Complex description of shading devices

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Sunshine protection of buildings can be implemented by using different shading devices, which may be mounted on frontal openings as part of a window or may complete the previous ones as outer and inner systems. In accordance with the literature shading devices are designed to "protect some areas, rooms or particular parts of a building from heat gain during the summer and its adverse or harmful (sanitary, structural, economic) effects, therefore (…) reduce the thermal mass of sunshine during the summer (…) as it is required (or prescribed) " Relying upon these findings lights are designed to transfer natural light to the inner space, nevertheless sunshine protection is approached only from the thermal aspect in this case. Whatever protective device is placed on the window it will influence the visual and thermal effects, as well. Aim is to control the visual and thermal effects in the inner space however; outlining these limitations as a demand can be done separately.

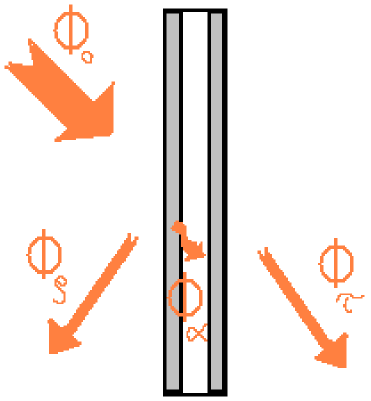
There is no doubt that thermal effect markedly influences the energetic balance of a building and has an enormous impact on the human comfort but meeting the visual claim has a pivotal role and thermal requirements can be met only along with it or subordinately. Therefore detailed analysis of protection is needed to meet both claims.

The two forms of external impact i.e. diffuse sky and direct sun radiation make the situation even complex, which is less problematic from the thermal aspect than from the visual aspect. Homogenous protection by shading devices resulting in diffuse light distribution and high luminance surface due to structural design in small areas may lead to glare. In the latter case average value may be appropriate but the local maximum value results in glare.

Proper protective structures are selected if they can meet the proscribed and aesthetic claims for inner space in case of a possible external impact. Parameters of the structures (i.e. how they affect the visual and thermal comfort of the inner space and what are they influenced by) have to be known to meet the requirements. Limitation can be distinguished by the distribution in the inner space; it can be homogeneous or inhomogeneous. Homogeneous protection reduces the amount of light and the external luminance homogeneously. Inhomogeneous protection while reduces the amount of light may let the effect of disturbing luminance causing glare After all the basis of the thermal limitation is another segment of the electromagnetic spectrum contrary to the visual limitation.

I assorted the shading devices commercially available and analysed theoretically their radiation transmitting characteristic from that point of view of thermal and visual.

Investigation of spectral material characteristics



If the surface is exposed to an external impact (radiation, Φ_o) that may result in three different changes:

1.) one part of the radiation is reflected(Φ_ρ),
2.) another part of the radiation is absorbed (Φ_α),
3.) the remaining radiation transmits the surface (Φ_τ).

According to the law of conservation of energy the following equation is true:

$$\Phi_o = \Phi_\rho + \Phi_\alpha + \Phi_\tau ,$$

both sides of the equation divided by Φ_o :

$$1 = \frac{\Phi_\rho}{\Phi_o} + \frac{\Phi_\alpha}{\Phi_o} + \frac{\Phi_\tau}{\Phi_o} = \rho(\lambda) + \alpha(\lambda) + \tau(\lambda) ,$$

It means, that the sum of the three spectral component is equal to 1 (or 100%).

