ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

1999-37

LESO-PB

Lighting controller : final schemes
Edificio, Subtask AD3

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OFES, Technical Report

Janvier 1999

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Lighting controller: final schemes

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This paper presents the final detailed scheme of the level 2 controller for the lighting control systems.

The three following chapters explain the complete level 2 controller. The first deals with the pre-processing phase. It describes the translation of the physical inputs in the values needed by the controller. The second one shows how works the controller when the user is present and the third one describes the controller when the user is not present.

Remarks:

- The choice of the controller (user present or not) comes directly from the IR-presence sensor which has, in general, an integrated temporisation system.
- In order to avoid potential mechanical damage of the blinds, a wind-velocity sensor could be implemented that forces the blinds staying open when the wind is too strong. It's not difficult to implement but it depends completely of the manufacturer specifications. For the experimental task, it's not planned to be done.

1. Pre-processing

The scheme of this phase is shown in the figure 1. The two pre-processing blocks are explained.

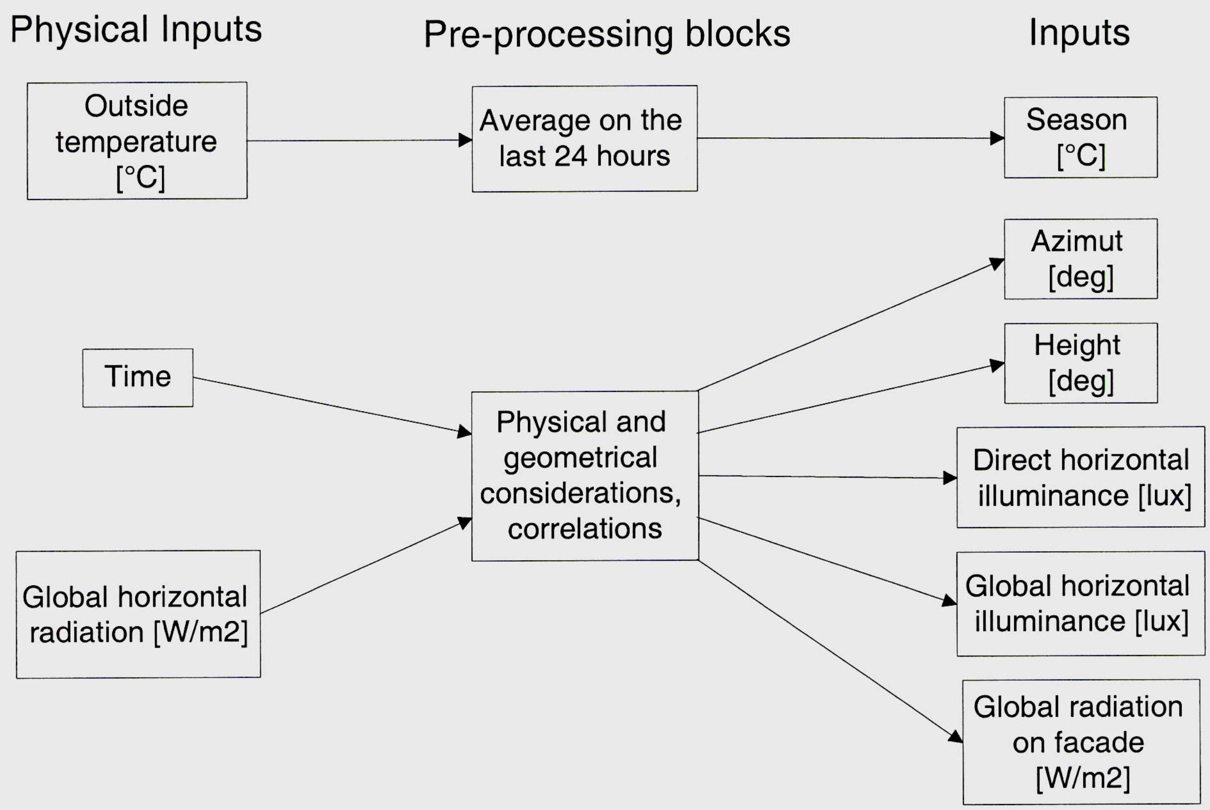


Figure 1: Pre-processing phase

Average on 24 hours block

This block is very simple. It does the average of the current outside temperature and the 23 previous hours.

