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## A Design Chart to Determine the Well Efficiency and the Maximum Spacing of Skylights for Daylighting as a Function of the Skylight Well Width

To cite this article: Shady Shawky Saifelnasr 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **397** 012025

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# A Design Chart to Determine the Well Efficiency and the Maximum Spacing of Skylights for Daylighting as a Function of the Skylight Well Width

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**Abstract.** The main objective of this paper is to introduce a simple tool for architects, represented by a design chart to find out the skylight well efficiency (WE) and the maximum skylight spacing (x), needed when utilizing top-lighting for daylighting as a function of the skylight well width (w). That would lead to suitable geometry and spacing of skylights inside a given space which directly affects the distribution of daylight, leading to better quality of light. The proposed design chart is used to find the skylight well efficiency (WE) and the maximum skylight spacing (x) of patterned skylights needed for ensuring proper admission and distribution of diffused light, i.e. quantity and quality of daylight. It consists of two parts and both parts consist of a number of graphs combined together, representing the different included variables that affect either the skylight well efficiency (WE), or the maximum skylight spacing (x) with a given skylight well width (w). Those graphs were developed by the author using different formulas except one graph that was previously designed and has been adapted by the author to be combined with the other graphs.

**Keywords:** *Design Charts, Skylights, Daylighting*

## 1. Introduction

Daylighting design involves providing spaces at the perimeter or at the core of the building with the suitable quantity and quality of daylight. A number of daylight media could be used for permitting daylight; windows for side-lighting and skylights for top-lighting [1]. One of the main problems of skylights that they permit more light and heat in summer than in winter which is not actually what is required [2]. Anyways, skylights could be used for daylighting the core of buildings with deep masses. Also, they could be used to permit higher amounts of daylight within locations with overcast skies, where the amount of daylight at the zenith is higher than at the horizon [3]. Skylights might have a number of functions or applications, e.g., ventilation, etc., but daylighting might be one of the most important reasons for the sizing of these skylights.

## Nomenclature

DF	daylight factor [%]	w	skylight well width [m]
H	ceiling height [m]	WE	skylight well efficiency [%]
h	skylight well height [m]	WI	skylight well index [1]
l	skylight well length [m]	WR	skylight well wall reflectance [%]
s	skylight splay width [m]	x	maximum skylight spacing [m]



## 2. Main Objective and Hypothesis

The main objective of this paper is to introduce a simple tool for architects, represented by a design chart to find out the skylight well efficiency (WE) and the maximum skylight spacing (x), needed when utilizing top-lighting for daylighting as a function of the skylight well width (w). That would lead to suitable geometry and spacing of skylights inside a given space which directly affects the distribution of daylight, leading to better quality of light.

The main hypothesis of this paper is the possibility of using a quick rule-of-thumb to find out some parameters related to skylights; the skylight well efficiency (WE) and the maximum skylight spacing (x). This could be done by the use of the proposed design chart that includes five graphs signifying most of the different variables that affect those required parameters.

## 3. Methodology

In a previous paper, the author carried out “A Design Chart to Determine the Sizing of Vertical Windows for Daylighting” and as a response to the proposed future research in that paper, the author used the same methodology for finding out the variables of other daylight media such as the skylights. The proposed design chart is used to find out the skylight well efficiency (WE) and the maximum skylight spacing (x).

To carry out that design chart, the scope and limitations of the paper, associated with the calculation method and the considered simplifications and assumptions are shown as follows.

### 3.1. Scope and Limitations

The paper mainly focuses on finding out the skylight well efficiency (WE) and the maximum skylight spacing (x). This is done using a simple method represented in the proposed design chart that consists of a number of graphs combined together, representing the different included variables.

The paper does not concern about a number of aspects or variables or parameters, which in turn could be addressed in future researches, such as the amount of daylight permitted through those skylights of given dimensions.

### 3.2. Used Calculation Methods

The proposed design chart; the first part and the second part are mainly derived from the following formulas; one [4] and two [5] respectively.

$$WI = \frac{h \times (w + l)}{2 \times w \times l}$$

$$x \leq (1.4 \times H) + (2 \times s) + w$$

### 3.3. Simplifications and Assumptions

Some simplifications and assumptions are considered in the first part and second part of the proposed design chart concerning the effect of the different included variables and its applicability.