In order to simplify the correlation the proportion of the radiated material's (surface's) absorption is supposed to be negligible besides the reflexion and transmission factors, i.e.:

$$\rho(\lambda) >> \alpha(\lambda) \text{ and, } \tau(\lambda) >> \alpha(\lambda) ,$$

then we can use this approximation:

$$\alpha(\lambda) \approx 0$$

In this case the correlation is modified that way:

$$1 = \rho(\lambda) + \tau(\lambda) ,$$

so:

$$\tau(\lambda) = 1 - \rho(\lambda) \text{ and } \rho(\lambda) = 1 - \tau(\lambda)$$

Accordingly, it follows that:

$$\boxed{\tau_a'(\lambda) > \tau_a''(\lambda) \Rightarrow \rho_a'(\lambda) < \rho_a''(\lambda)}$$

and:

$$\boxed{\tau_a'(\lambda) < \tau_a''(\lambda) \Rightarrow \rho_a'(\lambda) > \rho_a''(\lambda)},$$

where $\tau_a'(\lambda), \rho_a'(\lambda)$ represent the one, $\tau_a''(\lambda), \rho_a''(\lambda)$ represent the other side's spectral transmission and reflexion components.

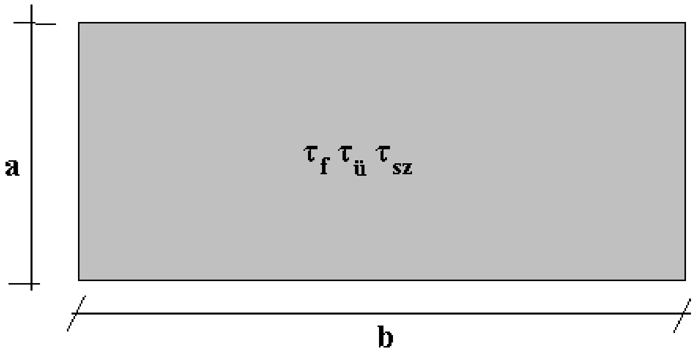
From the visual aspect the average transmission factor, $\bar{\tau}(\lambda)$ determines the level of the illuminance (E_m: derived from the Standard), while the maximal spectral transmission factor, τ_{max}, (where the restriction is the smallest) is responsible for the surfaces with maximal illuminance and luminance value in the interior therefore it is essential for the glare protection in the interior.

Classification of shading devices

1. group: Window films

Group of sunshine protection devices, which are installed fixed on the surface of the window. Moving is not possible later on.

See next image:



The geometrical extensions of the window are **a** and **b**. Let the spectral transmission factor of the window film be: $\boldsymbol{\tau_f(\lambda)}$, that of the glasing: $\boldsymbol{\tau_ü(\lambda)}$, that of the window construction: : $\boldsymbol{\tau_{sz}(\lambda)}$.

two cases are possible:

1.) if the spectral transmission factor is constant, $\tau_f(\lambda)$=const, the average transmission factor is the following:

$$\overline{\tau}(\lambda) = \tau_f \tau_ü(\lambda)\tau_{sz}$$

2.) if the spectral transmission factor is not constant, $\tau_f(\lambda) \neq$ const., then:

$$\overline{\tau}(\lambda) = \tau_f(\lambda)\tau_ü(\lambda)\tau_{sz}$$

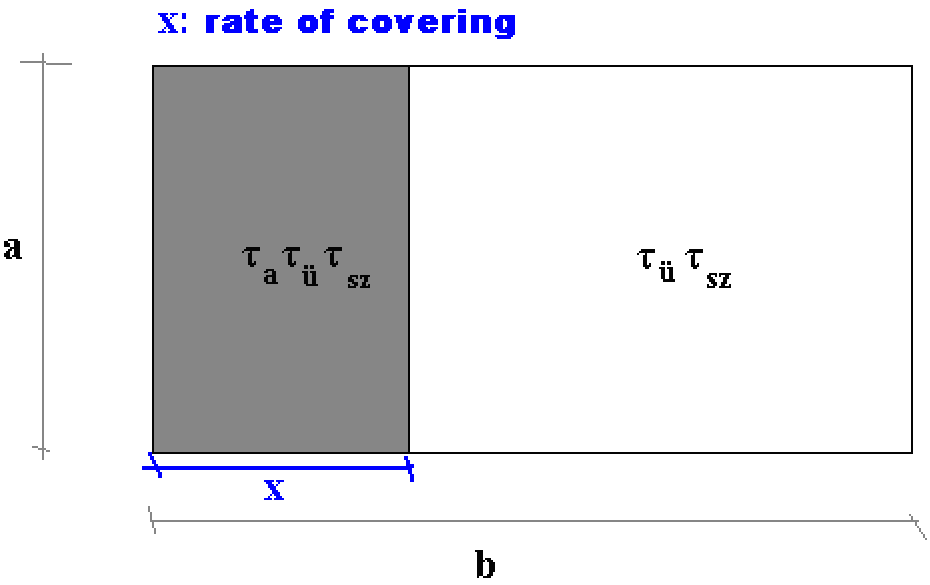
Since the window film covers the whole area of the window the distribution of the transmission factor is homogeneous, therefore the value of the maximal radiation transmission (TSE = UV + VIS + IR) equals the value of the average transmission:

$$\boxed{\overline{\tau}(\lambda) \equiv \tau_{\max}(\lambda)}$$

2. group: mobile shading devices

2.1) mobile, but not rotatable devices: curtains (horizontal movement)

See next image:



The geometrical values of the window are **a** and **b**. The spectral transmission factor of the curtain be: $\tau_a(\lambda)$, that of the glasing: $\tau_ü(\lambda)$, that of the window construction: $\tau_{sz}(\lambda)$. The curtain covers a part of the window. The ratio of covering is **x**.

The average spectral transmission factor can be determined according to the covering rate:

$$\bar{\tau}(\lambda) = \frac{x \cdot a \cdot \tau_a(\lambda) \cdot \tau_ü(\lambda) \cdot \tau_{sz}(\lambda) + (b - x) \cdot a \cdot \tau_ü(\lambda) \cdot \tau_{sz}(\lambda)}{a \cdot b}$$

simplifying the fraction:

$$\boxed{\bar{\tau}(\lambda) = \frac{x}{b} \cdot \tau_a(\lambda) \cdot \tau_ü(\lambda) \cdot \tau_{sz}(\lambda) + \frac{b - x}{b} \cdot \tau_ü(\lambda) \cdot \tau_{sz}(\lambda)}$$

The maximal spectral transmission factor can be determined:

$$\boxed{\tau_{\max}(\lambda) = \tau_ü(\lambda) \cdot \tau_{sz}(\lambda) \cdot \tau_a(\lambda) \equiv \bar{\tau}(\lambda)},$$

it means, if the curtain covers the whole surface of the window (if x=b)

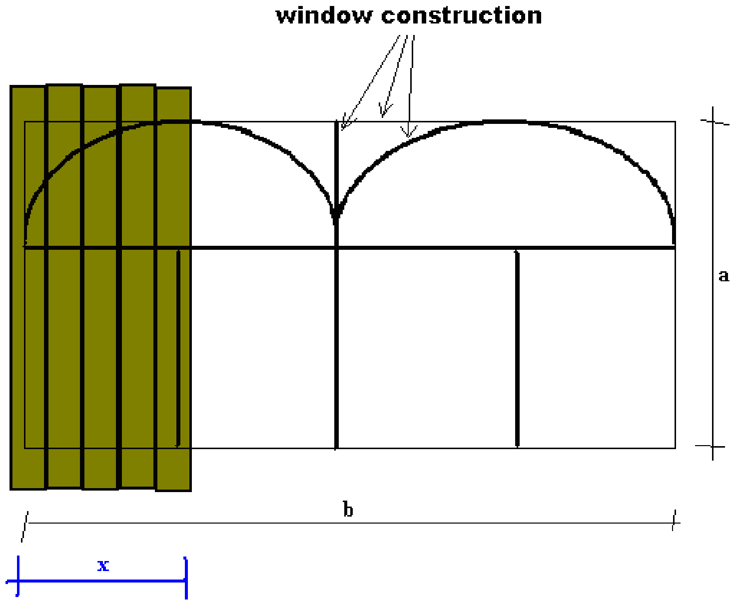
and

$$\boxed{\tau_{\max}(\lambda) = \tau_ü(\lambda) \cdot \tau_{sz}},$$

if the curtain does not cover the whole window (if x<b).

