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# Towards an analysis of the performance of lightwell skylights under overcast sky conditions

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ABSTRACT

The main aim of this article is to analyze the performance of lightwell skylights under overcast sky conditions, determining the daylight factors and luminous distribution produced inside a room. Four different studies are carried out considering a room with a lightwell skylight. The first analyzes the daylight factors according to the size and height/width ratio of the skylight, the second evaluates illuminance depending on the reflection index of the lightwell, the third studies different room proportions and the fourth establishes suitable spacing between skylights. All tests were carried out using Lightscape 3.2 software. Following the trials, it was concluded that daylight factors are almost directly proportional to the size of the skylights and inversely proportional to their height. There is also an approximate quantification of the influence of the reflection index of the lightwell on interior lighting. Finally, it is confirmed that, in the absence of a reflected component, the suitable spacing between openings is proportional to the height/width ratio of the skylight.



## 1. Introduction and objective

### 1.1. State of the art

The use of skylights is frequent in modern architecture since these allow access to daylight in rooms lacking façades, while providing homogeneous lighting over the horizontal plane. Most researchers in this field have based their methodology on classic treatises on daylighting [1] and computer simulation [2].

One of the many forms of providing daylight in rooms is that of lightwell skylights, horizontal openings placed on a prism which acts as a reflector and prevents the incidence of the sun on the interior.

One of the first authors to define this type of skylight was Lam [3], who states that lightwell skylights allow sufficient daylighting in rooms below attic level. He also concludes that this type of skylight projects the light onto the floor, and in most cases this results in dim lighting of walls.

One of the most comprehensive studies on lightwell skylights is by Bouchet and Fontoynont [4] and establishes the design rules to allow an adequate amount of daylight into underground spaces. Using daylight simulation software Genelux, based on the ray-tracing method, the authors carried out a series of tests which basically conclude that the reflection index of lightwells is a determining factor in the lighting of a space. They also determined that specular reflectors allow greater illuminance than diffuse reflectors.

Lightwell skylights have a highly practical application in architecture, as can be observed in the research on their use in residential buildings. Kristl and Krainer [5] researched the distribution of daylight factors produced by the use of lightwells in residential buildings. The authors determined the variation in lighting in rooms depending on the shape and width of the skylight, thus confirming the usefulness of this architectural element. In addition, practical cases can be observed in the research carried out by Kotani et al. [6] where the authors analyze the assessment of the environmental conditions carried out by the occupants.

As described above, lightwell skylights mainly project light on the floor and produce a very characteristic daylight distribution. Nabil and Mardaljevic [7] applied new metrics and assessed the lighting distribution produced by this type of skylight. This research emphasizes the interpretation of daylight factors compared to daylight autonomy and useful daylight illuminances.

In addition to their application in daylighting, lightwell skylights favor natural ventilation in buildings. This can be noted in the research carried out by Kotani et al. [8], analyzing the ventilation produced by lightwells in different case studies. Moreover, Lomas [9] concludes that lightwells act as a passive system favoring the natural ventilation of buildings.

A rather unique form of lightwell skylights not included in this research is daylight collector, which allows daylight to reach the

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darker areas of the rooms. Specifically, Wittkopf et al. [10] assessed the performance of different shapes of daylight collectors, and concluded that lightwells are a very practical element in daylighting in architecture.

### 1.2. Objective

The main objective of this research is to determine the performance of lightwell skylights under overcast sky conditions. In order to do so four trials were carried out to obtain the variation of performance depending on multiple variables, such as the size and the height/width ratio of the skylight, as well as the reflection index of the reflector or the spacing between openings.

Research on lightwell skylights is carried out under overcast sky conditions as these represent the worst lighting conditions. Lightscape 3.2 simulation software was used to carry out the trials, as described later in the methodology. A total of four trials were carried out to assess the influence on the lighting performance of the following variables:

- Size and height/width ratio of the skylight.
- Reflection index of the skylight.
- Height, width and length of the room.
- Spacing of the skylights.

## 2. Description of methodology for calculation

### 2.1. Choosing the calculation conditions

By definition, the calculation of daylight factor components is carried out considering an unobstructed sky of assumed or known illuminance distribution, excluding direct sunlight. The definition of traditional overcast sky is used to calculate the sky component.

The overcast sky model, used in the methodology, is that defined by Moon and Spencer [11], where the luminance values are distributed according to the following:

$$L_\theta = L_Z \times \frac{1 + 2\sin\theta}{3}$$

where "$L_Z$" is the luminance at the zenith of the sky vault and "$\theta$" the projection angle. This implies that the lowest luminance value in an overcast sky vault occurs on the horizon, and is equivalent to a third of the maximum luminance at the zenith:

$$L_0 = \frac{L_Z}{3}$$

The formulation established by Moon and Spencer corresponds to the definition of overcast sky accepted by the CIE [12], which is known as traditional overcast sky: Sky type 16.

### 2.2. Choosing the calculation program

The analysis of the daylight factors was carried out using simulation program Lightscape 3.2, which calculates luminous distribution using a radiosity process. Several studies have confirmed the correct behavior of this calculation program [13,14].

