Energy Saving Exploiting Light Availability: A New Method to Evaluate Daylight Contribution

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Abstract

Rhinoceros and *Grasshopper* have the extensibility which makes architects able to study forms, structures, acoustic behaviour, energy consumption, etc. as well as daylight availability: the most important aspect in this study. The software described has been useful to evaluate running costs including heating, cooling, electrical devices and lighting systems.

The software used includes *Ladybug* and *Honeybee*; they connect the *Radiance* and *Daysim* engines to *Grasshopper* and *Rhinoceros*.

The building analyzed in this study is a competition proposal for the New Town Hall in Remseck Am Neckar (Germany). The simulation started by designing the electric lighting system while the daylight availability was evaluated afterwards. The core study is the critical investigation of the daylight contribution necessary to satisfy the lighting demand.

Two simulations were run: the first one followed the European Regulation EN 15193, the second one was based on *Daysim*. If these methodologies gave two equivalent results for the north-exposed offices, on the other hand the south-exposed rooms obtained slightly different values. The idea consists in developing a third method to use opposed to the others described before, called the 'Octopus method' (OM) and based on *Octopus*, a multi-objective evolutionary algorithm integrated within *Grasshopper*. The new feature the OM introduces is the annual illuminance data computation being different from *Daysim*. The latter just makes a multiplication between the illuminance deficiency and the required comfort level. The OM considers the comfort level throughout the year simulating the real illuminance distribution within the ambient of study and the effect of electric light system installed.

1. Building Simulation: Nowadays

A critical approach is introduced to evaluate the lighting system consumption depending on the daylight availability – the most critical aspect about energy demand for office buildings (Tuoni et al., 2010; Leccese et al., 2012).

Originally, the matter of understanding and controlling the energy demand came from the need to check if the design proposed fulfills the requirements.

The more complex a project is, the more the desire to control it increases, due to the need to evaluate costs and benefits through simulation tools (Leccese et al., 2009; Angeli et al. 2005; Angeli et al. 2004; Lazzarotti et al. 2003).

Lately, software solutions have become more and more advanced to satisfy professionals' necessities as much as possible.

The authors looked for a software environment for having both a strong reliability and a smart user interface to focus on the physical behaviour.

2. The choice of the software environment

The choice was *Rhinoceros* (RH) and *Grasshopper* (GH). The software environment, thanks to its add-on architecture, allows us to pursue aspects more in depth than was possible until now. They have the extensibility that makes architects able to study daylight availability: the most important aspect in this study.

Since both RH and GH do not include any

environmental tools, but just geometry and data structure management engines, the *Ladybug* (LB) and *Honeybee* (HB) add-ons were added to the tool package.

For those who are not confident with this plug-in, a brief description follows.

LB and HB are a collection of user components developed in *Python* programming language within GH by Mostapha Sadeghipour Roudsari et al. at Thornton Tomasetti as Integration Applications Developer. The tool connects the *Radiance* and *Daysim* engines to *Grasshopper* and the *Rhinoceros* 3D-environment. The software described has been useful to evaluate running costs of the New Town Hall building including heating, cooling, electrical devices and lighting system which is deeply analyzed in this study.

The RH and GH interface is well known and generally user-friendly while the reliability has been checked through tests conducted on already-known conditions.

Once the tool-ecosystem is described, it is also necessary to talk about the environmental data source. The U.S. Department of Energy, thanks to their database based on *.epw files (*EnergyPlus weather* file format), was chosen thanks to its intrinsic interoperability and completeness. Consequently, input data were verified in comparison with the Italian Regulation Weather Data: the difference found was acceptable (Campanile, 2014).

In addition to this, it must be said that the reliability checking was done even for LB and HB *Radiance* implementation: a test model was processed both in *DIALux* and HB and then the results were compared (Campanile, 2014). The geometry is a simple room with one window and a test grid able to measure the illuminance level from a light source. Once again, difference was around 2%, which is more than acceptable.

