ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

# 1999-39

# LESO-PB

## Lighting controllers : Venitian Blinds, Edificio
## SubTask AD3
## OFES, Technical Report

Guillemin A.; Morel N.

**OFES, Technical Report**

*1999*

# Document EDIFICIO/LESO/AD3/R23/12.5.99
# Lighting Controllers: Venetian Blinds

**Antoine Guillemin, Nicolas Morel, LESO-PB/EPFL, 12.5.99**

This paper describes the complete controller for the venetian blind case. The textile blind controller is already described in previous papers (mainly, " user Present, visual optimisation " dated 25.11.1998 and " user not present, energy optimisation " dated 5.10.1998).
Here is only discussed the user present case, because in the other case (user not present) the controller for the venetian blind is identical to the textile blind (the slats are simply closed and only the vertical position is regulated).

First, some theoretical aspects are presented and then the controller is explained step by step.

## Daylight factor

This part describes the daylight factor used in the venetian blind case.

For the textile blind, one had the following daylight factor (see LESO paper dated 3.12.1998):

$$E_{inside} = (a \bullet \alpha + b) \bullet E_{outside} \qquad \text{(I)}$$

With:
- $\alpha$ vertical position of the blind, $\alpha$=0 for blinds closed, $\alpha$=1 for blinds completely opened
- $E_{inside}$ the inside illuminance due only to natural lighting
- $E_{outside}$ the outside illuminance
- a, b two constants of the daylight factor

For the venetian blind, we decide to use a same kind of daylight factor:

$$E_{inside} = [a \bullet [\alpha + (1-\alpha)\bullet VSF] + b] \bullet E_{outside} \qquad \text{(II)}$$

With: VSF Visible Sky Fraction (solid angle), depends of the slats angle ($\beta$)

The equation I is equivalent to (II) except the term $\alpha$ that has been changed into $[\alpha + (1-\alpha)\bullet VSF]$.
In the venetian blind case, one considers separately the closed and opened part of the window. The opened part ($\alpha$) is kept as in the textile blind case. The fraction of light passing through the closed part is expressed by the supplementary term $(1-\alpha)\bullet VSF$, which depends of the slats angle through the VSF function.
So, $(1-\alpha)$ gives the fraction of the window closed by the blind and the VSF allows determining how much light goes through the closed part following the slats angle.

The only difficulty is to evaluate the VSF as a function of the slats angle. The VSF is the solid angle fraction of the visible sky through the slats.

Remind: the slats angle ($\beta$) is given following the standard convention: a tilt of 0° means that the slats are horizontal and a tilt of 90° means that they are vertical (completely closed position). $\beta$ is positive when the side of the slats towards outside goes down (in the figure 2, $\beta$ is positive in the case represented).

First, we have developed the VSF function with the following assumptions: isotrope sky radiation, "black ground" and "black slats" (that means no reflections). Geometrical considerations allow obtaining some expressions with term in arctan:

$$VSF = \frac{\arctan\left(\frac{d - \sin\beta}{\cos\beta}\right)}{\pi/2} \qquad \text{(III)}$$

Instead of using this equation as the VSF function, we have preferred to take a linear approximation of this function and weight the function with a parameter CORR that although reflects the reality. Moreover, since we need to solve the equation for β, it's easier to use the approximated VSF function:

$$\mathrm{VSF} = \left[\mathrm{CORR} \bullet \frac{\beta}{\pi/2} - \mathrm{CORR}\right] \qquad \text{(IV)}$$

With:

$$\mathrm{CORR} = \frac{\arctan(\mathrm{d})}{\beta_{\min} - \pi/2}$$

So, using the equation IV in the equation II, one obtains finally:

$$\mathrm{E}_{\text{inside}} = \left(\mathrm{a} \bullet \left(\alpha + (1-\alpha)\cdot\left[\mathrm{CORR} \bullet \frac{\beta}{\pi/2} - \mathrm{CORR}\right]\right) + \mathrm{b}\right) \bullet \mathrm{E}_{\text{outside}} \qquad \text{(V)}$$

With: d the ratio y/x, see figure 2

$\beta_{min}$ the minimum possible value for the slats angle (the most open position)

In order to understand the VSF function, the equation IV is plotted in the figure 1. The default values used for plotting are: d = 0.875 and $\beta_{min}$ = -20°.

