Surface temperature of wooden window frames under influence of solar radiation

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Under influence of solar radiation the surface temperature of wooden window frames can reach values above 60 ^{0}C. High temperature can cause considerable tensions within the window frame; as a result joints can be cracked and rain water can penetrate into these joints. This penetration of rain water is often the start of considerable degradation of the window frame. Which surface temperatures can be reached depends on the colour of used paint and the orientation of the surface. The frame sill appears to be the surface that is most heated by solar radiation; window frames that are painted in a dark colour show the highest surface temperatures because of the relatively high absorption coefficient of dark coloured paints. Calculations with an dynamic model are made to predict which surface temperature can be reached on sunny days. It appears that surface temperatures up to more than 60 ^{0}C can be reached. To avoid these high surface temperatures light coloured paints are preferable.

Key words: sun radiation, surface temperature, wooden window frames

1 Introduction

From experience it is known that the total solar radiation on a surface depends on its orientation. Horizontal surface receive normally more radiation than vertical surfaces. Shadowing from others constructions parts or buildings will however reduce the total received solar radiation. The more radiation a surface receives the higher the surface temperature can rise. Furthermore the colour of the surface plays an important roll; dark coloured surfaces reaches higher surface temperatures then light coloured surfaces.
Which surface temperature can be reached on a sunny day is calculated with a dynamic model; in such model the heat capacity of the material is taken into account. The heat capacity is defined as the amount of heat (energy) that is needed to change the temperature of 1 kg material 1 degree Celsius (or Kelvin) and is expressed in J/(kg.K).

2 Solar radiation

The flux density of solar radiation on a surface normal to the sun's rays and beyond the earth's atmosphere is not constant but varies during the year. As the earth's orbit is not perfect circular but slightly elliptical and the solar radiation intensity varies inversely as the square of the sun-earth distance the maximum intensity is reached in mid-winter (for the northern hemisphere), when the earth is closest to the sun. The minimum intensity is reached in mid-summer and is about 7 % lower then the maximum value.
Furthermore the earth's axis is tilted at an angle of 23.5 degree to its orbital plane, therefore the solar declination also varies during the year (see figure 1)

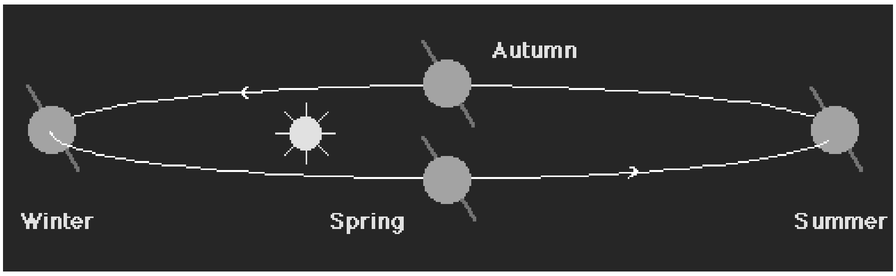

Figure 1: Solar declination during the year

At the 21st of March and September the declination is 0 degree; at the 21st of June the declination is 23,5 degree; at the 21st of December the declination is –23.5 degree.
In figure 2 the solar declination is given during a year; the days are number from 1 (1st of January) till 365 (31st of December).

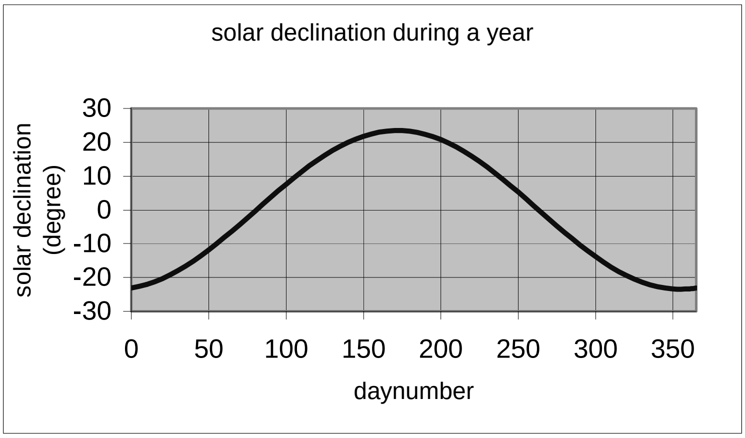

Figure 2: Solar declination during a year

As a result the flux density on a certain place on earth varies; this variation causes the changing of seasons and the unequal periods of daylight.