Physical and geometrical considerations block

This block provides all the needed illuminances for the controllers and provides also the height and the azimut of the sun relative to the facade. Its inputs are the time and the global horizontal radiation [W/m^2]. Furthermore, four parameters are needed for the block calculations. The longitude (λ), the latitude (ϕ) and the time zone (T_z [hour]) of the building position and also the facade orientation (f_o). The three angles are in degrees.

First of all, one has to determine the solar angles (azimut and height angles in particular). Many books allow obtaining the following formulas (for instance, *Solar Energy Thermal Processes*, Duffie & Beckman, John Wiley Ed, 1974 edition):

<u>Warning</u>: not all the textbooks assume the same angle conventions! Depending on the author, some signs might differ therefore it is not advisable to take an equation from one textbook and mix it with an equation from another textbook!

$\sin h = \sin \delta \cdot \sin \phi + \cos \delta \cdot \cos \phi \cdot \cos \omega$

$\sin a = \sin \omega \cdot \cos \delta / \cos h$

with:

- h = sun height (angle between the sun direction and its projection on a horizontal plane, positive when the sun is above the horizontal plane)
- a = azimut angle of the sun (angle between the South direction and the direction of the sun projected on a horizontal plane, positive towards the East direction)
- ϕ = latitude [degrees] (North positive)
- ω = hour angle (0° = solar noon, ± 180° = midnight, morning > 0, afternoon < 0)
- δ = declination (the angular position of the sun at solar noon with respect to the plane of the equator, North positive)

The equation for δ and ω are:

$\delta = 23.45° \cdot \sin [360 \cdot (n - 81) / 365)]$
$\omega = 15 \cdot (12 - \text{Solar time})$
$\text{Solar time} = \text{Time} + \Delta H + (\lambda/15) - T_z$

with:

- n = the day number of the year (coming from the Time input)
- ΔH="time equation" [hour] that take into account both the ellipticallity of the movement of the earth around the sun and the declination (see appendix)
- T_z = time zone [hour] (0 = GMT, positive towards East)
- λ = longitude [degrees] (0 = Greenwich, positive towards East)

So, the height (h) of the sun (used in the control algorithm) is simply given by:

$h = \arcsin (\sin \delta \cdot \sin \phi + \cos \delta \cdot \cos \phi \cdot \cos \omega)$

Concerning the azimut angle (a), it's a little bit more complicated. Because the azimut can be greater than 90° or smaller than –90° one needs to consider another condition, depending on whether or not the sun is behind a South vertical surface. That condition is given by the critical hour angle ω_s:

$\cos \omega_s = \text{tg}\, \delta / \text{tg}\, \phi \qquad (0 < \omega_s < 180)$

So, the value of the azimut angle a following ω is given in the table below:

ω	a	
$\|\omega\| < \omega_s$	a = arcsin (sin a)	morning: a>0; afternoon: a<0
$\omega = \omega_s$	a = 90	sun at East
$\omega = -\omega_s$	a = -90	sun at West
$\omega > \omega_s$	a = 180 - arcsin (sin a)	early morning (sun between East and North)
$\omega < -\omega_s$	a = -(180 + arcsin (sin a))	evening (sun between West and North)

Finally, the azimut (a_r) of the sun relative to the facade (used in the control algorithm) is given by:

$a_r = a - f_o$

with:

f_o= facade orientation (angle between the perpendicular to the facade and the South direction, positive towards the East)

After the determination of the solar angles, the needed illuminance and radiation are calculated.
The Liu and Jordan correlation is used to reconstruct the direct and diffuse component from the global radiation (Qh) on a horizontal surface (reference: *The interrelationship and Characteristic Distribution of Direct, Diffuse and Total Solar radiation*, B. Liu & R. Jordan, Solar Energy 4, n° 3, 1960).
The direct (Qh_{dir}) and diffuse (Qh_{diff}) horizontal radiation are given by:

$Qh_{dir} = Qh \cdot (1 - f_{diff})$
$Qh_{diff} = Qh \cdot f_{diff}$

with:

Qh = global radiation on a horizontal surface [W/m2] (measured value)
$f_{diff} = 1.0045 + 0.04349 \cdot f - 3.5227 \cdot f^2 + 2.6313 \cdot f^3$
f = limit (Qh/Qh_{ext}, 0, 0.75)
Qh_{ext} = extraterrestrial radiation on a horizontal surface [W/m2]

Qh_{ext} is calculated through:

$Qh_{ext} = 1353 \cdot [1 + 0.033 \cos (2\pi \cdot n /365)] \cdot \sin h$

The first term corresponds to the average extraterrestrial radiation on the earth (1353 W/m^2). The second term takes into account the ellipticallity of the earth's orbit around the sun and the third one deals with the orientation of the horizontal plane considered towards the sun direction.

Once the two components of the radiation are available on a horizontal surface, they can be calculated on a vertical surface of any orientation, using the simplifying assumption of isotropic diffuse component.

- For the diffuse component:

$$Qv_{diff} = 0.5 \cdot Qh_{diff} + 0.5 \cdot Qh \cdot r$$

Note: r is the albedo (ground reflection coefficient, a default value of 0.3 is reasonable for concrete surfaces and grass).

- For the direct component, we have to take precautions following the sun position:

If $5° < h \leq 90°$ and $-90° < a_r < 90°$: $Qv_{dir} = Qh_{dir} \cdot \cos h \cdot \cos (a_r) / \sin h$
Else : $Qv_{dir} = 0$

Note: when h (sun height) is below 5°, the building receives nearly no direct solar radiation. This assumption avoids numeric problems that could occur with very small value of sin h.

The last thing to do is to change the radiation value into illuminance. One has the two following correlations (reference: *Daylighting simulation in the DOE-2 Building Energy Analysis Program*, F. Winkelmann & S. Selkowitz, LBL Report, USA, 1984):

E_{dir} [lux] = 93 · Q_{dir} [W/m^2]
E_{diff} [lux] = 111 · Q_{diff} [W/m^2]

So, to summarise here the three last outputs of the pre-processing block (used in the control algorithm):

- Global radiation on facade: $Qv = Qv_{dir} + Qv_{diff}$
- Direct horizontal illuminance: $Eh_{dir} = 93 \cdot Qh_{dir}$
- Global horizontal illuminance: $Eh = 93 \cdot Qh_{dir} + 111 \cdot Qh_{diff}$

2. *User present controller*

The complete scheme of this controller is given in the figure 2.
The fuzzy controller block is already completely described in the LESO paper (Visual optimisation) dated 25.11.1998, so only the "Daylight factor and artificial lighting estimator" block is explained.