Simulation programs based on the radiosity process can only define surfaces emitting a completely diffuse inter-reflection, unlike the programs which use the ray-tracing process. However, programs using the radiosity process are more precise when using high inter-reflection values [13].

The accuracy of calculations using the radiosity process depends basically on the mesh spacing. For the calculation model in this research, mesh spacing is between 10 and 20 cm, enough to guarantee that precise results are obtained [14]. In addition, a trial contrasting parameters was carried out to determine the values suited to the calculation model.

**Table 1**
Parameters of the calculation program.

| Lightscape 3.2 | | | |
|---|---|---|---|
| Sky conditions | Overcast sky | | |
| Mesh spacing | Min | | 0.10 m |
| | Max | | 0.20 m |
| Subdivision contrast threshold | | | 0.40 |
| Skylight accuracy | | | 0.60 |
| Source | Direct source | Min | 0.20 |
| | | Subdivision accuracy | 0.70 |
| | Indirect source | Min | 0.40 |
| | | Subdivision accuracy | 0.70 |
| | Shadow grid size | | Five |
| Tolerances | Length | | 0.0005 |
| | Ray offset | | 0.001 |
| | Initialization min area | | 0.01 |

The calculation parameters used by this program are shown in Table 1.

### 2.3. Choosing the calculation model

The initial model used for the trials was a room 9 m wide by 9 m long by 4.5 m high. A lightwell skylight, with a square floor and variable height ($H$) and width ($W$) (Fig. 1), was placed in the centre of the roof. The work plane on which daylight factors are studied is located 1.00 m above the floor.

The model represents the typical dimensions of a museum or library room. The low height of the ceiling in relation to the measurements of the space allows a distribution of light that is largely dependent on the Sky Component and is therefore suitable for analyzing the efficiency of the skylight proportions under study.

To adapt the results to the skylight proportions, the optical properties of surfaces – reflection, inter-reflection and transmission – are considered invariable. The inter-reflection of all the surfaces is completely diffuse under Lambert's cosine law, and as a result the light falling on a surface is reflected in all directions. Each surface has a different reflection index: the ceiling and skylight have an index of 0.9, the walls 0.7, and the floor 0.5, normal values in the design of interiors.

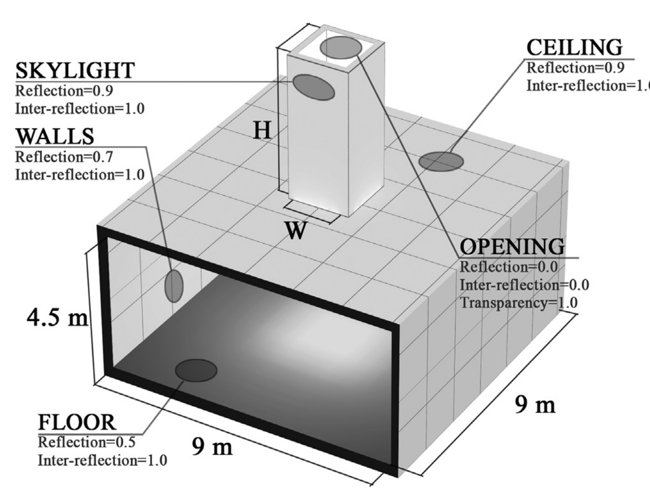



**Fig. 1.** Initial calculation model.

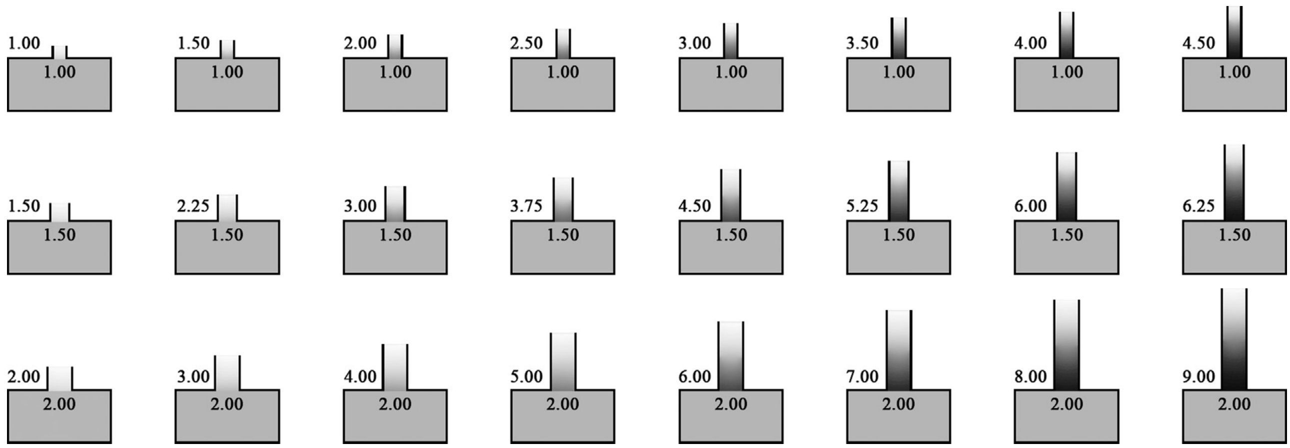



**Fig. 2.** Trial 1: variation in size and height/width ratio of the lightwell skylights.

## 3. Calculation

### 3.1. Trial 1: size and ratio of the lightwell skylight

The first trial analyzed the performance of a lightwell skylight, considering variations in size and the height/width ratio of the reflector. In order to carry out this first study, three skylight models were established, according to the base measurements:

- M1: lightwell skylight with 1.00 m × 1.00 m base and variable height.
- M1.5: lightwell skylight with 1.50 m × 1.50 m base and variable height.
- M2: lightwell skylight with 2.00 m × 2.00 m base and variable height.

Eight skylights of different heights were measured according to the base of each model. The height of the skylights varied between 1 and 4.5 times the width of the base (Fig. 2).

From Fig. 2, it is deduced that models M1, M1.5 and M2 are proportional to each other, thus helping us assess the variations in illuminance caused by the size and height/width ratio of the lightwell. A total of 24 simulations were carried out for this test.

Table 2 shows the maximum, average and minimum daylight factors on the work plane for each calculation model under the conditions described in the methodology and the variation in size and ratio of the skylight.

As can be observed in Table 2, the daylight factors measured on the work plane decrease as the height of the lightwell increases. Considering the calculation model used, where the reflection index of the skylight is 0.9, it is deduced that daylight factors decrease in inverse proportion to the height of the lightwell. This behavior can also be seen in Fig. 3, which shows the average daylight factors measured using the simulation program and those defined following the hypothesis that the results obtained are inversely proportional to the height of the lightwell. The mean value of the daylight factors is considered as a starting point to establish the hypothesis and the remaining values are determined according to the height/width ratio for each skylight.

As can be deduced from Fig. 3, considering the calculation model conditions, the hypothesis that average daylight factors are inversely proportional to the height of the lightwell provides results similar to those of the simulation program, with an average relative difference of 9.47%. The margin of error of the simulation program results and the hypothesis proposed increases as the height of the skylight increases and decreases as the height decreases.

The hypothesis proposed makes it possible to calculate the relative variation in lighting in a room as a result of the modification in height of lightwell skylights.

From Table 2, it is also possible to deduce that daylight factors are almost directly proportional to the size of the skylight. This can be seen when comparing lightwells of equal height/width ratio but different size, so that with identical ratios, model M1.5, which is 1.5 m wide produces daylight factors almost 1.5 times those measured for model M1, which is 1 m wide. An equivalent observation can be made for model M2, which is 2 m wide and produces approximately double the daylight factors measured in model M1. Thus, it can be deduced that the quotient of daylight factors and the surface base of the skylight is practically invariable, providing the height/width ratio remains constant.

**Table 2**
Trial 1: maximum, average and minimum daylight factors on the work plane. Variable size and ratio of the skylight.

| Trial 1: size and ratio | | | |
|---|---|---|---|
| Skylight height | Daylight factor | | |
| | Max (%) | Ave (%) | Min (%) |
| Lightwell skylight base of 1 × 1 (M1) | | | |
| 1.00 | 1.95 | 0.59 | 0.17 |
| 1.50 | 1.65 | 0.42 | 0.12 |
| 2.00 | 1.44 | 0.33 | 0.09 |
| 2.50 | 1.24 | 0.25 | 0.07 |
| 3.00 | 1.07 | 0.20 | 0.06 |
| 3.50 | 0.94 | 0.16 | 0.04 |
| 4.00 | 0.82 | 0.13 | 0.03 |
| 4.50 | 0.72 | 0.10 | 0.02 |
| Lightwell skylight base of 1.5 × 1.5 (M1.5) | | | |
| 1.50 | 3.93 | 1.36 | 0.39 |
| 2.25 | 3.27 | 1.00 | 0.28 |
| 3.00 | 2.71 | 0.78 | 0.21 |
| 3.75 | 2.30 | 0.59 | 0.17 |
| 4.50 | 1.93 | 0.47 | 0.13 |
| 5.25 | 1.63 | 0.37 | 0.10 |
| 6.00 | 1.39 | 0.30 | 0.08 |
| 6.75 | 1.19 | 0.23 | 0.06 |
| Lightwell skylight base of 2 × 2 (M2) | | | |
| 2.00 | 6.38 | 2.49 | 0.71 |
| 3.00 | 5.11 | 1.81 | 0.52 |
| 4.00 | 4.20 | 1.41 | 0.39 |
| 5.00 | 3.44 | 1.07 | 0.30 |
| 6.00 | 2.84 | 0.86 | 0.23 |
| 7.00 | 2.38 | 0.67 | 0.18 |
| 8.00 | 1.98 | 0.54 | 0.14 |
| 9.00 | 1.66 | 0.41 | 0.11 |