2.2) mobile and rotatable shading devices: vertical blinds (horizontal movement)

See next picture:



More conditions should be investigated:

2.2.1) The distribution of the louvers is homogeneous, so there is no overlapping or rotation

In this case the average spectral transmission factor can be determined similarly to the determination of the curtain:

$$\boxed{\overline{\tau}_{I.}(\lambda) = \frac{x}{b} \cdot \tau_a(\lambda) \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda) + \frac{b-x}{b} \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}$$

Note: $\tau_a(\lambda)$ can have two values theoretically, because the louver has two sides, which can be different, too. The value of the louver's surface has to be applied, which is turned into the direction of the external impact.

The maximal spectral transmission factor can be determined:

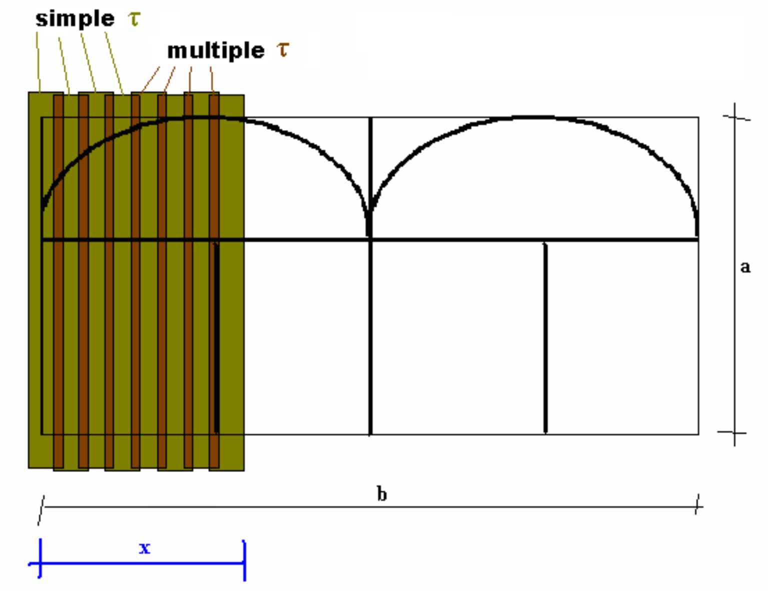
$$\boxed{\tau_{\max}(\lambda) = \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}, \qquad \text{if } x<b$$

and

$$\boxed{\tau_{\max}(\lambda) = \tau_{ü}(\lambda) \cdot \tau_{sz} \cdot \tau_a^*(\lambda)}, \qquad \text{if } x=b.$$

where $\tau_a^*(\lambda)$ means the spectral transmission value of the surface, which is directly turned into the direction of the external impact.

2.2.2) The distribution of louvers is inhomogeneous, so there is overlapping, but no rotation



In this case besides the simple τ the quadratic and higher ($τ^2$, $τ^3$, $τ^4$, ...) factors appear because of overlapping.

Note: to make demonstration simplier remember that instead of $\tau_a(\lambda)$ *later* $\tau_a^*(\lambda)$ *is used (with the appropriate side's value).*

Consider the width of a single louver: **z**, and the number of the louvers: **n**. The ratio of covering by louvers is **x**.

Let the ratio of multiple overlapping (min.$τ^2$) be: **y**.

If we would like to determine **y** as a function of **z, n, x,** we can do it this way:

$$y = \frac{n \cdot z - x}{n-1} \text{ [dimension in Meter]}$$

or in percentage, if we compare the ratio of overlapping to a single louver's width:

$$y = \frac{n \cdot z - x}{(n-1) \cdot z} \text{ [\%]}$$

The ratio of louvers with simple transmission factor related to a single lover's width, according to the previous information is: 1-y.