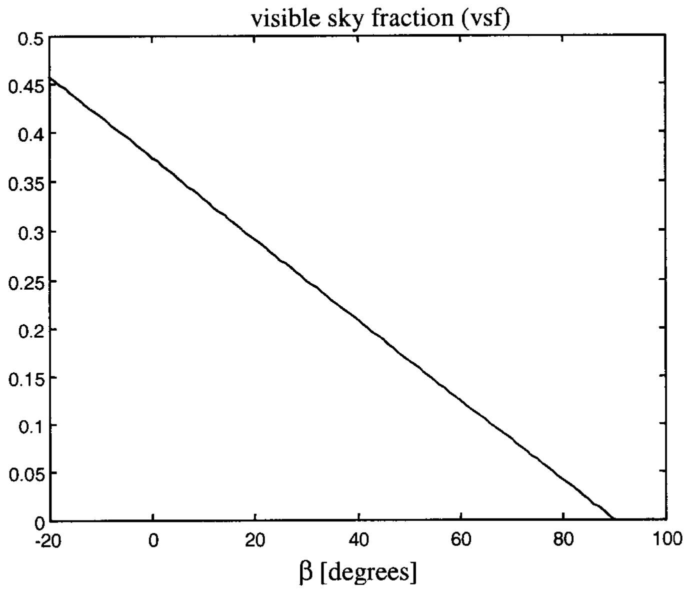


*Figure 1: the visible sky fraction depending on the slats angle*

Here are some comments about this figure:

- The quantity of light passing through the closed part of the window decreases with an increase of β (slats more closed)
- There is no light passing through the blinds when the slats are completely closed (β= 90°)
- The maximum amount of light occurs when the slats are completely opened (typically β= -20°)
- The maximum value of VSF doesn't reach one because some parts of the sky are hidden by the slats even if they are opened completely

## Critical slats angle

This part explains how we calculated the critical slats angle ($\beta_c$) that just cuts completely the direct radiation.

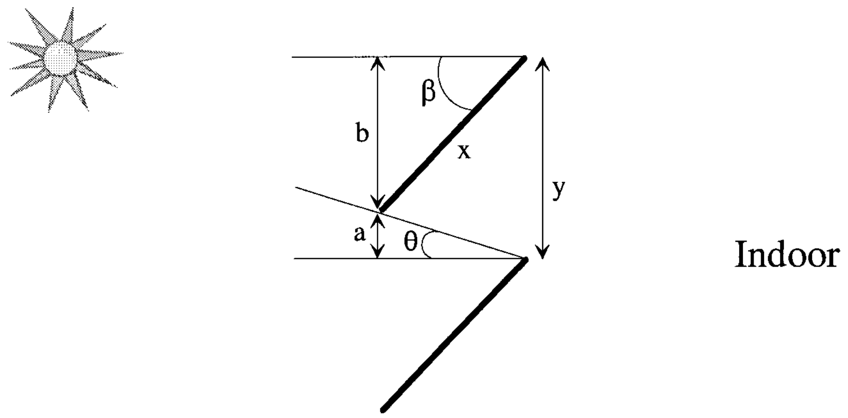


*Figure 2: lateral view of two slats*

The figure 2 gives a representation of two slats of a venetian blind.

Let's define the different parameters:

x is the slat width
y is the distance between two slats
$\beta$ is the slats angle as previously defined (positive on the figure 2)
$\theta$ is the height of the sun projected on the plan perpendicular to the facade

Defined on the figure 2, a and b can be easily calculated:

$b = x \bullet \sin\beta$
$a = x \bullet \cos\beta \bullet \tan\theta$

And one has:

$y = a + b$

So,

$y = x \bullet (\sin\beta + \cos\beta \bullet \tan\theta)$

Then, if one uses the previously defined parameter $d = y/x$ (see part "Daylight factor"),

$d = \sin\beta + \cos\beta \bullet \tan\theta$ for $\beta = \beta_c$ (the critical slats angle)

Finally, using the azimuth $\tau$ (angle between the perpendicular to the facade and the direction of the sun projected on a horizontal plane, positive towards the East direction) and the real height of the sun $\eta$ instead of the projected sun height $\theta$, one can write:

$\tan\theta = \tan\eta / \cos\tau$

And,

$d = \sin\beta + \cos\beta \bullet \tan\eta / \cos\tau$ for $\beta = \beta_c$ (VI)

The equation VI is solved using Matlab Symbolic Calculation Toolbox.

There are two solutions, only one of them has a physical meaning:

$$\beta_c = 2 \cdot \arctan\left\{ \frac{1 - \sqrt{1 + \frac{\tan\eta}{\cos\tau} - d^2}}{\frac{\tan\eta}{\cos\tau} + d} \right\} \qquad \text{(VII)}$$

## Controller's working

The controller works in four steps. First, some fuzzy rules are used to produce a value for the vertical position ($\alpha$) of the blind. Both thermal and visual aspects are taken into account in this step. In the second step, the slats angle ($\beta$) is calculated following the daylight factor, the critical angle and the ratio "direct/global" illuminances. The third step allows moving once again the vertical position if the slats are in an extreme position and the illuminance level is still not good enough. Finally, the artificial lighting system completes the illuminance level if it's necessary.