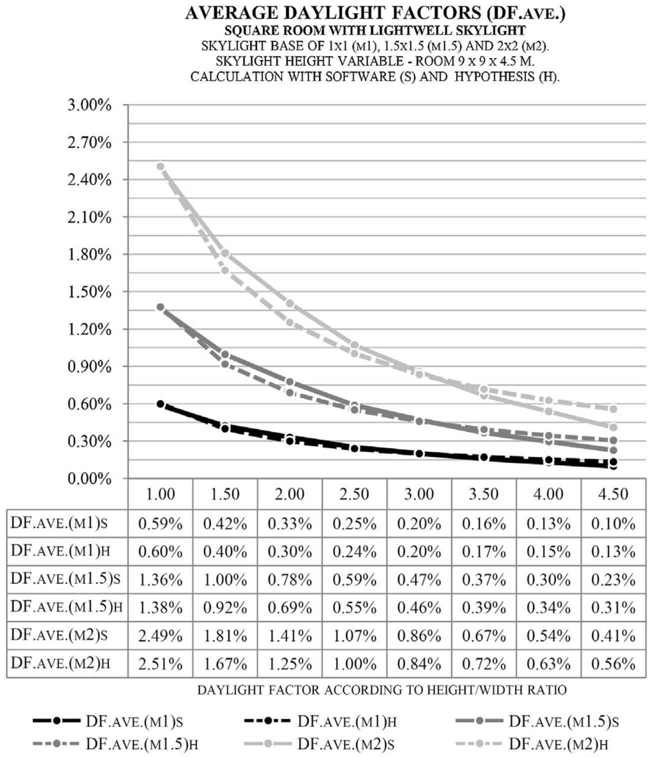



**Fig. 3.** Trial 1: average daylight factors (DF.ave.) on the work plane according to simulation software (S) and hypothesis (H). Variable size and ratio of the skylight.

Fig. 4 shows the relative difference for models M1.5 and M2 compared to model M1, considering the daylight factors and the surface base of the skylight.

As can be observed in Fig. 4, the relative difference for models M1.5 and M2 with respect to model M1 has a maximum value of 7.25% and an average of 4.72%. Thus, it can be stated that the daylight factors produced by a lightwell skylight are almost directly proportional to size. This statement allows us to calculate the relative variation in daylight for a room, caused by the modification of the size of the lightwell skylight.

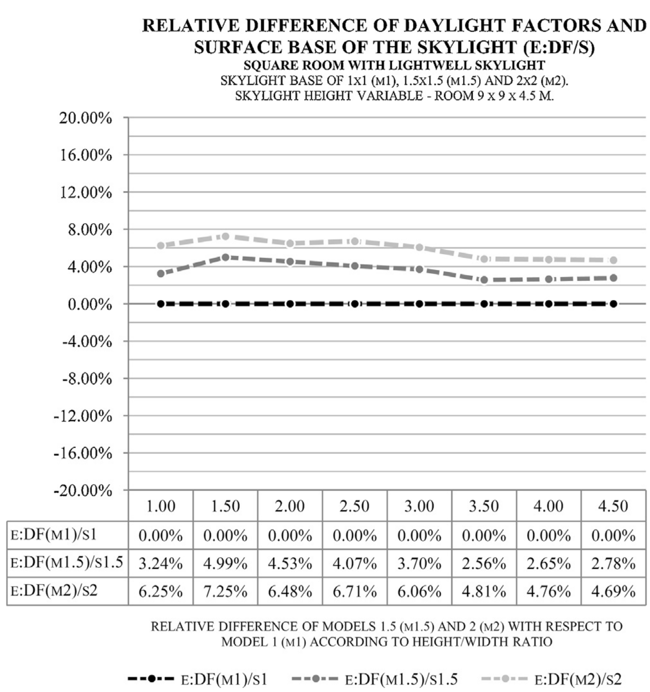



**Fig. 4.** Trial 1: relative difference of the quotient of average daylight factors on the work plane and the surface base of the skylight, according to simulation software. Models 1.5 (M1.5) and 2 (M2) with respect to model 1 (M1). Variable size and ratio of the skylight.

**Table 3**
Trial 2: maximum, average and minimum daylight factors on the work plane. Variable reflection index of the skylight.

| Trial 2: skylight reflection | | | |
|---|---|---|---|
| Skylight height | Daylight factor | | |
| | Max (%) | Ave (%) | Min (%) |
| Lightwell skylight reflection of 0.7 (R0.7) | | | |
| 1.50 | 3.48 | 1.09 | 0.28 |
| 2.25 | 2.73 | 0.72 | 0.17 |
| 3.00 | 2.15 | 0.48 | 0.12 |
| 3.75 | 1.74 | 0.34 | 0.08 |
| 4.50 | 1.42 | 0.24 | 0.06 |
| 5.25 | 1.17 | 0.18 | 0.04 |
| 6.00 | 0.98 | 0.13 | 0.02 |
| 6.75 | 0.83 | 0.10 | 0.02 |
| Lightwell skylight reflection of 0.5 (R0.5) | | | |
| 1.50 | 3.20 | 0.92 | 0.21 |
| 2.25 | 2.44 | 0.56 | 0.12 |
| 3.00 | 1.90 | 0.36 | 0.07 |
| 3.75 | 1.52 | 0.24 | 0.05 |
| 4.50 | 1.24 | 0.17 | 0.03 |
| 5.25 | 1.02 | 0.12 | 0.02 |
| 6.00 | 0.86 | 0.09 | 0.02 |
| 6.75 | 0.74 | 0.07 | 0.01 |
| Lightwell skylight reflection of 0.3 (R0.3) | | | |
| 1.50 | 3.00 | 0.76 | 0.16 |
| 2.25 | 2.27 | 0.45 | 0.09 |
| 3.00 | 1.76 | 0.28 | 0.06 |
| 3.75 | 1.41 | 0.19 | 0.04 |
| 4.50 | 1.16 | 0.13 | 0.02 |
| 5.25 | 0.96 | 0.09 | 0.02 |
| 6.00 | 0.81 | 0.07 | 0.01 |
| 6.75 | 0.70 | 0.06 | 0.01 |