**3.3.1. Range of the Different Included Variables.** The different graphs of the proposed design chart involves different variables with different ranges that were selected to be applicable for small, medium and large spaces of ceiling height up to 6.0 m; skylight well width (w) ranging from 0.6 m till 6.0 m, skylight well length (l), ranging from 0.6 m till 6.0 m, skylight well height (h), ranging from 0.6 m till 6.0 m, skylight well index ranging from 0.0 till 3.0, skylight well wall reflectance (WR), ranging from 40% till 90%, skylight well efficiency (WE), ranging from 0% till 100%, ceiling height (H), ranging from 0.6 m till 6.0 m, skylight splay width (s), ranging from 0.0 m till 3.0 m, and maximum skylight spacing, ranging from 0.0 m till 10.0 m.

**3.3.2. Applicability of the Design Chart.** The design chart is applicable for small, medium and large spaces of maximum ceiling height = 6.0 m. Those spaces are utilizing top-lighting by means of a single skylight or patterned skylights. Since a number of formulas are utilized to design the different graphs in the proposed design chart, it is mainly applicable for locations with overcast skies. It could be also used for locations with clear skies based on the assumption that the direct sunlight is totally blocked by any means.

#### 4. Results

The proposed design chart is used to find the skylight well efficiency (WE) and the maximum skylight spacing ( $x$ ) of patterned skylights needed for ensuring proper admission and distribution of diffused light, i.e. quantity and quality of daylight. It consists of two parts; the first part and the second part as shown in Fig. 1 and Fig. 2 respectively. Both parts consist of a number of graphs combined together, representing the different included variables that affect either the skylight well efficiency (WE), or the maximum skylight spacing ( $x$ ) with a given skylight well width ( $w$ ). Those graphs were developed by the author using different formulas except one graph that was previously designed and has been adapted by the author to be combined with the other graphs as will be shown in their following description.

##### 4.1. Description of the First Part of the Design Chart

The first part of the design chart shown in Fig. 1 is used in an anticlockwise direction to find the skylight well efficiency (WE), knowing the skylight well width ( $w$ ). It consists of three graphs; the first graph at the top right, the second graph at the top left and the third graph at the bottom left. The third graph is a previously designed chart that has been adapted by the author to be combined with the other two graphs. Both of the first and second graphs are derived from the following formula [4].