A surface can receive solar radiation directly radiated by the sun. However, passing through the earth's atmosphere the sun's radiation is scattered and absorbed by water vapour, ozon, dust and gas molecules. Some of the short wave radiation which is scattered reaches the earth in the form of diffuse radiation. Since this diffuse radiation comes from all parts of the sky its intensity is difficult to predict and is subject to a wide variation due to moisture and dust content. This is however the reason why surfaces facing (a part of) the sky can receive solar radiation, although the surface is not direct radiated by the sun. Besides direct and diffuse radiation a surface can receive radiation due to reflection from the ground or for instance buildings.

The direct solar radiation on a surface depends on the sun's position in the sky and the orientation of the surface. The solar position depends on the latitude L, the solar declination (δ) and the time. The solar position can be characterised by the solar altitude (or elevation) and the solar azimuth (see figure 3).

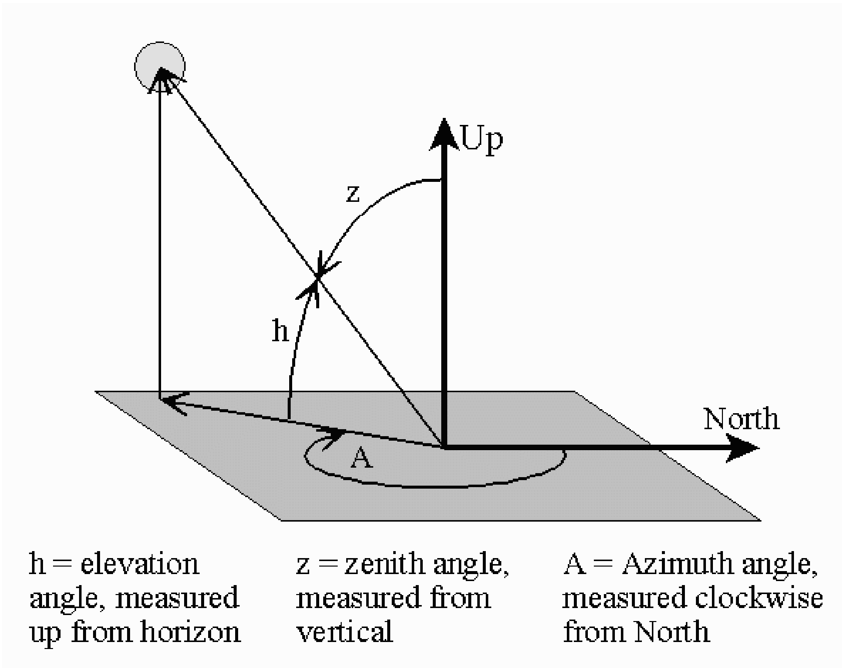

Figure 3: Position of the sun in the sky

The solar altitude (h) above the horizon and the solar azimuth (A_z) can be calculated by:

$$\text{Sin}(h) = \cos(L)\cos(\delta)\cos(t) + \sin(L)\sin(\delta) \qquad (1)$$

$\mathrm{Sin}(A_z) = \cos(\delta)\sin(t)/\cos(h)$ (2)

Where t is the hour angle, measured in relation to the south direction. The hour angle can be calculated by:

$t = 15.(Ts-12)$ (3)

where Ts = solar time .

Solar time is 12 o'clock when the sun reaches his highest position during that day. If differs form clock time due to the latitude, the date and the time zone. The difference between clock time and solar time can amount to about 50 minutes (+ 1 hour in the summer).

The incident angle on a surface (I) is related to the solar altitude (h), the surface-solar azimuth (A_{ss}) and the orientation of the surface (E = the angle of the surface from horizontal) by:

$\mathrm{Cos}(I) = \cos(h)\cos(A_{ss})\sin(E) + \sin(h)\cos(E)$ (4)

The value of the direct normal solar intensity (I_{dn}) – measured perpendicular on the direction of the sun rays - on the earth on a clear day varies during the year because of seasonal changes in the dust and water vapour content of the atmosphere and also because of the changing of the earth-sun distance.

The average value of I_{dn} during the year is given in figure 4 (see [1]). For very clear atmospheres (for instance in mountainous areas) the value of I_{dn} can be as much as 20 % higher; in very dirty atmospheres (industrial area) the value of I_{dn} can be as much as 20 % lower.