The usage of GH and its add-ons led us to consider the overall software reliability. Since GH lets literally everyone able to make new open source *environmental plug-ins*, this has two effects. The first one, which is positive, is that researchers have either a flexible, free, powerful and diffused tool to deepen their studies. The other side of the coin is that sometimes these software extensions do not follow a proper reliability check and might be fine for the purpose they was developed for, but not for other cases. As we expected from an add-on created by Thornton Tomasetti, the checking results have been excellent even if LB and HB are still a work in progress.

3. Case of study

The building tested is part of a competition proposal for the New Town Hall in Remseck Am Neckar (Stuttgart, Germany) designed by C. Campanile (Campanile, 2014) at MDU Architetti (Prato, Italy), see Figs. 1-3. The buildings are glaze-enveloped volumes which, on one hand are strongly naturally enlightened; on the other, they have been defined to create a strong linkage between external and internal spaces due to the high quality natural surrounding: the confluence of two rivers. This has been the result of the design research, conducted to be satisfactory in terms of the membrane's performance behaviour.

The analysis was run for the Town Hall Building for two reasons: firstly, this is the most complex building compared to the Library and the Civic Hall (Fig. 1). On the other hand, it is actually an office building: it is a much-diffused typology and mostly it is affected by high-energy consumption because of its electrical light system.

Before proceeding, it is useful to present the Town Hall Building (Fig. 4): a four-storey building with a courtyard closed with a transparent rooftop. The higer visitors go, the larger the internal void is: on the way up to the wedding room, two internal terraces host the public front offices. Around this space, the horizontal circulation is shaped through a timber stick membrane: they are for the horizontal circulation. Beyond them, office rooms are organized along the northern and southern facades.

3.1 Light Design

First of all, the simulation was conducted designing the electric lighting system, and daylight availability was evaluated afterwards.

Since the gross building area measures 6000 m^2, the lamp density is calculated on several test rooms

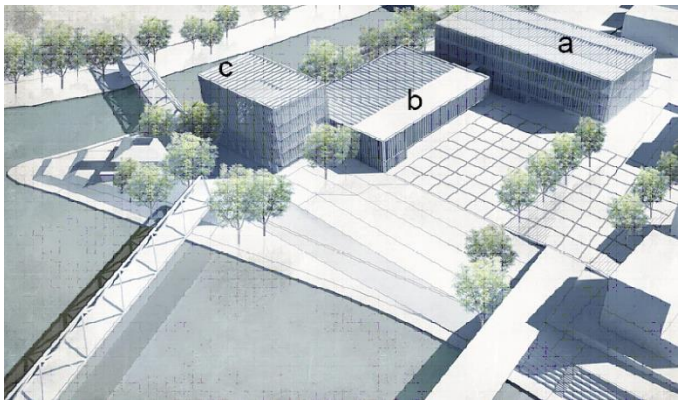

Fig. 1 – New Town Hall proposal: a) Town Hall, b) Civic Hall, c) Library.

Fig. 2 – New Town Hall proposal: plan of the first floor.

Fig. 3 – Rendering of the New Town Hall in Remseck Am Neckar (Stuttgart, Germany): competition proposal.

and split between those exposed to the north and those exposed to the south.

The electric light system was designed studying four different test rooms: single (1P), double (2P), triple (3P) and open space office (S). Then, results were interpolated to devise a function able to match the power needed with their areas (Fig. 5). From this point forwards, we will consider the triple office (3P) as our test room for (Fig. 6). Illuminance and presence sensors have been added to the system. This feature allows the authors to consider the installed lights, which are sensitive to the illuminance levels. Therefore, the system is able to fix automatically the intensity (dimmer value) of the lamps. It must be said that actual sensors are one per light line (Fig. 6), while in the GH definition they are on each point of the test grid (Paragraph 3.4). This has been affected because of the will to make the method flexible and helpful for other kinds of design.