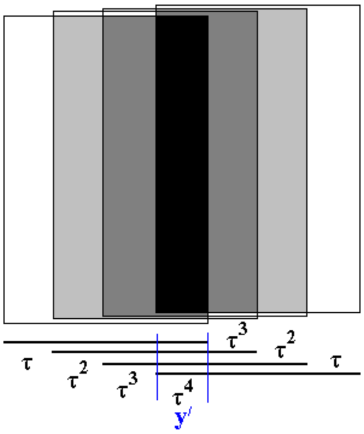
If we would like to determine how many louvers are overlapped maximally, we can do it this way:

$$\frac{1}{1-y}.$$

This value is a decimal fraction. It has to be interpreted the following way:

a.) If the decimal fraction is greater than zero the exponent will be (the round part + 1), and the decimal value determines the percentage of the highest exponential τ related to one louver's width.

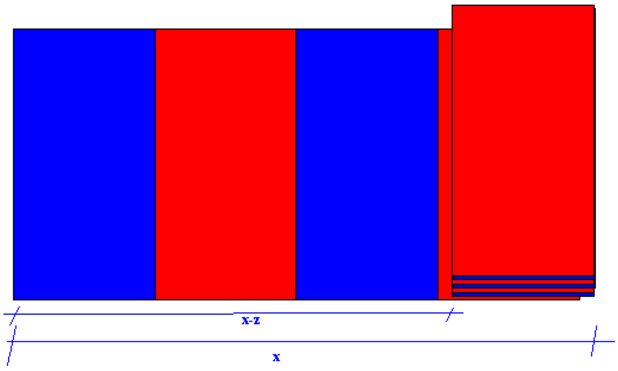
b.) If the decimal value is exactly zero (this is only theoretically possible), then the exponent of the τ is the round value.



Example: if $\frac{1}{1-y}$=3,2847, then the exponent of the τ is four (τ^4) and the ratio of overlapping (**y'** indicates it in the picture) is 28,47 % related to a single louver's width (which is 100 %). The ratio of the widths of the louvers with τ, τ^2 and τ^3 is exactly 1-y [%].

To investigate the overlapping of the louvers from the aspect of the spectral transmission factor can be modified that way:

Suggested the vertical blind is re-pulled to a certain extent from 100 % coverage of the window, so the window is not covered entirely. A value equivalent to the previously outlined overlapping is reached, if we consider the state of covering as only the last piece of the louvers is moving (overlapping the next to it) and so on. In this case the distribution is the following:



It resulted in simple transmission value regarding the width of **x-z,** and multiple value regarding the width of **z**.
Introduce the following equation: $n \cdot z - x = \delta$, which determines the uncovered rate of width of the louvers.

If we split $\frac{\delta}{z}+1$ instead of δ/z (in order to manage it better), which is a decimal numeric value, into the round part (**i**) and the decimal part (**j**), so: $\frac{\delta}{z}+1$=i+j, where j<1, then the following equation is valid:

$$\boxed{\overline{\tau_{II.\,louver}}(\lambda) = \frac{(x-z)\tau_a(\lambda) + j \cdot z \cdot \tau_a^{\,i+1}(\lambda) + (1-j) \cdot z \cdot \tau_a^{\,i}(\lambda)}{x}}$$

so:

$$\boxed{\overline{\tau_{II.}}(\lambda) = \frac{x}{b} \cdot \overline{\tau_{II\ louver}}(\lambda) \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda) + \frac{b-x}{b} \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}$$

The maximal spectral transmission factor can be determined:

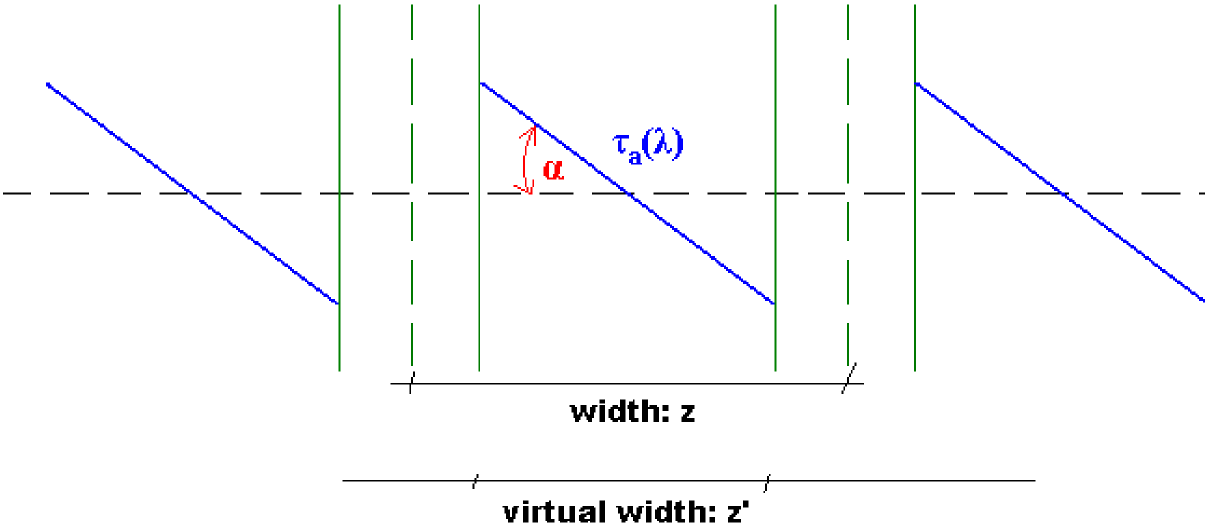
$$\boxed{\tau_{\max}(\lambda) = \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}, \qquad \text{if } x<b,$$

and

$$\boxed{\tau_{\max}(\lambda) = \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda) \cdot \overline{\tau_{II.\,louver}}(\lambda)}, \qquad \text{if } x=b.$$

2.2.3) Rotation of the louvers

See next picture to understand the method better:



$$\bar{\tau}(\lambda) = \frac{(z - z') \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda) + z' \cdot \tau_a(\lambda) \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}{z} =$$

$$= \frac{z(1 - \cos\alpha) \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda) + z \cdot \cos\alpha \cdot \tau_a(\lambda) \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}{z}$$

simplified this equation by **z**:

$$\boxed{\overline{\tau_{III.}}(\lambda) = (1 - \cos\alpha) \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda) + \cos\alpha \cdot \tau_a(\lambda) \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}$$

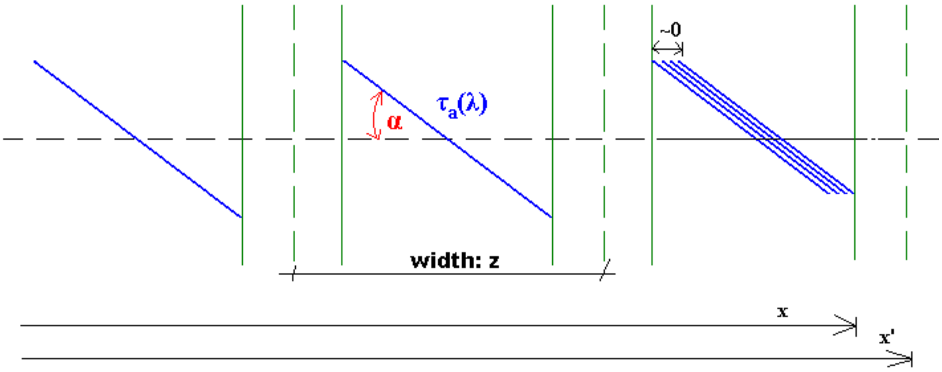
$$\boxed{\tau_{\max}(\lambda) = \tau_a(\lambda) \cdot \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}, \qquad \text{if } \alpha=0°$$

and

$$\boxed{\tau_{\max} = \tau_{ü}(\lambda) \cdot \tau_{sz}(\lambda)}, \qquad \text{if } 180° > \alpha > 0°$$