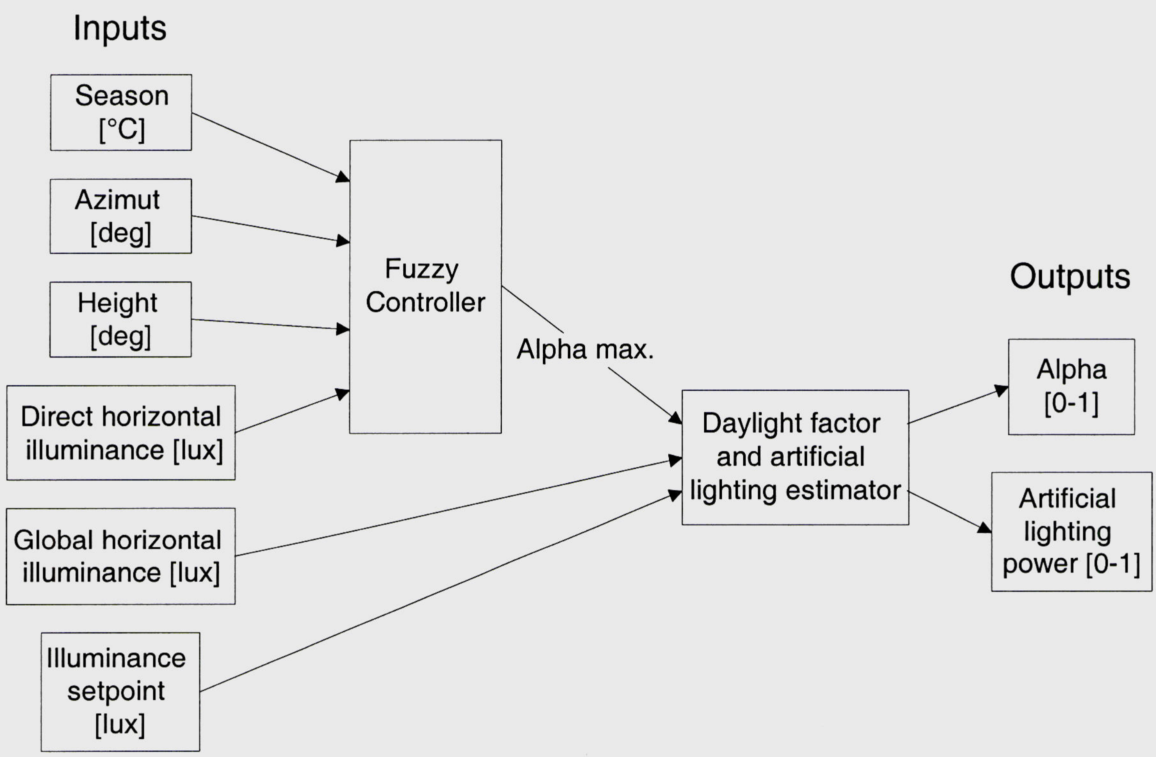


Figure 2: User present controller

Daylight factor and artificial lighting estimator block

This block calculates the final blind position α (between 0 and α_{max}) and the artificial lighting power, from the inputs global illuminance on the facade and inside illuminance setpoint.

The models used are first explained and then the function of the block is described.

Theory

The use of a pseudo-daylight factor allows writing (see LESO paper dated 3.12.1998):

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

Note: E_{inside} is the inside illuminance due only to natural lighting.

We want to adjust α such that $E_{inside} = E_{setpoint}$, so with (I) one has:

$$E_{setpoint} = (a \bullet \alpha_{cal} + b) \bullet E_{outside} \qquad \text{(II)}$$

Solving (II) for α_{cal}, one obtains:

$$\alpha_{cal} = \frac{E_{setpoint}}{E_{outside} \bullet a} - \frac{b}{a} \qquad \text{(III)}$$

Remarks:

- The α_{cal} is not a physical value. It may be negative or higher than 1 but in the controller non-physical values are rejected (see further).
- The parameters a and b are determined experimentally and continuously adjusted (see LESO paper dated 3.12.1998).

Concerning the lighting one defines:

P_{al} : relative electrical power applied to the artificial lighting system [0-1]
$E_{al}(P_{al})$: Illuminance provided by the artificial lighting system [lux]

At the commissioning (and each night), two points are measured in order to determine the relation between the electrical power applied and the illuminance level corresponding to this power:

$P_{al} = 1$ (maximum power applied) $\Leftrightarrow E_{al}(1)$
$P_{al} = 0.4 \Leftrightarrow E_{al}(0.4)$

Let's define (to simplify the notation)
$c = E_{al}(1)$
$d = E_{al}(0.4)$

The value of 0.4 is chosen because it is sufficiently low to have a good estimation of the slope (0.4 << 1) and it is high enough for a dimming controller (the dimming controllers are generally not able to provide lighting with a power less than 20% – 30% (P_{min}) of the maximum electrical power).

So, the relation between the electrical power and the illuminance is given by:

$$E_{al}(P_{al}) = d + (P_{al} - 0.4) \bullet \frac{[c - d]}{0.6} \qquad \text{(IV)}$$

We want that the artificial lighting complete the inside illuminance to the setpoint, so:

$$E_{al}(P_{al}) = E_{setpoint} - E_{inside}$$

Solving (IV) for P_{al} :

$$P_{al} = 0.6 \bullet \frac{E_{al} - d + \frac{0.4}{0.6} \bullet [c - d]}{c - d} \qquad \text{(V)}$$

Remarks:

- The P_{al} is not a physical value. It may be negative or higher than 1 but in the controller non-physical values are rejected (see further).
- The parameters c and d are determined experimentally and periodically readjusted (see LESO paper dated 1.12.98).
- The minimal power (P_{min}, fraction of the maximum electrical power) needed by the dimming control system to provide artificial lighting should be measured or given at the commissioning.