3.2 Electrical Light and Daylight Interaction: An Actual Question

Evaluate daylight contribution means to study the illuminance level through a year and to figure out if the daylight is enough to satisfy the comfort level: if not, calculate the percentage of the electric light power usage.

Fig. 4 – Town Hall Building: perspective section.

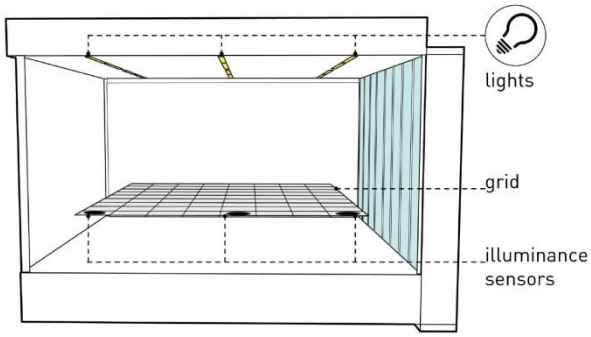

Fig 6 – 3P test room with the electric light system.

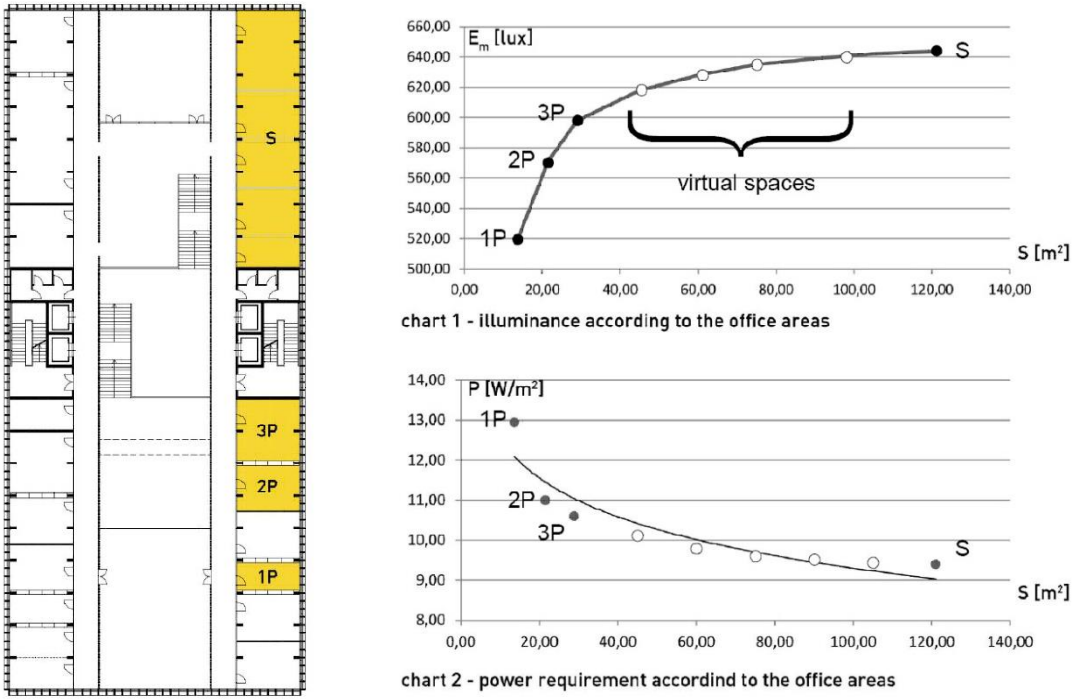

Fig.5 – (left) Plan for the test rooms. In the charts (right) are represented the illuminance and the power requirement for the test rooms (1P: 1 person, 2P: 2 persons, 3P: 3 persons, S: open space). Virtual spaces has been returned from a double data interpolation.