### 3.2. *Trial 2: reflection index of the lightwell skylight*

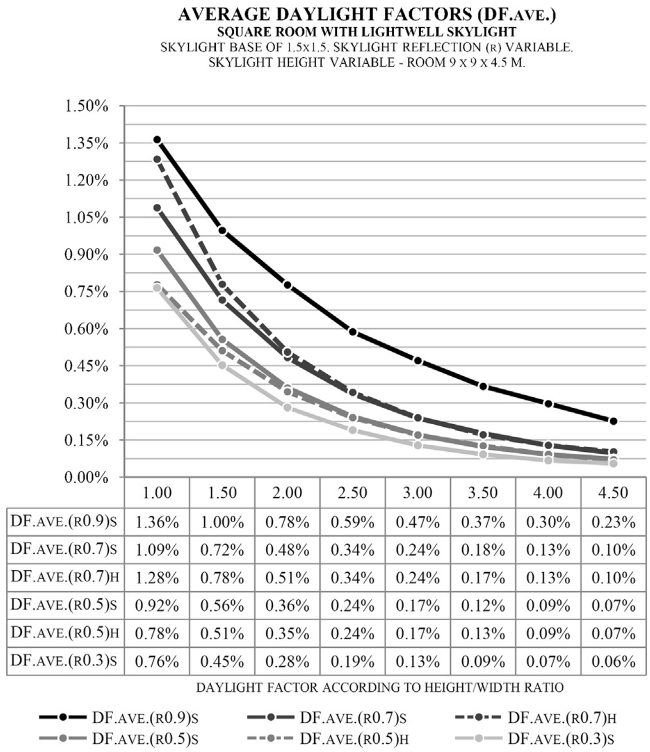
The second trial analyzed the performance of a lightwell skylight, considering the variation of the reflection index of its surfaces. For this study, skylight model M1.5 was used for the room described in the calculation model.

Eight skylight models of varying heights were analyzed. The height of the skylight varied between 1 and 4.5 times the width of the base (Fig. 2). Thus, a skylight measuring 1.5 m × 1.5 m and with a height varying between 1.5 and 6.75 m was used. The reflection index of the skylight varied between 0.3 and 0.9. A total of 24 simulations were carried out in this trial, complementing the previous one, which simulated a skylight with a reflection index of 0.9.

Table 3 shows the maximum, average and minimum daylight factors on the work plane for each calculation model under the conditions described in the methodology and with a variation in the height and reflection index of the skylight.

As was concluded in the previous trial, the daylight factors on the work plane decrease proportionally as the height of the skylight increases, although this tendency is more noticeable when the reflection index is lower.

As can be observed in Table 3, the average daylight factors obtained on the work plane vary considerably depending on the reflection index of the skylight, and the difference can be noticed mainly in the higher lightwells. Specifically, if the lightwell is high enough, the skylight with a reflection index of 0.7 produces an increase of around 30% in comparison with the skylight with an index of 0.5 which produces a similar increase over the skylight




| | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 |
|---|---|---|---|---|---|---|---|---|
| DF.AVE.(R0.9)S | 1.36% | 1.00% | 0.78% | 0.59% | 0.47% | 0.37% | 0.30% | 0.23% |
| DF.AVE.(R0.7)S | 1.09% | 0.72% | 0.48% | 0.34% | 0.24% | 0.18% | 0.13% | 0.10% |
| DF.AVE.(R0.7)H | 1.28% | 0.78% | 0.51% | 0.34% | 0.24% | 0.17% | 0.13% | 0.10% |
| DF.AVE.(R0.5)S | 0.92% | 0.56% | 0.36% | 0.24% | 0.17% | 0.12% | 0.09% | 0.07% |
| DF.AVE.(R0.5)H | 0.78% | 0.51% | 0.35% | 0.24% | 0.17% | 0.13% | 0.09% | 0.07% |
| DF.AVE.(R0.3)S | 0.76% | 0.45% | 0.28% | 0.19% | 0.13% | 0.09% | 0.07% | 0.06% |

**Fig. 5.** Trial 2: average daylight factors (DF.ave.) on the work plane according to simulation software (S) and hypothesis (H). Variable reflection index and height of the skylight.

with an index of 0.3. These increases become much more noticeable the higher the skylight is, as there is a larger surface for reflection. These observations show that despite the high performance of lightwell skylights, their reflection index is a determining factor for an efficient use of lighting, particularly in the case of lightwells with a high height/width ratio.