$$WI = \frac{h \times (w + l)}{2 \times w \times l}$$

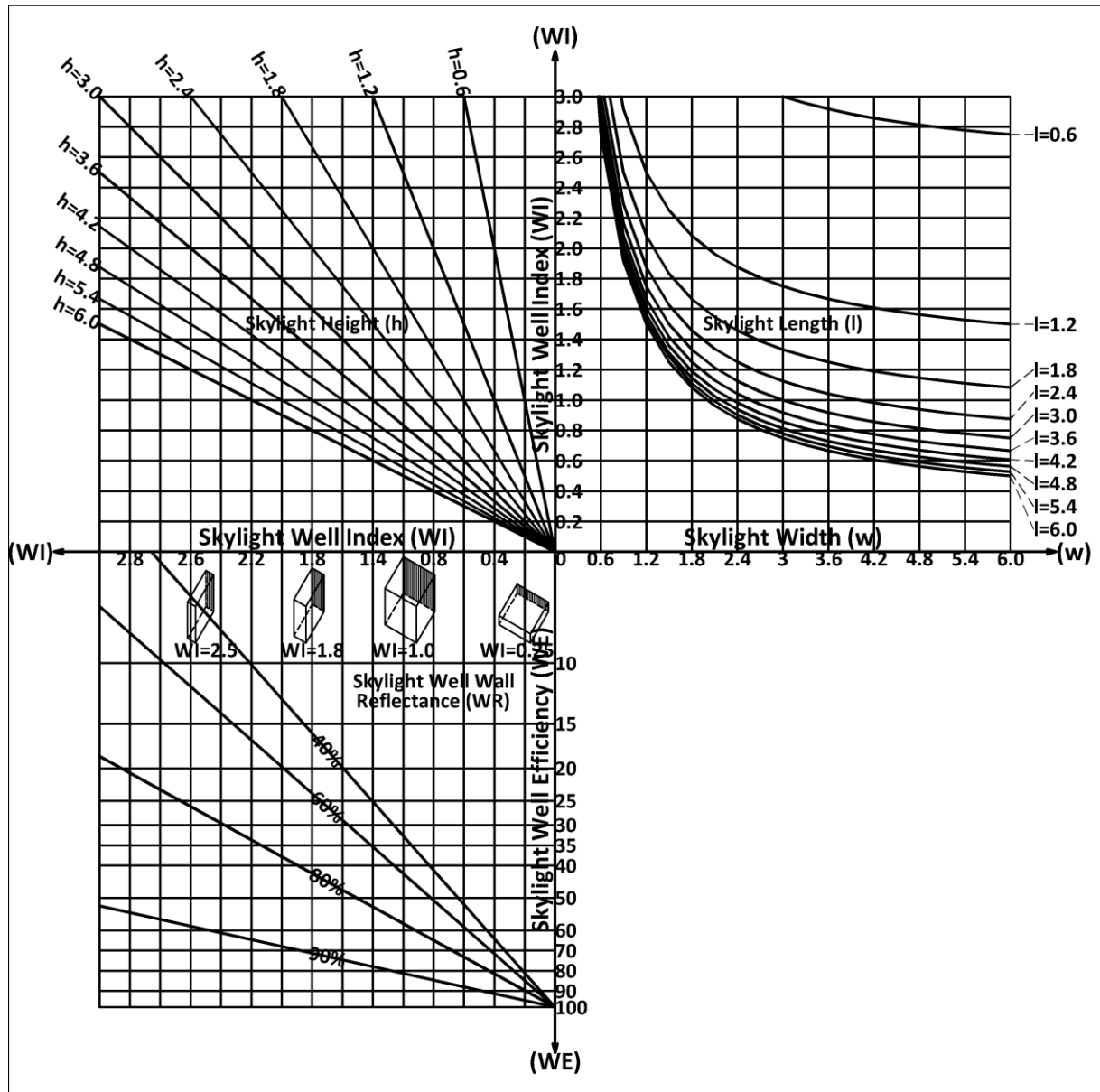


Fig. 1. The first part of the design chart to find the skylight well efficiency (WE), knowing the skylight well width (w) (Source: the author).

The first graph (at the top right) finds the skylight well index  $(WI)_{firstgraph}$ . The obtained value of the skylight well index  $(WI)_{firstgraph}$  is a function of the skylight well width ( $w$ ) and the skylight well length ( $l$ ), while maintaining the skylight well height ( $h$ ) = 3.0 m, and it is drawn using the following formula:

$$\begin{aligned}(WI)_{firstgraph} &= \frac{h \times (w + l)}{2 \times w \times l} \\ &= \frac{3.0 \times (w + l)}{2 \times w \times l} \\ &= 1.5 \times \left( \frac{1}{w} + \frac{1}{l} \right)\end{aligned}$$

It consists of two axes and ten curves; the horizontal axis represents the skylight well width ( $w$ ), ranging from 0.6 m till 6.0 m, while the vertical axis represents the skylight well index  $(WI)_{firstgraph}$ , ranging from 0.0 till 3.0. That skylight well index  $(WI)_{firstgraph}$  on the vertical axis is obtained after intersecting one of the ten curves that represent the skylight well length ( $l$ ), ranging from 0.6 m till 6.0m.

The second graph (at the top left) finds the skylight well index ( $WI$ ). The obtained value of the skylight well index ( $WI$ ) is a function of all the dimensions of the skylight well; width ( $w$ ), length ( $l$ ) and height ( $h$ ), which must be expressed using the same units [6], and it is drawn using the following formula:

$$WI = (WI)_{firstgraph} \times \frac{h}{3}$$

It consists of two axes and ten diagonal lines; the vertical axis represents the skylight well index  $(WI)_{firstgraph}$  obtained from the first graph (at the top right), while the horizontal axis represents the skylight well index ( $WI$ ), ranging from 0.0 till 3.0. That skylight well index ( $WI$ ) on the horizontal axis is obtained after intersecting one of the ten diagonal lines that represent the skylight well height ( $h$ ), ranging from 0.6 m till 6.0 m.

The third graph (at the bottom left) is a previously designed chart [5] that has been adapted by the author to be combined with the other two graphs. It finds the skylight well efficiency ( $WE$ ). The obtained value of the skylight well efficiency ( $WE$ ) is a function of the skylight well index ( $WI$ ), i.e., all the dimensions of the skylight well, and the skylight well wall reflectance ( $WR$ ).

It consists of two axes and four diagonal lines; the horizontal axis represents the skylight well index ( $WI$ ) obtained from the second graph (at the top left), while the vertical axis represents the skylight well efficiency ( $WE$ ), ranging from 0% till 100%. That skylight well efficiency ( $WE$ ) on the vertical axis is obtained after intersecting one of the four diagonal lines that represent the skylight well wall reflectance ( $WR$ ), ranging from 40% till 90%.

#### 4.2. Using the First Part of the Design Chart

To find the skylight well efficiency ( $WE$ ), all three graphs of the first part of the design chart are used as follows.