This percentage is called dimmer value and it is between 0 (system turned off) and 1 (system at maximum power). Before introducing the OM, two simulations have been run using two already tested methods: the first one follows the European Regulation EN 15193 (EN 15193, 2007; Leccese et al. 2013; Bertozzi et al. 2012), the second is based on *Daysim*. The annual daylight dependance factor values are shown in Table 1. It is possible to say that (Reinhart, 2001; Daysim , 2014):

- 1) if these methodologies give two equivalent results for the North-exposed offices, on the other hand the South-exposed rooms get slightly different values;
- 2) they are both generic, the 1st one does not take into account both the physical situation of rooms and the electrical lights, the 2nd one just not the electrical light system which is just conceptualized.

The goal of this study consists in developing a third method. The results of this third method can be useful compared with the results of the methods above.

Table 1 - Annual daylight dependance factor values.

	EN 15193	Daysim	Octopus
North	0.48	0.47	0.41
South	0.32	0.41	0.25

3.3 An Initial Daylight Evaluation

Since this two methods are commonly used for this purpose, we will skip the EN 15193 one and present briefly the second one because of it is strongly connected to the OM. *Daysim* is useful to calculate the Daylight Autonomy and has been integrated in HB. This properly means that, when an annual daylight study is run, it gives back the hourly illuminance level through the whole year. Even automatic systems and sensors are taken into account. In this case study two functions are considered as integrated in the system: illuminance sensors and automatic dynamic blinds. The second one useful for what concern the comfort, but not influential for the OM. Once that *Daysim* returns the results about illuminance levels, an approximate system just makes a multiplication between the illuminance deficiency and the required comfort level. This is the way *Daysim* use to "conceptualize" the electrical light system. From this point forward it is shown how to include the actual electrical light system into the evaluation through the OM. It must be said that its development is enough to use it not to substitute the other two methods, but to help users to understand the behavior.

3.4 The Octopus Method

The name 'Octopus Method' (OM) is due to the fact that it is based on *Octopus*, a multi-objective evolutionary algorithm integrated within *Grasshopper* (Octopus, 2014). The new feature the OM introduces is the annual illuminance data computation being different from *Daysim*. The latter just makes a multiplication between the illuminance deficiency and the required comfort level. The OM takes into account the comfort level throughout the year simulating the actual illuminance distribution within the ambient of study and the real electric light system installed.

(**Step 1**) The OM has been run inside a test room - once South-oriented, once North-oriented - already designed in RH and used for the *Daysim* method (Fig. 7). Since nothing changes talking about the method, only the South-oriented room is considered to show the OM, while both the results will be shown. The room test is intended in this way: illuminance levels are measured on the desktop height where a grid has been created and it correspond to zero (0 lx). Since this, illuminance graphs are drawn above. The grid definition has been tailored to its proper measure: 8x9=72 points. Basically one per half a meter.

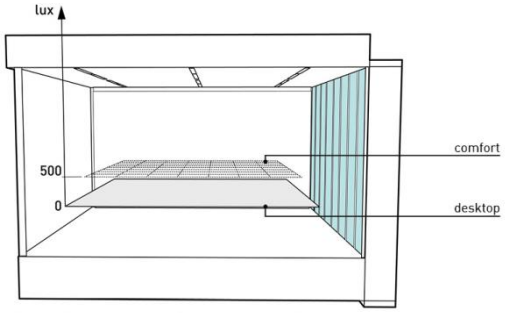

Fig. 7 – Test room: a typical office room (3P).

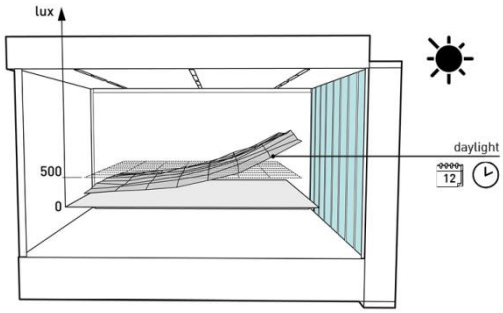

Fig. 8 – Sample 1: illuminance level at a random time.