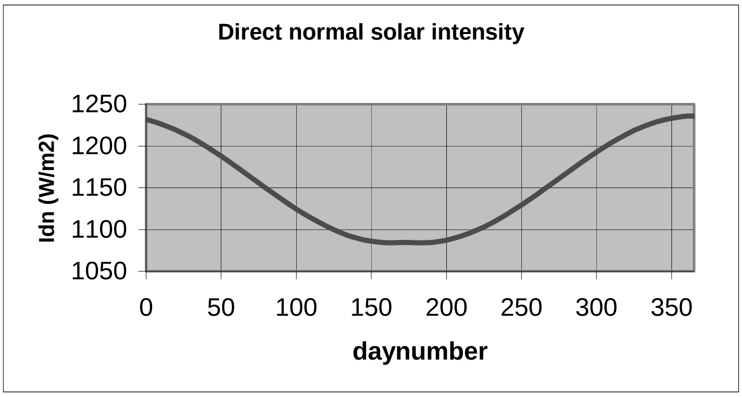

Figure 4 Direct normal solar intensity during the year

The diffuse solar radiation (I_{ds}) (see [1]) can be calculated approximately by the equation:

$I_{ds} = C.I_{dn}.Fss$ (5)

Where Fss is the angle factor between the surface and the sky. The value of C varies, like the value of I_{dn}, during the year; the values are derived from [1] and is given as a function of the day number in figure 5.

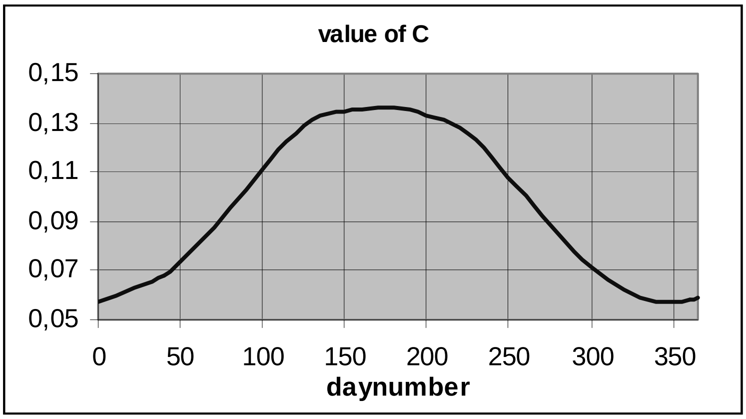

Figure 5: Value of C during the year

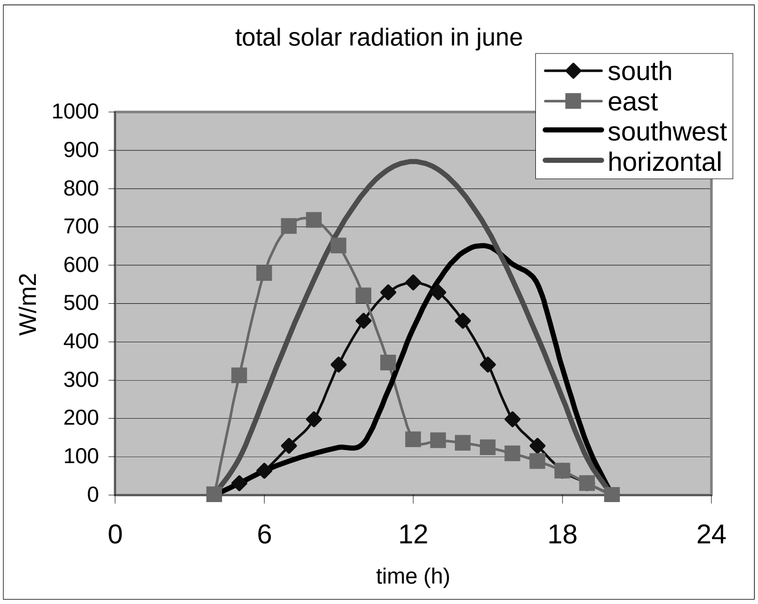

Figure 6: Total solar radiation in June for surfaces with different orientation

3 Solar radiation on a surface

The solar radiation on a surface depends on the orientation of the surface. A vertical surface facing east will receive direct solar radiation at sunrise, while a vertical surface facing west only receives direct radiation after noon (when the sun passes its zenith). A horizontal surface can receive solar radiation during the whole day when no shadowing from the surrounding area (like other buildings or constructions) appears. The total solar radiation (direct and diffuse) for different orientations is given in figure 6 for the month of June.
As can be seen in figure 6 a horizontal surface will receive the most radiation on a sunny day. A east facing (and also a west facing) vertical surface receive more radiation than a south facing vertical surface.
As a result the highest surface temperatures can be expected for horizontal surfaces.