Controllers

The inputs are $E_{outside}$, $E_{setpoint}$ and α_{max} . First the blind controller is presented, and then the artificial lighting controllers (one for the dimming case and one for the On/Off case).

Blind controller:

The α_{cal} is calculated with (III) :

$$\alpha_{cal} = \frac{E_{setpoint}}{E_{outside} \bullet a} - \frac{b}{a}$$

If $\alpha_{cal} < \alpha_{min}$ then $\alpha = \alpha_{min}$
If $\alpha_{cal} > \alpha_{max}$ then $\alpha = \alpha_{max}$

- The new α is applied only if the absolute difference with the current α is bigger than a parameter *move* (0.2 for instance).
- α_{min} could depend of the user (some people dislike to have no visual contact with the outside). We propose to have an initial value $\alpha_{min} = 0.1$. Perhaps, that will be a parameter adaptable through the user wishes.

Artificial lighting controller (dimming):

If $\frac{E_{inside}}{E_{setpoint}} < E_{low}$ the artificial lighting system is switched on and the electrical power is calculated with (V):

$$P_{al} = 0.6 \bullet \frac{E_{setpoint} - (a \bullet \alpha + b)E_{outside} - d + \frac{0.4}{0.6} \bullet [c - d]}{c - d}$$

If $P_{al} < 0$ then $P_{al} = 0$
If $0 < P_{al} < P_{min}$ then $P_{al} = P_{min}$
If $P_{al} > 1$ then $P_{al} = 1$

If $\frac{E_{inside}}{E_{setpoint}} > E_{high}$ the artificial lighting system is switched off.

Typically, the couple of values (E_{low}; E_{high}) could be something like (0.6; 0.8) according to the features of the dimming and blind controllers (minimum value of electrical power, the value of the parameter *move*, etc...).

Artificial lighting controller (On/Off):

If $\frac{E_{inside}}{E_{setpoint}} < E_{low}$ the artificial lighting system is switched on.

If $\frac{E_{inside}}{E_{setpoint}} > E_{high}$ the artificial lighting system is switched off.

Typically, the couple of values (E_{low}; E_{high}) could be something like (0.5; 0.8) according to the features of the blind artificial lighting controllers (in particular the value of the parameter *move* and the illuminance provided by the artificial lighting system).

3. User not present controller

The complete scheme of this controller is shown in the figure 3.
The fuzzy controller block is already completely described in the LESO paper (Energy optimisation) dated 15.9.1998, so only the "Alpha converter" block is explained.

