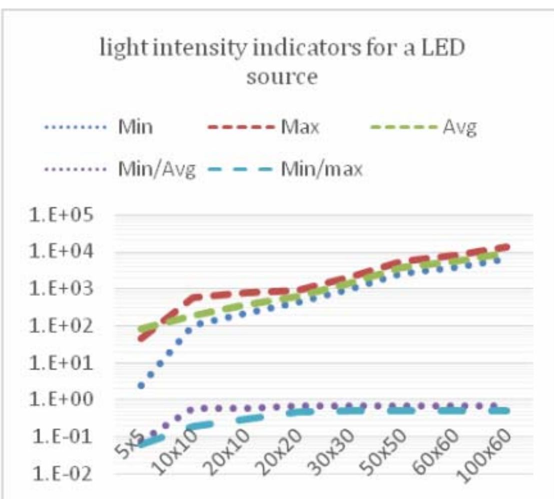

Fig.6. Artificial light source indicators for many luminaire density.

With a logarithmic scale, both Min/Avg and Min/max indicators tends to be constant from a certain luminaire density.Min, Max and Avg light intensity indicators are proportional to luminaire density.

II. RESULTS: INDOOR NATURAL LIGHT DISTRIBUTION

i. Evaluation of available solar radiation

Evaluate of solar radiation available for a known site represents an important factor for design PV system. The dates concerning solar radiation can be taken from meteorology and hydrology publication. Solar radiation potential in Tunisia is represented by global solar radiation maps. In figure 1 is noticed that there are places in which yearly solar energetic flux increase until 2000[kWh/m2/year], in the south

Fig.7. Tunisian Map for solar radiation potential

As can be seen from the previous figure, the solar radiation in Tunisia is very important and it remains to prove that diffused or indirect natural light is important inside buildings.

ii. Indoor Natural light simulationResults

The sky is divided into customizable luminous surfaces, which, depending on the sky model, location, date and time, a lighting density is affected.The natural light illuminance can also be calculated for many sky conditions like clear, overcast and partially overcast sky as shown in the next table.

TABLE V: THE AVERAGE ILLUMINANCE OF DIFFERENT SKY SITUATIONS

	Average illuminance on working plan (lux)	Average illuminance on wall (lux)
Clear sky	310	144
Partially overcast sky	450	120
Overcast sky	399	97

For natural light simulation, we haveas input some parameters as the date 07/07/2015, time on 10h30 and the type of sky, we choose an overcast Sky.Table II shows levels of light intensity from the window side to the inner side on the working plane, ground, ceiling and walls.

TABLE VI.PHOTOMETRIC RESULTS FOR AN OVERCAST SKY

Surfaces	ρ [%]	Emoy [lx]	Emin [lx]	Emax [lx]	Emin / Emoy
Working plane	/	455	43	3226	0.095
Ground	20	315	110	769	0.348
Ceiling	70	63	47	88	0.74
wall (4)	50	111	25	354	/

From version 4, Dialux is able to calculate the daylight. Calculation is based on the standard DIN 5034 and the publication of IEC 110.

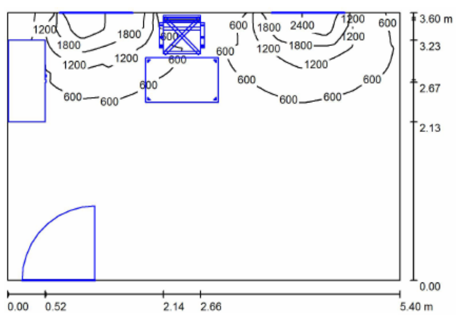

Fig.8. iso curve of natural light on the working plane

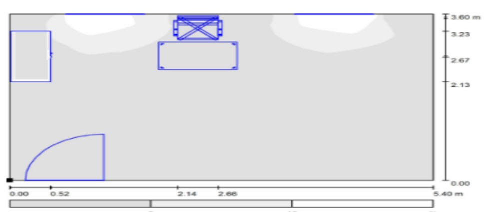

Fig.9. Natural light distribution on the work plane

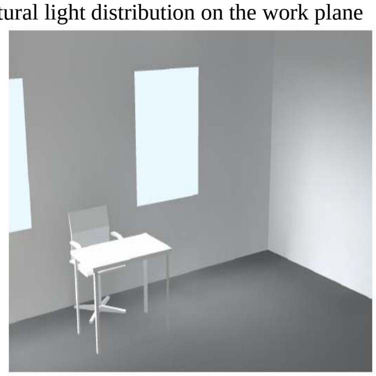

Fig.10. 3D preview of the office space with only naturallight.

Light intensity propagates from the window to the inner side of the office.

iii. Effect of location

Next table present indoor natural light simulation results for different locations.

TABLE VII.

	Working plan (lux)	*Ground (lux)*	*Wall (lux)*
Tunis	*294*	*181*	*114*
Sousse	*296*	*183*	*115*
Sfax	*298*	*184*	*115*
Tataouine	*304*	*188*	*116*

The increase of average light intensity, on the working plan ground or wall, when varying location can be contributed to approaching the south.

iv. Effect of orientation

In this section, we will study the effect of the orientation of the office on the average natural light illuminance when the sky is clear.