4 Calculation of the surface temperature

The temperature a surface reaches under the influence of solar radiation is dependent not only on the total solar radiation but also on the air velocity at the surface and on the absorption coefficient of the surface. During a day the surface temperature normally increases due to the solar radiation and will therefore be higher than the surrounding air temperature.
Heat exchange with surrounding air increases with increasing air velocity at the surface. The highest surface temperatures can therefore be expected at calm, windless weather conditions.
The heat exchange between the surface and the surrounding air can be characterised by the surface coefficient of heat exchange or the α-value. Normally an α-value of 20 W / (m^2.K) for free convection (heat exchange due to differences in temperature between surface and surrounding air) is used.
The amount of solar radiation absorbed by a surface depends on the absorption coefficient of the surface; because wooden window frames are mostly painted the absorption of solar radiation depends on the absorption coefficient of the paint (a).
The absorbed total solar radiation can be calculated by:

$$I_{tot} = a \cdot (I_{dn} + I_{ds}).\cos(I) \qquad (6)$$

Dark paints have a higher absorption coefficient then light coloured paint. In table 1 some absorption coefficient are given for different coloured paints.

Table 1: The absorption coefficient for solar radiation for some paints

Colour of the paint	Absorption coefficient
White	0.25
Crème	0.35
Light yellow	0.45
Light green	0.50
Grey	0.75
Black	0.97

4.1 The increase of the surface temperature

For a standard used timber window frame in the Netherlands the increase of the surface temperature due to solar radiation is calculated. Theses calculations are made with a dynamic program; heat capacity of the material is taken into account.

The air temperature on the inside and the outside of the window frame is considered to be equal and constant, so the calculated increase of the surface temperature is fully the result of the solar radiation.

As an example the increase of the surface temperature for the frame sill of a window frame with east orientation is given in figure 6. For the absorption coefficient of the surface the value 1 (maximum possible value) is used.

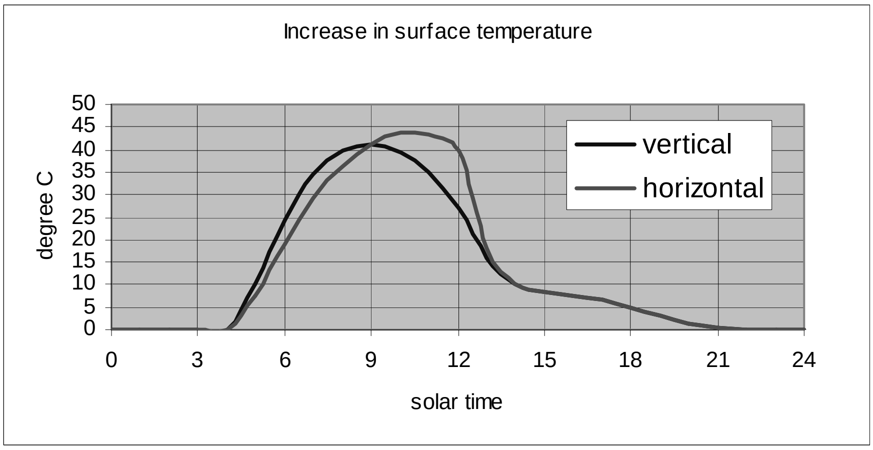

Figure 7: Increase of the surface temperature during a sunny day in June for an east orientated window frame

It is important to know that the time is given as solar time; this means that the sun reaches his highest altitude at12 o'clock'. The clock time in the Netherlands is about 40 minutes behind and in the summer even 1.40 hour behind.
As can be seen in figure 6 the surface temperature of the vertical front side increases more rapidly than for the horizontal side due to the fact that a vertical surface receives more radiation early in the morning. As the sun rises the incident angle on a vertical surface decreases where the incident angle on a horizontal surface increases. Eventually the surface temperature of a horizontal surface reaches higher values then on a vertical surface. Maximum is reached at about 10 o'clock.
A second example is given in figure 7; here the surface temperature is given for a vertical intermediate post with a south orientation.