Disregarding the daylight factors observed in extreme cases where the reflection index of the lightwell is below 0.3 or above 0.9, it can be deduced that the average daylight factors are almost directly proportional to the skylight reflection, providing the lightwell is high enough to reflect daylight. The lower the skylight, the lower the influence of the reflection index on the resulting daylight factors, as the reflection surface is smaller and therefore less of a determining factor in generating the reflected component.

As is represented in Fig. 5, considering a height/width ratio of the skylight over 2.00, in cases where the reflection index of the lightwell is between 0.5 and 0.7, average daylight factors are almost directly proportional to this index.

As can be deduced from Fig. 5, the hypothesis that daylight factors are directly proportional to the reflection index of the lightwell is true for skylights with a height/width ratio over 2.00, where the index is between 0.5 and 0.7, with an average relative difference of 2.53%.

As can be deduced from Table 3, the lower the lightwell, the lower the influence of the reflection index as a determining factor, meaning that the daylight factors tend to converge when the skylight has a smaller surface area, that is to say, when the height/width ratio tends towards 0 and does not comply with the proportionality between reflection indexes, as can be observed in Fig. 5.

### 3.3. Trial 3: room ratio

The third trial analyzed the performance of lightwell skylights, considering the variation in measurements of the room. The aim of this was to generalize the conclusions obtained in the previous trials and observe the lighting performance in higher rooms. Skylight model M1.5 was used to carry out this study on two types of rooms:

- Square room measuring 9.00 m × 9.00 m and variable height.
- Rectangular room measuring 12.00 m × 6.00 m and variable height.

**Table 4**
Trial 3: average daylight factors on the work plane. Variable room and skylight height.

| Trial 3: room ratio | | | |
|---|---|---|---|
| Skylight height | Average daylight factor according to room height | | |
| | 4.50 | 6.00 | 7.50 |
| Lightwell skylight room floor of 9 m × 9 m | | | |
| 1.50 | 1.36 | 1.12 | 0.96 |
| 2.25 | 1.00 | 0.92 | 0.79 |
| 3.00 | 0.77 | 0.64 | 0.58 |
| 3.75 | 0.59 | 0.57 | 0.50 |
| 4.50 | 0.47 | 0.46 | 0.40 |
| 5.25 | 0.37 | 0.32 | 0.29 |
| 6.00 | 0.29 | 0.27 | 0.23 |
| 6.75 | 0.23 | 0.21 | 0.20 |
| Lightwell skylight room floor of 12 m × 6 m | | | |
| 1.50 | 1.42 | 1.16 | 0.97 |
| 2.25 | 1.05 | 0.98 | 0.81 |
| 3.00 | 0.81 | 0.68 | 0.61 |
| 3.75 | 0.62 | 0.59 | 0.50 |
| 4.50 | 0.50 | 0.46 | 0.41 |
| 5.25 | 0.39 | 0.34 | 0.29 |
| 6.00 | 0.31 | 0.28 | 0.24 |
| 6.75 | 0.23 | 0.21 | 0.20 |

The rooms were designed so that the floorplan perimeters were the same and interior surfaces were similar for rooms of the same height.

The height of the rooms varied between 4.5 and 7.5 m. Eight skylights of variable height were analyzed for each floorplan model. The height of the skylights varied between 1 and 4.5 times the width of their base. A total of 40 simulations were carried out in this study, complementing the results of the first study, which simulated the initial calculation model.

Table 4 shows the average daylight factors on the work plane for each calculation model under the conditions described in the methodology and the variations in room and skylight height.

As can be observed in Table 4, for a same room height, the average daylight factors are very similar for different floor measurements, resulting in an average relative difference of 3.45%. Therefore, the conclusions obtained in trials 1 and 2 can be seen as general for similar room shapes.

From Table 4 it can also be deduced that considering skylights with a very high height/width ratio, the average daylight factors do not decrease much as room height increases. This effect is due to the fact that the main characteristic of the lightwell skylight is that it mainly projects daylight on the horizontal plane, neglecting the walls. If the skylight is high, the projection of the daylight is more focused, meaning that the difference of the average daylight factors between rooms of different heights is lower when using lightwells with a very high height/width ratio.

### 3.4. Trial 4: lightwell spacing

The distribution of the light within a room makes it possible to determine the spacing between skylights to ensure homogeneous illuminance on the work plane. Accordingly, a new study was carried out, analyzing different layouts for lightwells in the same room, in order to establish the correct distance at which they should be placed.

For this trial we considered a room that was 12 m long, 6 m wide and 4.5 m high. The lightwell skylights were 1 m long and 2 m high. The lightwell skylights were as wide as the room so that the illuminance distribution was noticeable on the walls.