2.2.4) Determination of spectral transmission factor with covering (**x**) and rotation (**α**)

1.) if **x** and **α** are given:



2.) we have to determine the value of **x’** because we’ll calculate with this modified covering value:

$$\boxed{x' = x - \frac{z}{2}\cos\alpha + \frac{z}{2} = x + \frac{z}{2}(1-\cos\alpha)}.$$

3.) we calculate the average τ of the “only covered by louvers” with the usage of **x’**:

$$\boxed{\overline{\tau_{II.\ louver}}'(\lambda) = \frac{(x'-z)\tau_a(\lambda) + j\cdot z\cdot \tau_a^{\,i+1}(\lambda) + (1-j)\cdot z\cdot \tau_a^{\,i}(\lambda)}{x'}}$$

ahol where $n\cdot z - x' = \delta$ és and $\frac{\delta}{z} + 1$=i+j , ahol where j<1.

4.) Using this equation we put it into the expression of the rotation:

$$\boxed{\overline{\tau_{III.}}'(\lambda) = (1-\cos\alpha)\cdot\tau_{ü}(\lambda)\cdot\tau_{sz}(\lambda) + \cos\alpha\cdot\overline{\tau_{II.\ louver}}'(\lambda)\cdot\tau_{ü}(\lambda)\cdot\tau_{sz}(\lambda)}$$

it applies only to the covering **x’**, and not to the whole window, hence we weight it:

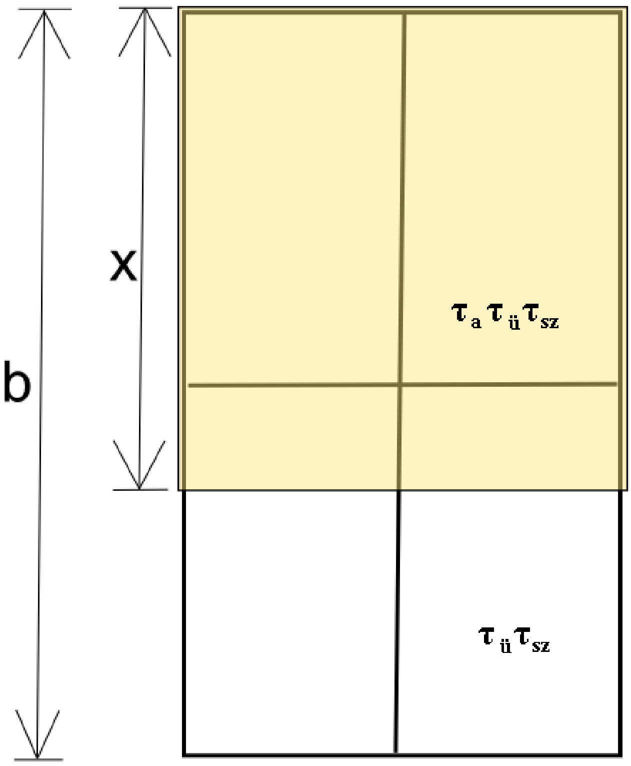
5.) so, the resultant spectral transmission factor can be given for the whole window’s surface as a function of **x**, **x’** and **α**:

$$\boxed{\overline{\tau}(\lambda) = \frac{x'\cdot\overline{\tau_{III.}}'(\lambda)\cdot\tau_{sz}(\lambda)\cdot\tau_{ü}(\lambda) + (b-x')\cdot\tau_{sz}(\lambda)\cdot\tau_{ü}(\lambda)}{b}}$$