Enter the first graph (at the top right) by specifying the skylight well width ( $w$ ) on the horizontal axis. Draw a vertical construction line upwards till it intersects one of the ten curves representing the skylight well length ( $l$ ). From the point of intersection, extend a horizontal construction line to the left till it intersects one of the ten diagonal lines representing the skylight well height ( $h$ ). From the point of intersection, extend a vertical construction line downwards till it intersects one of the four diagonal lines representing the skylight well wall reflectance ( $WR$ ). From the point of intersection, draw a horizontal construction line to the right till the skylight well efficiency ( $WE$ ) is found on the vertical axis.

To calculate the revised daylight factor  $(DF)_{revised}$ , multiply the available daylight factor ( $DF$ ) by the obtained skylight well efficiency ( $WE$ ).

$$(DF)_{revised} = DF \times WE$$

4.3. Description of the Second Part of the Design Chart

The second part of the design chart shown in Fig. 2 is used in an anticlockwise direction to find the maximum center-to-center skylight spacing (x), knowing the skylight well width (w). It consists of two graphs; the first graph at the right, the second graph at the left. Both graphs are derived from the following formula [5].

$$x \leq (1.4 \times H) + (2 \times s) + w$$

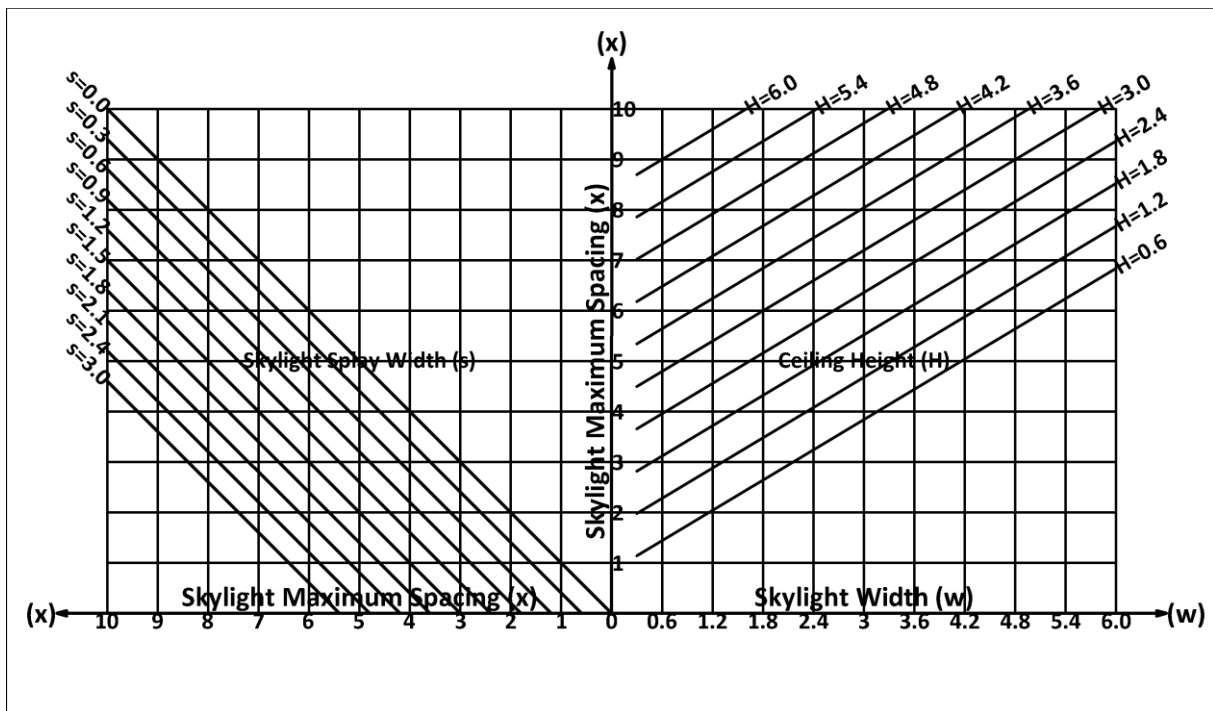


Fig. 2. The second part of the design chart to find the maximum skylight spacing (x), knowing the skylight well width (w) (Source: the author).