Unlike in earlier trials, the interior surfaces of the room had zero reflection value, meaning that only the sky component was assessed. As a result, the internally and externally reflected components were not included in the calculation. It should be noted that

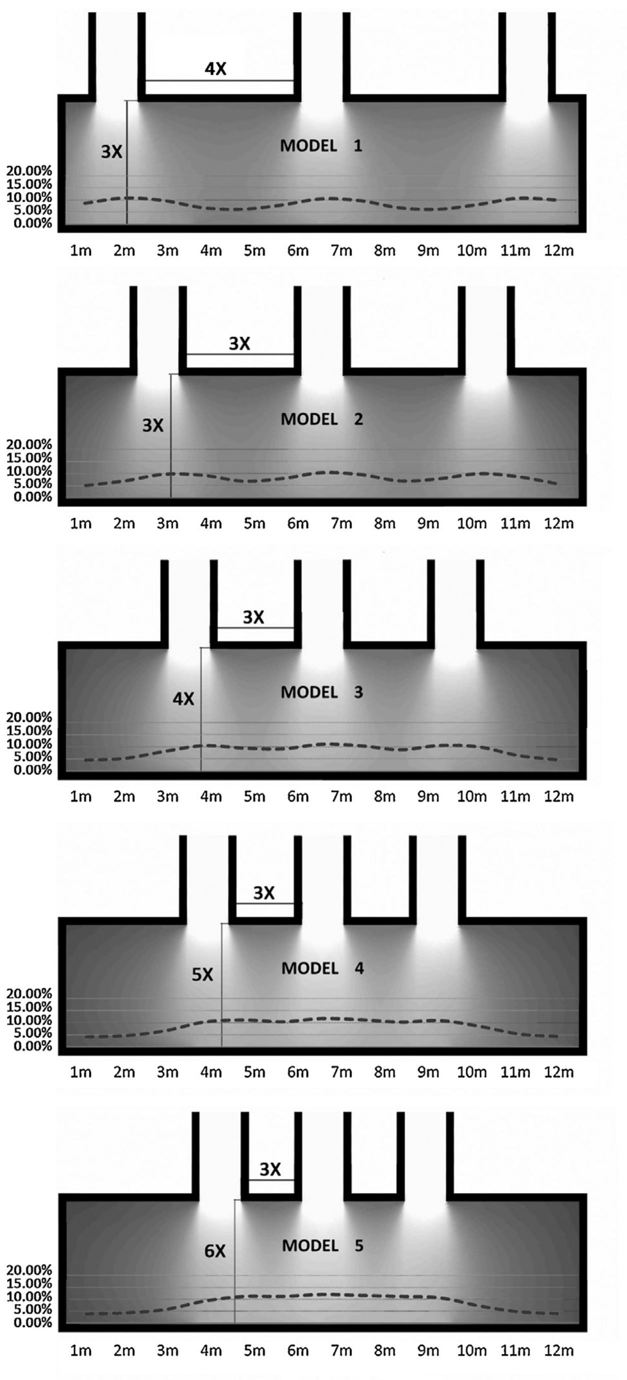



**Fig. 6.** Trial 4: daylight factors within a room in overcast sky conditions with lightwell skylights with a height/width ratio of 2/1. Variable spacing of the lightwells.

**Table 5**
Trial 4: daylight factors on the work plane, according to measuring distance and skylight spacing between room height.

| Trial 4: skylight spacing | | | | | |
|---|---|---|---|---|---|
| Measuring distance | Daylight factor according to skylight spacing/room height | | | | |
| | 4/3 | 3/3 | 3/4 | 3/5 | 3/6 |
| Lightwell Skylight 1 m × 6 m × 2 m | | | | | |
| 1.00 | 10.56 | 6.19 | 5.44 | 5.03 | 4.68 |
| 2.00 | 13.18 | 8.52 | 6.38 | 5.66 | 5.15 |
| 3.00 | 11.93 | 11.86 | 9.86 | 8.13 | 6.87 |
| 4.00 | 8.32 | 11.30 | 12.77 | 12.54 | 11.26 |
| 5.00 | 7.55 | 8.38 | 11.56 | 13.56 | 13.68 |
| 6.00 | 9.67 | 9.69 | 11.13 | 12.69 | 13.70 |
| 7.00 | 12.74 | 12.63 | 13.49 | 14.29 | 14.70 |
| 8.00 | 11.84 | 11.64 | 12.69 | 13.65 | 14.19 |
| 9.00 | 8.26 | 8.48 | 10.71 | 12.53 | 13.67 |
| 10.00 | 7.59 | 9.63 | 12.87 | 13.24 | 12.91 |
| 11.00 | 9.97 | 12.13 | 12.11 | 10.33 | 8.70 |
| 12.00 | 13.07 | 10.57 | 7.75 | 6.48 | 5.72 |

if inter-reflection were considered, the spacing between lightwells would be greater.

Five simulations were carried out with different spacings between skylights. The spacing between the lightwells is proportional to the height of the room (Fig. 6). The daylight factors were analyzed on the floor plan and represented in the room section.

The daylight factors measured in the longitudinal axis of symmetry of the room are observed in Table 5.