TABLE VIII: EFFECT OF THE ORIENTATION ON THE NATURAL LIGHT DISTRIBUTION INSIDE THE OFFICE

Orientation to north(degree)	Average illuminance on working plan (lux)	Average illuminance on wall (lux)
00	*329*	*120*
20	*293*	*114*
40	*271*	*107*
60	*265*	*106*
80	*263*	*108*
90	*263*	*104*
120	*282*	*110*
140	*310*	*122*
160	*358*	*133*
180	*877*	*229*

The finding is quite expected since the maximum of incident natural light is obtained when the location is oriented to the south but the 144% of increase between 160 and 180 degree to the south is not a conclusive result.

III. DIMENSIONNING OF PHOTOVOLTAIC HARVESTER TO SUPPLY A SENSOR NODE

We have simulated the daylight intensity between 09:00 and 17:00. The result was calculated on wall n°2 which is considered as a matrix with a (32, 32) point. We will calculate the amount of natural light falling in this wall all over the day.

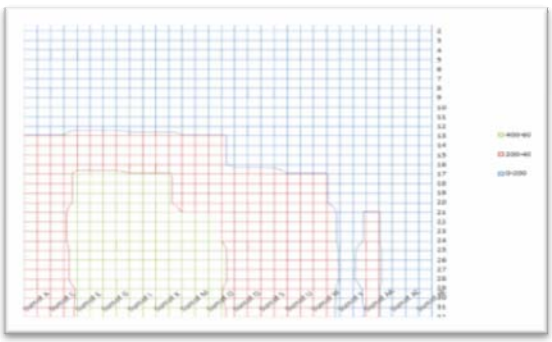

Fig.11. the total Daylight intensity on wall n°2

As is clear from Fig.10 the zone that receives the maximum of natural light is for the x axisfrompoint C to O and for the Y axis from point 17 to point 32 (green zone). From this we deduce that it's logical to place the PV cell in this zone.Since the irradiance is assumedto be constant, the performance of the solar cells does notvary throughout the year and during night the irradianceis assumed to be zero.This result was compared to other results such in [10-11]and found to be very compatible.

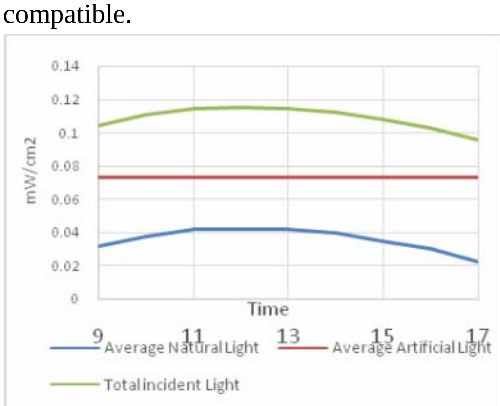

Fig.12. natural and artificial indoor light irradiance from 09:00 AM to 05:00PM.

Photovoltaic harvesting is a promising energy source because of the available irradiance both indoors and outdoors[12-13].

We consider that the sensor sleeps when not being active using a current of 2.95 µA and a voltage of 3.18 V. Thus, itis sleeping for 1785 sec using 17 mJ and requesting and receiving data for 5 sec. This leads to an energy consumptionof 17.6 J/day or 4.9 mWh/day [5].

TABLE IX. ENERGY AND POWER DENSITIES FROM A SOLAR CELL

WSN energy consumption (mWh/day)	*Irradiance* (mW/cm2)	*hours*	*Average Power generated* (mWh/cm2)	*Cell surfaces* (cm2)
4.9	0.1	8	0.144	20.5

Amorphous-silicon and dye-sensitized solar cells have been tested extensively as indoor light harvesters due to their wide bandgaps that are optimum for absorption of the spectra from compact fluorescent lamp (CFL) and light-emitting diode (LED) bulbs [14].The amorphous silicon solar cell was judged as the most suitable cell for indoor conditions in terms of efficiency reaching 18% for 0.24mWh/cm2[3] ofaveraged energy delivered. The sensor with anenergy consumption of 4.9 mW/h/day could thus be poweredwith an amorphous silicon solar cell with an area of20.5 cm2.

IV. Discussion

This paper is a modest contribution to the ongoing discussion about supplying WSN by iPV.Particular attention is paid to the important contribution of natural diffused light in Tunisia to satisfy the load need. The realized simulations allow us to define the most appropriate location orientation and position to fix the solar cell and to know if the amount of the hybrid indoor light is sufficient to supply a node.

V. Conclusion

We used simulations to study the characteristics of indoor electricalartificial and natural light in a typical office in Tunisia.

The majority of inside light study are looking for reducing building's energy consumption while this paper presents a novel exploitation method using Dialux software for estimating the amount of natural and electricalartificial indoor light and its characteristics in order to supply a sensor node.The research question of this study is where the optimal PV panel position is, to avoid the light nonuniformity phenomenon and mostly to well know the indoor light distribution.

In means of conclusion, the results of our study are strongly related to our assumptions, the artificial and natural light in our case do satisfy the visual comfort conditions on a working place and also could supply a sensor node.

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LIST OF FIGURES