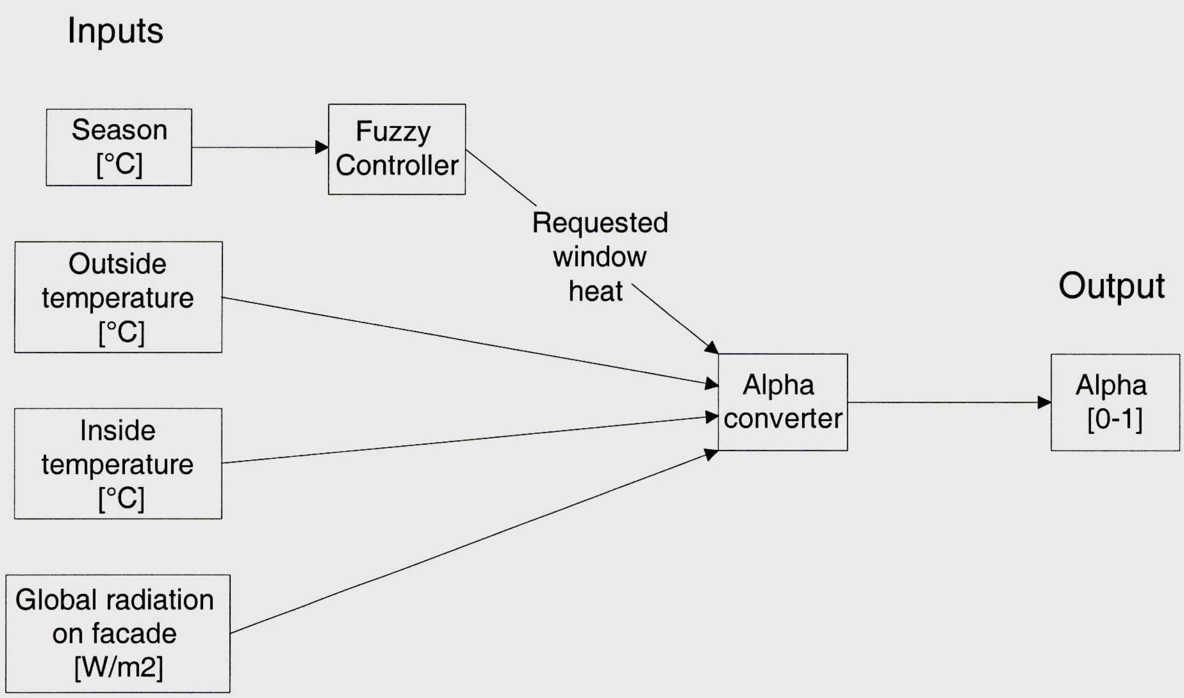


Figure 3: User not present controller

Alpha converter block (user not present case)

This block converts the "requested window heat" P_s [Watts] provided by the fuzzy controller in a value of a blind position (α).

The needed variables are:

- G_v: global vertical radiation on the facade, W/m2
- T_i: inside air temperature, °C
- T_e: outside air temperature, °C

The needed parameters are:

g:	solar radiation transmission coefficient of window
g_s:	solar radiation transmission coefficient of blind
k:	Heat-loss coefficient of window (without blind, W/m^2K)
R:	additional thermal resistance of blind (m^2K/W)

The relation is given by the following equation:

$$\alpha = \frac{P_s - G_v \cdot g \cdot g_s + k' \cdot (T_i - T_e)}{G_v \cdot g \cdot (1 - g_s) - (k - k') \cdot (T_i - T_e)} \qquad \text{with} \qquad k' = \frac{k}{1 + R \cdot k}$$

If $\alpha<0$ then $\alpha=0$
If $\alpha>1$ then $\alpha=1$

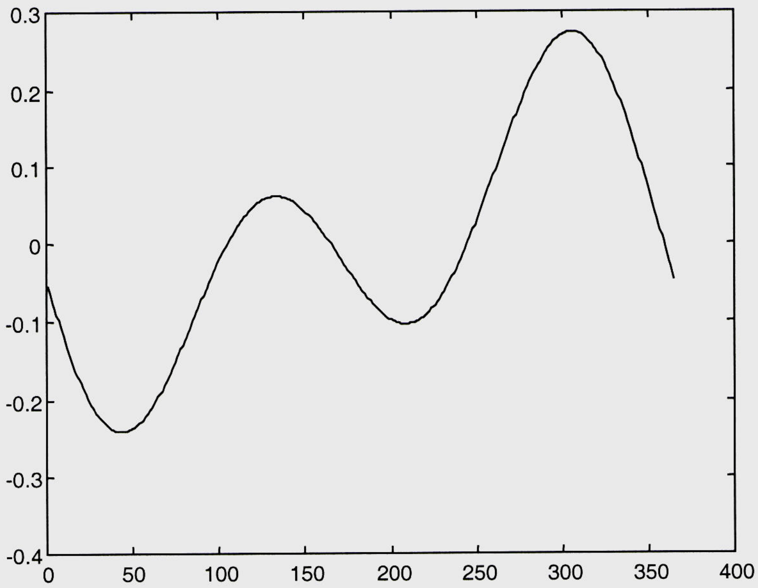
If the needed parameters are not known one may use default values, like the following ones:

$g=0.70$;
$g_s=0.20$;
$k=3\ W/m^2K$;
$R=0.16\ m^2K/W$;

Appendix

The "time equation" ΔH is shown graphically below.

ΔH [hour] is given in function of the day number.



The empirical expression is:

$\Delta H = 0.0072 \cdot \cos(da) - 0.0528 \cdot \cos(2 \cdot da) - 0.0012 \cdot \cos(3 \cdot da) - 0.1229 \cdot \sin(da) - 0.1565 \cdot \sin(2 \cdot da) - 0.0041 \cdot \sin(3 \cdot da)$

with:

day angle:	$da = 2 \cdot \pi \cdot n / 365$
day number:	$n = 1$, the first of January