After determining the illuminance resulting from the different spacings between skylights, an assessment was carried out of the uniformity of the illuminance on the work plane in each trial. To do so, attention was paid to the quotient resulting from the minimum and maximum value of illuminance in the range of influence of the series of skylights. This range considered the illuminance at points located between the 4 and 9 m marks in the length of the room, as the ends of the room fell outside the influence of the skylights.

As was observed in Fig. 7, the highest coefficient of uniformity corresponded to the spacing between the lightwells for a room with a skylight spacing/room height ratio of 3/6. It was also observed that

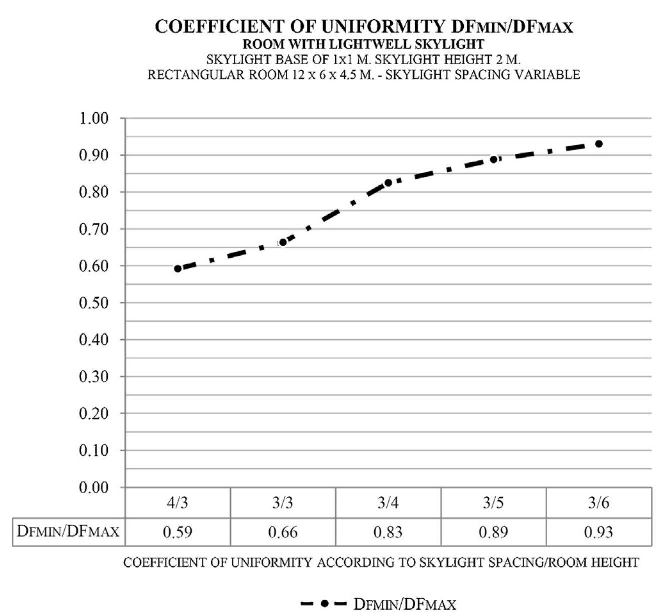



**Fig. 7.** Trial 4: coefficient of uniformity: quotient of the minimum daylight factor divided by the maximum on the work plane, with room length ranging between 4 and 9 m.

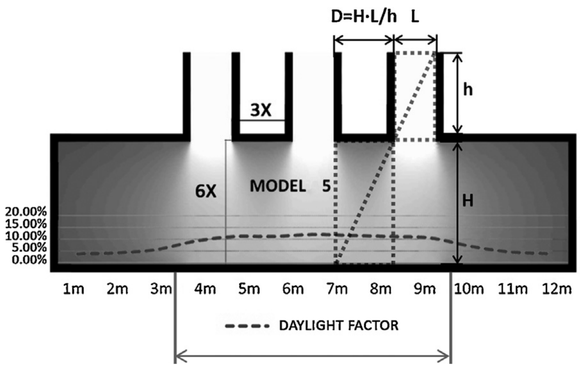



**Fig. 8.** Trial 4: skylight spacing according to width/height ratio of the lightwell.

the skylights with a greater distance between each other cause a non-uniform distribution while those closer together provide an acceptable distribution of illuminance.

It should be noted that the skylight spacing/room height ratio which produces the greatest uniformity is identical to the width/height ratio of the lightwell. Thus, it is concluded that the optimum skylight spacing, producing the greatest illuminance uniformity, is directly proportional to the width/height ratio of the lightwell in the absence of a reflected component (Fig. 8).

## 4. Conclusion

In accordance with the results of the studies carried out under overcast sky conditions, the illuminance produced by lightwell skylights is practically inversely proportional to the height of the reflectors, if the lightwells have high reflection indexes. Under identical conditions it can also be observed that the illuminance generated by a lightwell skylight is almost directly proportional to its size, so that conserving a height/width ratio, a skylight double the size produces approximately double the illuminance. This conclusion supports the statements by Lam [3] on the usefulness of this type of skylight when the height/width ratio is not very high. The results obtained are in line with those of the research by Kristl and Krainer [5], where daylight factors are seen to decrease on the lower floors of residential buildings.

As can be deduced from trial 2, the reflection index of the lightwell skylight is a determining factor in the illuminance measured in the interior of a room. Specifically, the skylight with a reflection index of 0.7 produces an increase in illuminance of over 30% compared to the skylight with an index of 0.5 which produces a similar increase compared to the skylight with an index of 0.3. From this trial it can also be deduced that in cases where the reflection index of the skylight is between 0.5 and 0.7, considering a height/width ratio of the lightwell greater than 2, the daylight factors are almost proportional to the reflection index. This statement is coherent with the studies by Bouchet and Fontoynont [4], which establish empirical functions in agreement with the statements made regarding skylight performance depending on the reflection index.

Since the lightwell skylight projects daylight mainly on the floor, horizontal illuminance barely varies as the height of the room varies. The higher the skylight the more focused the projection of the daylight, so the difference of the average daylight factors between rooms with different heights is even smaller.

It is finally concluded that the optimum skylight spacing, which produces the greatest uniformity of illuminance, is proportional to the width/height ratio of the lightwell in the absence of a reflected component. As the reflection index of the skylight increases, the spacing between openings can be greater without its affecting the uniformity of the daylight.

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