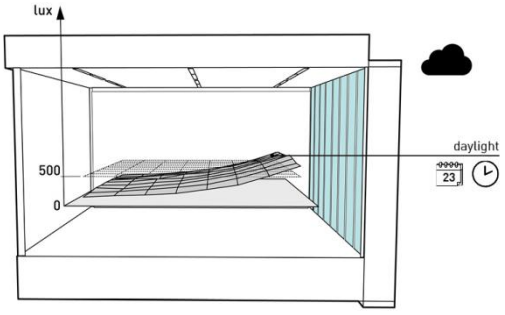

Fig.9 – Sample 2: illuminance level at a random time.

(**Step 2**) *Daysim* data that comes from the annual analysis are collected into a database: it includes hourly illuminance level over the whole year. Since the grid has 72 points and the annual hours are 7860, the database is built of 72x7860=630720 values assembled in 7860 charts. A couple of examples are shown in Figs. 8-9.

(**Step 3**) A first data cleanup is made cutting out no-working hours because of no electric lights are turned on outside of the work schedule: Monday to

Friday (5 days per week), 8 am to 6 pm (10 hours per day). Holidays are not included: we will see later that this is not conclusive, and the reason is that the method is based on monthly average daylight availability. At the end of this step the data pattern is changed: only 50 out of 178 weekly hours are included in the calculation. Since one year is made of 52 weeks, the result is that in the whole year only 2600 hours (charts) out of 7680 are taken into account (and 2600x72=187200 point values).

Within the last step, the average monthly daylight availability (True Monthly Average, TMA) has been introduced: the method is based on the average since the goal is to calculate the energy consumption. From this point forward, the database is useless for the comfort level evaluation. Before going further, it is appropriate to show how the average is made up or, we could say, how we extrapolate 12 charts (one per month) from 2600. The TMA is calculated about the single value (grid point) in the chart, for that charts which are included in one month. We call it 'true', because actually, to go forward into the method, we need a Fake Monthly Average (FMA). It is so-called because it included all the 187200 point values, whereas it includes a condition: the values 'bigger than the comfort level' are considered 'at the comfort level' (500 lx). The reason of this is understandable through the following example: a grid-point, at a certain time, has the illuminance level at 200 lx. The same point, at another certain time, has the illuminance level at 800 lx. The average is (200+800)/2=500 lx, i.e. the comfort level. The average shows that no electrical light is required, while actually, it is. Since this thought, we can proceed as it follows.

(**Step 4**) Each point grid value bigger than the comfort level is equal to 500 lx. In Fig. 10 a cut chart is shown.

(**Step 5**) The FMA daylight availability is made from the cut charts (Fig. 11) for each month. Daylight availability data has been processed so far. The electric light effect is added from this point towards: the overall system has illuminance sensors as introduced before (Step 4). The building considered is big enough for including automatic systems for environmental controls: it must be said that the OM is available only for light systems that include this kind of amenities.

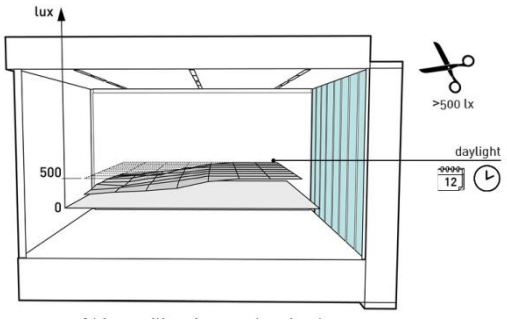

Fig.10 – Cut of bigger illuminance level values (>500 lx).

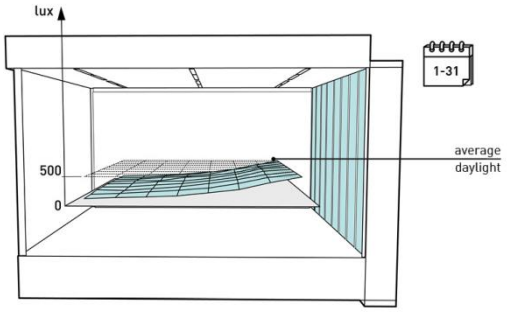

Fig.11 – Montly average illuminance within working hours (8am-6pm, Mon-Fri).