Each step is explained more precisely in this part.

### STEP 1: Primary vertical positioning

The fuzzy rules are mainly inspired by the work done for the textile blind (see LESO paper dated 25.11.1998). The sun position relatively to the facade is also divided in nine positions as shown on the figure 3. The benefit is that the user adaptation will differentiate the rules with the same height of sun but with a different azimuth. It allows an adaptation of the fuzzy controller following the user position in the room.

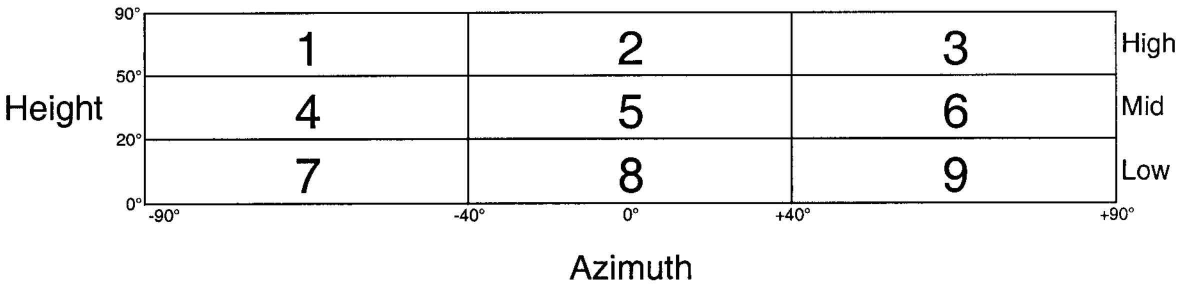


*Figure 3: Sun position relatively to the facade*

FUZZY INPUTS VARIABLES

| | |
|---|---|
| Outside average temperature (24h) | Season |
| Height of the sun | Height |
| Azimuth of the sun | Azimuth |
| Global horizontal radiation (outside) | Gh |

FUZZY OUTPUT VARIABLE

| | |
|---|---|
| Vertical position of the blind | $\alpha$ |

RULES

If *Gh* is high and *Season* is winter and "position of the sun is 1,2 or 3" then $\alpha$ is 1 *
If *Gh* is high and *Season* is winter and "position of the sun is 4,5 or 6" then $\alpha$ is 0.7 *

If *Gh* is high and *Season* is winter and "position of the sun is 7,8 or 9" then $\alpha$ is 0.4 *

If *Gh* is high and *Season* is winter and *Azimuth* is > +90° then $\alpha$ is 1
If *Gh* is high and *Season* is winter and *Azimuth* is < -90° then $\alpha$ is 1

If *Gh* is low and *Season* is winter then $\alpha$ is 0.1

If *Gh* is high and *Season* is summer then $\alpha$ is 0.1
If *Gh* is low and *Season* is summer then $\alpha$ is 1

* means that the rule correspond in fact to three rules

So, these rules show that this controller takes both visual and thermal aspects into account.

**STEP 2: Slats angle calculation**

Depending of the ratio direct/global outside illuminances, the slats angle is calculated.

- If the ratio is near zero, that means there is no glare risk, the slats angle ($\beta$) may be any physically possible value calculated through the Daylight factor (using equation V).
- If the ratio is more than a certain value (0.25 for example, should be adapted through level 3), that means glare is possible, the slats have to be closed, at least, to the critical angle ($\beta_c$) in order to avoid direct radiation penetration inside the room. So, the slats angle is also calculated through the Daylight factor equation, but if the calculated slats angle is inferior to $\beta_c$ (more opened than the critical angle) the final slats angle value is fixed at $\beta_c$.

These two rules are applied as fuzzy rules in order to have a smooth transition between the "no glare risk" case and the "glare possible" case.

**STEP 3: Secondary vertical positioning**

This step allows re-determining a vertical position of the blind if the illuminance level is still not good enough (too high or too low):

- If the slats are in an extreme position (closed or opened), a new vertical position ($\alpha$) is calculated using the equation V ($\beta$ determined by step 2).
- If the slats are not in an extreme position, the value $\alpha$ calculated in step 1 is used.

**STEP 4: Artificial lighting**

If the illuminance level is still too low after the three previous steps, the artificial lighting system completes the illuminance to the required level.
The artificial lighting system is identical to the one developed for the textile blind case (see LESO paper "Final schemes" dated 6.1.1999).

## Final remark

The controller presented here has just been tested on few days, in order to remove all logical errors in the Matlab programming. No tests concerning the quality of the algorithm have been undertaken. Nevertheless, it seems that the controller works well and gives fair results.
The working of the controller may be seen in the latest version of the Simulink overall model.