$\boxed{\tau_{\max}(\lambda) = \tau_a(\lambda)\cdot\tau_{sz}(\lambda)\cdot\tau_{ü}(\lambda)}$, if **x** = **nz** and **α = 0°** (or **α = 180°**)

$\boxed{\tau_{\max} = \tau_{ü}(\lambda)\cdot\tau_{sz}(\lambda)}$ if **x** < **nz** or if **180° > α > 0°**

2.3) mobile, not rotatable shading devices: window shade (vertical movement)



See the following picture to determine the resultant transmission factor of the window shade:

The window's height is **b**, the shade covers **x** part of the window . The shading material's spectral transmission factor is **$\tau_a(\lambda)$**, that of the window construction is **$\tau_{sz}(\lambda)$**, that of the glazing is **$\tau_ü(\lambda)$.**

The average spectral transmission factor can be derived the following way – similar to the outline of the curtains:

$$\boxed{\bar{\tau}(\lambda) = \frac{x}{b} \cdot \tau_a(\lambda) \cdot \tau_ü(\lambda) \cdot \tau_{sz}(\lambda) + \frac{b-x}{b} \cdot \tau_ü(\lambda) \cdot \tau_{sz}(\lambda)}$$

The maximal spectral transmission factor can be determined:

$$\boxed{\tau_{\max}(\lambda) = \tau_ü(\lambda) \cdot \tau_{sz}(\lambda) \cdot \tau_a(\lambda)}\ , \qquad \text{if } x=b$$

and

$$\boxed{\tau_{\max}(\lambda) = \tau_ü(\lambda) \cdot \tau_{sz}(\lambda)}\ , \qquad \text{if } x<b.$$

2.4.) mobile and rotatable shading devices: horizontal blinds (vertical movement)

The movement of the horizontal blinds is similar to the method outlined for vertical blinds but there are two differences:
1.) The vertical blinds move horizontally, the horizontal blinds move vertically.
2.) The depth of the vertical blinds can be ignored and the louver can be considered as a flat surface, however, the horizontal blinds have (because of their construction) depth. This depth should be taken into consideration in case of calculation.

3.) group:
Shading devices which modify their transmission values according to the sun radiation

This group involves shading devices, which can modify their spectral transmission value according to the amount of solar radiation. Further investigation is needed to gain more information about the features of glass, what determinates the transmission (and reflexion) factor in case of any spectral radiation.

4. group
Outdoor, not mobile shading devices (mounted on the façade fixed or positioned close to the façade and fixed)

This shading devices based on their structure can modify the radiation penetrating into the interior several way. Since their design is arbitrary, there is no possibility for generalization or making general correlations. However, the effect of these structures can be simplified, if the material of the shading device does not let through any radiation ($\tau = 0$): it does not let the effect of direct sunshine into the interior in case of/above a given angle (which depends on the observation site and shading (frontal) geometry). It is likely to influence the effect of other environmental factors, like the area, covering or the sky less than the restriction of the direct effect of sunshine.

Abbreviations:

$\tau(\lambda)$ – spectral transmission factor

$\rho(\lambda)$ – spectral reflection factor

$\alpha(\lambda)$ – spectral absorption factor

VIS – visible spectrum, λ= 380 – 780 nm

IR – infrared, λ> 780 nm

UV – ultra violet, 100 nm < λ < 400 nm

TSE – TotalSolarEnergy (UV+VIS+IR)

$\bar{\tau}$ – general ability of transmission

τ_{max} – ability of maximal transmission (case of minimal limitation)

τ_a – spectral transmission factor of the material

$\tau_{ü}$ – spectral transmission factor of the glazing

τ_{sz} – spectral transmission factor of the window structure

τ_f – spectral transmission factor of the window film

z – width of a single louver

n – total number of pieces of the louvers in the shading device