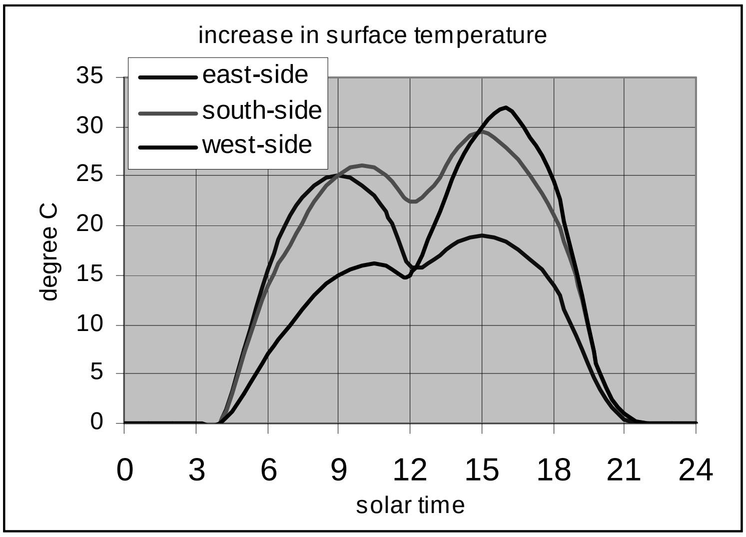

Figure 8: Increase in surface temperature for a sunny day in June for a vertical intermediate post

This figure shows a more complicated picture. The surface temperature on the east side of the vertical post rises more quickly as this part is radiated first. After about 9 o'clock the surface temperature drops but increases again after 12 o'clock influenced by the surface temperature on the front and the west side of the post. The surface temperature on the front side of the post decreases after about 10 o'clock because the incident angle on this surface decreases and the surface receives less radiation. In the afternoon the incident angle increases again and the surface temperature rises again, also under the influence of the surface temperature on the west side.

The surface temperature at the west side increases in the morning due to the surface temperature on the east side and the front; after 12 o'clock the west side receives direct solar radiation and increases more rapidly.

5 Maximum surface temperatures

The maximum increase of surface temperature is calculated for both sills and posts as an function of the orientation and the absorption coefficient of the surface (paint).
The results are given in table 2.

Table 2: Maximum increase of surface temperature (in degree Celsius) due to solar radiation

Absorption coefficient of the used paint		**Frame sill (horizontal surface)**	
	East in June	South in March	Southwest in June
0.6	26.0	24.3	28.1
0.7	30.7	31.8	32.8
0.8	35.0	36.4	37.5
0.9	39.4	40.9	42.2
1.0	43.8	45.5	46.9
		Intermediate vertical post	
	East in March	South in June	Southwest in August
0.6	19.4	18.2	19.3
0.7	22.6	21.2	22.6
0.8	25.8	24.0	25.8
0.9	29.0	26.9	29.0
1.0	32.3	29.8	32.2
		Side post orientated on the South, in June	
0.6		17.8	
0.7		20.8	
0.8		23.7	
0.9		26.7	
1.0		29.7	

Actual surface temperature can be obtained by adding the increase of the surface temperature due to solar radiation (table 2) to the outside air temperature. For the outside air temperature the maximum outside air temperature can be used.

In table 3 the maximum outside air temperature during the period 1998 – 2003 is given for the Netherlands for March till September.

Table 3: Maximum outside air temperature for the Netherlands in the period 1998-2003

	1998	**1999**	**2000**	**2001**	**2002**	**2003**
March	19.3	19.3	15.8	13.2	14.5	19.5
April	21.7	20.8	23.0	22.2	20.4	24.7
May	32.0	28.1	29.6	25.3	25.5	27.5
June	29.7	25.3	33.6	28.6	23.7	28.1
July	30.5	30.6	24.9	31.6	31.0	34.3
August	30.9	31.4	28.9	31.4	29.5	35.0
September	22.5	29.3	23.9	19.2	23.1	24.9

6 Conclusions

Table 2 shows the increase of the surface temperature which can reach values up to 45 ^{0}C above air temperature. From table 3 it is clear that air temperatures more than 30 ^{0}C are possible. Therefore surface temperature of dark coloured painted window frames can reach values of more than 75 ^{0}C. Such high temperatures can cause high tension inside the window frame and joints can be cracked. Penetration of rain water inside these joints can start degradation of the window frame.

Temperatures up to 60 ^{0}C must be avoided to limit these risks. This can be reached by applying light coloured paints.

References

[1] ASHRAE: Handbook of fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York (1968)

[2] Recknagel-Sprenger: Taschenbuch fur Heizung + Klimatechnik, R.Oldenburg Verlag GmbH, Munchen, Wien (1979)

[3] CRC Handbook of chemistry and physics, Edition 78th, 1997-1998