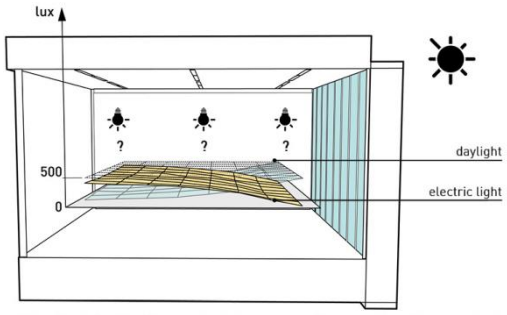

Fig.12 – Electrical light and daylight overlay for reaching the comfort.

(**Step 6**) In Fig. 12 we can see an example of the over layering effect of electric light (yellow chart) and daylight (blue chart): the latter is not enough to satisfy the comfort level, which is reached through the lamps usage. Therefore, the lamp graph shown represents the optimal dimmer setting to achieve the comfort level. As described at the Step 6, the ideal chart is known: on the other hand, lamp dimmers are not. Through OM it is possible to calculate the combination between electric light and daylight. In Fig. 12 is also clear

that the yellow chart can be affected by lower dimmer on the window side (right) and bigger values on the wall side (left).

Octopus is used to find it through "smart" iterations. Basically it makes several attempts (Figs. 13-15) trying to find that combination, which, if used, causes an illuminance, represented by the ideal chart. Octopus is able to "read" the output chart and "understand" if it fits the ideal one through a fitness parameter (called F1). Before running the process, it is useful to introduce an additional fitness parameter (called F2) which is able bring our GH definition closer to the effective physical situation: the illuminance uniformity, which is basically a ratio between the average illuminance level and the maximum value (both are taken from the TMA). The next steps are summarize as follows.

(**Step 7**) Setting of the *Octopus* reading definitions: the chart fitness F1 and the illuminance uniformity fitness F2.

(**Step 8**) Definition of the dimmer inputs: the multiplying factors are applied to the grid values and not to the light system. This is a means, which allows us to do the ray-tracing to compute the electric light one time instead of for each attempt.

(**Step 9**) *Octopus* is set to make 50 genes replicating 100 times. This is the minimum to consider the result acceptable.

(**Step 10**) In Fig. 16 the best solution found is shown. Since there are two fitness parameters, the choice is made considering F1 and F2 weight both at 50%. In Fig. 17 the chart represents the hundredth step i.e. the final one: the intersection between the bisector line and the Pareto Front point at the solution.

4. Conclusive remarks

The method described has been applied for each month in the overall year, which means for each FMA (Fig. 18). Steps 1 to 5 show how to build the database to extract the FMA and TMA. In other cases, of course, it can be done for different time steps or period, depending on the design needs.

In conclusion, the whole software environment allows designer to evaluate many aspects, included those which are within country regulations. The case of study analyzed shown that Grasshopper reveals itself more convenient than conventional software solutions.

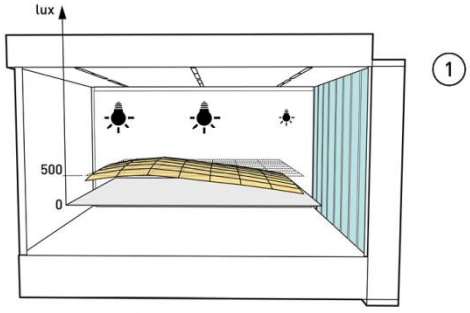

Fig.13 – Octopus: #1 attempt.