The first graph (at the right) finds the maximum skylight spacing  $(x)_{\text{firstgraph}}$  without splay. The obtained value of the maximum skylight spacing  $(x)_{\text{firstgraph}}$  is a function of the skylight well width ( $w$ ) and the ceiling height ( $H$ ), while maintaining the skylight splay width ( $s$ ) = 0.0 m, and it is drawn using the following formula.

$$\begin{aligned}(x)_{\text{firstgraph}} &= (1.4 \times H) + (2 \times s) + w \\ &= (1.4 \times H) + (2 \times 0) + w \\ &= (1.4 \times H) + w\end{aligned}$$

It consists of two axes and ten diagonal lines; the horizontal axis represents the skylight well width ( $w$ ), ranging from 0.6 m till 6.0 m, while the vertical axis represents the maximum skylight spacing  $(x)_{\text{firstgraph}}$ , ranging from 0.0 m till 10.0 m. That maximum skylight spacing  $(x)_{\text{firstgraph}}$  on the vertical axis is obtained after intersecting one of the ten diagonal lines that represent the ceiling height ( $H$ ), ranging from 0.6 m till 6.0 m.

The second graph (at the left) finds the maximum skylight spacing ( $x$ ) with splay. The obtained value of the maximum skylight spacing ( $x$ ) is a function of the skylight well width ( $w$ ), the ceiling height ( $H$ ) and the skylight splay width ( $s$ ), and it is drawn using the following formula:

$$x = (x)_{\text{firstgraph}} + s$$

It consists of two axes and ten diagonal lines; the vertical axis represents the maximum skylight spacing  $(x)_{\text{firstgraph}}$  obtained from the first graph (at the right), while the horizontal axis represents the maximum skylight spacing ( $x$ ), ranging from 0.0 m till 10.0 m. That maximum skylight spacing ( $x$ ) on the horizontal axis is obtained after intersecting one of the ten diagonal lines that represent the skylight splay width ( $s$ ), ranging from 0.0 m till 3.0 m.

#### 4.4. Using the Second Part of the Design Chart

To find maximum skylight spacing ( $x$ ) with splay, both graphs of the second part of the design chart are used as follows.

Enter the first graph (at the right) by specifying the skylight well width ( $w$ ) on the horizontal axis. Draw a vertical construction line upwards still it intersects one of the ten diagonal lines representing the ceiling height ( $H$ ). From the point of intersection, extend a horizontal construction line to the left till it intersects one of the ten diagonal lines representing the skylight splay width ( $s$ ). From the point of intersection, draw a vertical construction line downwards till the maximum skylight spacing ( $x$ ) is found on the horizontal axis.

#### 4.5. Notes on the Design Charts

**4.5.1. Effect of the Skylight Well Index (WI) on the Skylight Well Efficiency (WE).** From the first part of the design chart Fig. 1, it is notable that when the skylight well index (WI) increases, i.e., its proportions are extended vertically rather than horizontally, the skylight well efficiency (WE) is minimized which might be suitable for locations with clear skies, where it is required to decrease the brightness of light at the source. On the contrary, when the skylight well index (WI) decreases, i.e., its proportions are extended horizontally rather than vertically, the skylight well efficiency (WE) is maximized which might be suitable for locations with overcast skies, where there is less availability of daylight [7].

**4.5.2. Effect of the Skylight Well Wall Reflectance (WR) on the Skylight Well Efficiency (WE).** From the first part of the design chart Fig. 1, it is notable that when the skylight well wall reflectance (WR) increases, i.e., brighter surfaces, the skylight well efficiency (WE) is maximized which in turn would increase the amount of permitted daylight factor (DF), i.e., the revised daylight factor  $(DF)_{\text{revised}}$ .

*4.5.3. Effect of the Skylight Splay Width (s) on the Maximum Skylight Spacing (x).* From the second part of the design chart Fig. 2, it is notable that when the skylight splay width (s) increases, the maximum skylight spacing (x) increases which ensures the cost-effectiveness of using the splayed patterned skylights because it would result in lesser number of skylights with better spreading and diffusion of light within the space.

## 5. Discussion and Conclusions

It is possible to use the proposed design chart as a rule-of-thumb, especially within the preliminary stages of design, to find out some parameters related to skylights; the skylight well efficiency (WE) and the maximum skylight spacing (x), needed when utilizing top-lighting for daylighting as a function of the skylight well width (w). That would lead to suitable geometry and spacing of skylights inside a given space which directly affects the distribution of daylight, leading to better quality of light.

In future researches, both parts of the proposed design chart could be upgraded by adding more graphs to include more variables. The same methodology could be used for finding the dimensions of other daylight media such as courtyards, etc., or other architectural elements such as climatic envelopes, etc. Other researches might include studying the sizing of skylights for ventilation or for passive solar heating [8] or for two or more building integrated systems. In addition, future researches might include advanced studies related to the quantity or quality of daylight besides the cost effectiveness or energy savings that might result from the use of such skylights within the clear and the overcast skies.

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