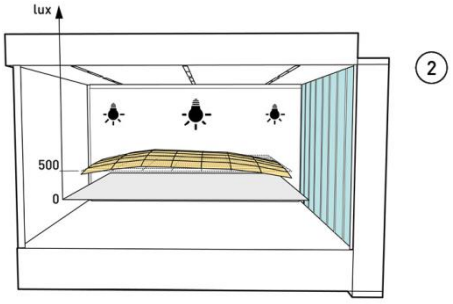

Fig.14 – Octopus: #2 attempt.

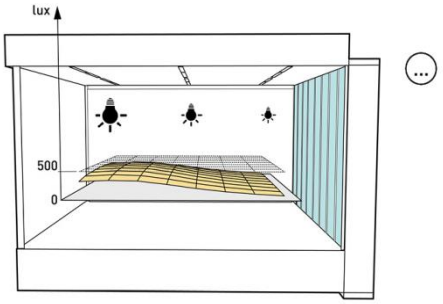

Fig.15 – Octopus try to come up a solution.

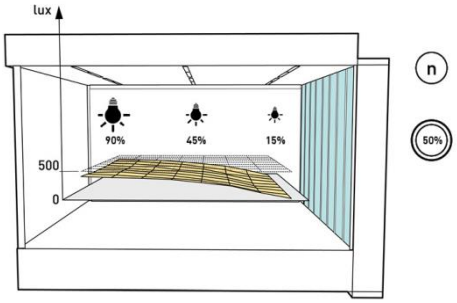

Fig.16 – A possible solution is got at the end of the process. The overall dimmer value is the average of the single ones.

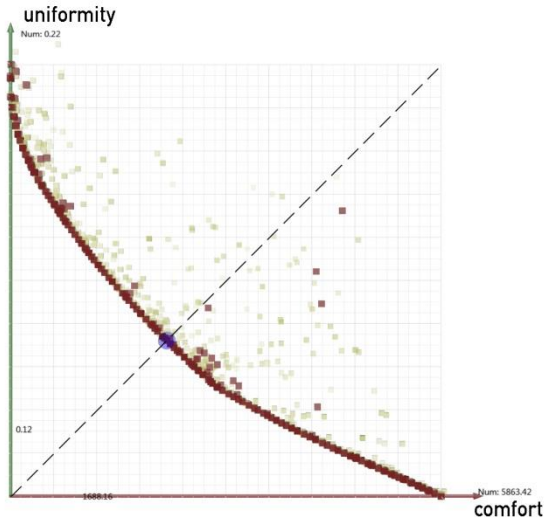

Fig.17 – Good solution (red) aggregated together from the Pareto Front. The best one (blue circle) is chosen due to its proximity to the bisector line.

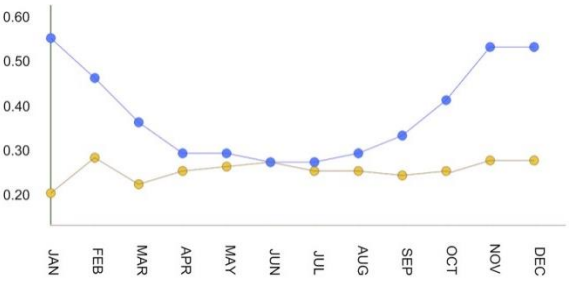

Fig.18 – Dimmer values returned through the OM: annual monthly results. The North-exposed test room (blue) shows a typical behavior because of the daylight availability. The South-exposed test room (yellow) shows a linear trend of the presence of the blinds. During the Daysim simulation, the blinds was down mostly from March to October, from 11 am to 3 pm.

The annual daylight dependance factor values are shown in Table 1. In the first column we can see Italian Regulations' results (according to EN 15193); in the second one, *Daysim* annual averages are shown (extracted from hourly dimmer level - properly processed). The OM returns a data, in the third column, which lead our choice through the EN 15193 results.

The big difference between the dimmer values for the South-exposed office is due to the fact that the direct daylight and the dynamic (automatic) blinds affects strongly the result. On the other hand, the North-exposed office room receive only diffused daylight: since it has not a direction, peculiarities do not affect the study case.

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