LONG-TERM INVESTIGATION OF THE ADVANTAGES OF ANTI REFLECTION TREATED GLASS COVERS EXPOSED TO REAL CLIMATIC CONDITIONS

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Abstract

Outdoor long-term side-by-side laboratory measurements during a Danish summer elucidate how much the transmittance for a glass cover can be improved in practice by antireflection treatment of the glass surfaces. The influences of water caused by rain and dew and dirt on the glass surfaces are included in the measurements.

During the test period the solar transmittance for the glass is increased by 8% due to the antireflection treatment of the glass surfaces. The measured transmittances are 2-3% lower than calculated transmittances based on measurements for the clean glasses. The antireflection treatment has no significant influence, negative or positive on the transmittance reduction caused by water and dirt attached to the glass surfaces during the summer period.

Keywords: Cover glass, antireflection treatment, solar transmittance, long term measurements

1. Introduction

Investigations have shown that the transmittance of a clean glass cover is increased by 5-9% by equipping the glass cover with antireflection surfaces by means of a liquid-phase etching by Sunarc Technology A/S [1]. The increase from 5 to 9% depends on the incidence angle. The investigations were carried out for different incidence angles in an outdoor solar tracker.

The surfaces of glass with the antireflection treatment are hydrophilic, which influences the time it takes for water caused by rain or dew to disappear from the surfaces. The hydrophilic surfaces might also influence the amount of dirt attached to the glass surfaces. The transmittances for cover glasses with and without antireflection treated surfaces might therefore in practice be different than the transmittances for the glass covers calculated based on measurements for clean glasses.
This paper describes long term measurements of the transmittance for an antireflection treated glass and a normal glass carried out as side-by-side tests in an outdoor laboratory test facility. The measured transmittances are compared to theoretically calculated transmittances based on transmittance measurements for clean glasses.

2. Transmittance measurements for clean glasses

Measurements have been carried out on two low iron 4 mm "Eurowhite" glasses from Euroglas GmbH. One of the glasses is equipped with the commercial antireflection surfaces prepared by means of a liquid-phase etching by Sunarc Technology A/S.

The transmittances of the two clean glasses were first measured in an indoor goniospectrometer test facility [2]. A ray of light from a tungsten halogen lamp is reaching the surface of the glass, which is installed in the test facility in such a way that the transmitted radiation through the glass is measured in a half sphere with a diameter of 2 m for different wavelengths. Measurements of the irradiance in the sphere are carried out with and without the glass installed in the test facility. In this way the transmittance, that is the ratio between the transmitted radiation and the total radiation from the lamp, is determined. Since the wavelength distribution of the lamp is not identical to the wavelength distribution of solar radiation, a correction based on the wavelength distributions of the lamp and the sunlight (ISO 9050) is done in order to determine the solar transmittance.

The glass in the test facility can be rotated through a vertical axis. In this way the incidence angle can be changed. The transmittance is determined for five different incidence angles: 0°, 30°, 45°, 60° and 75°. The measured transmittances as functions of the wavelength and the incidence angle for the two glasses are shown in figures 1 and 2. The transmittance is reduced for increasing incidence angle. The maximum value for the transmittance is for increasing incidence angles moving towards small wavelengths, especially for the antireflection treated glass.

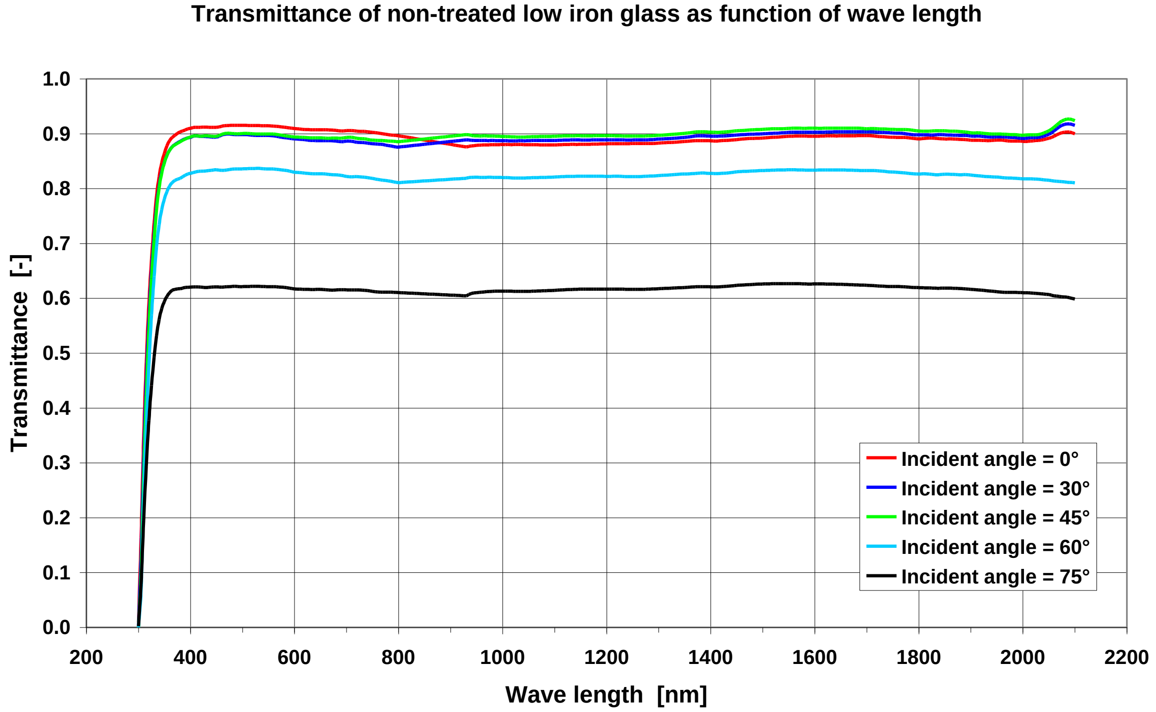

Fig. 1. Transmittance for the normal glass as functions of the wavelength and the incidence angle.

The measured solar transmittances for the two glasses are shown in table 1. The solar transmittance is increased by about 6-10 % point by the antireflection treatment. The increase is dependent on the incidence angle.

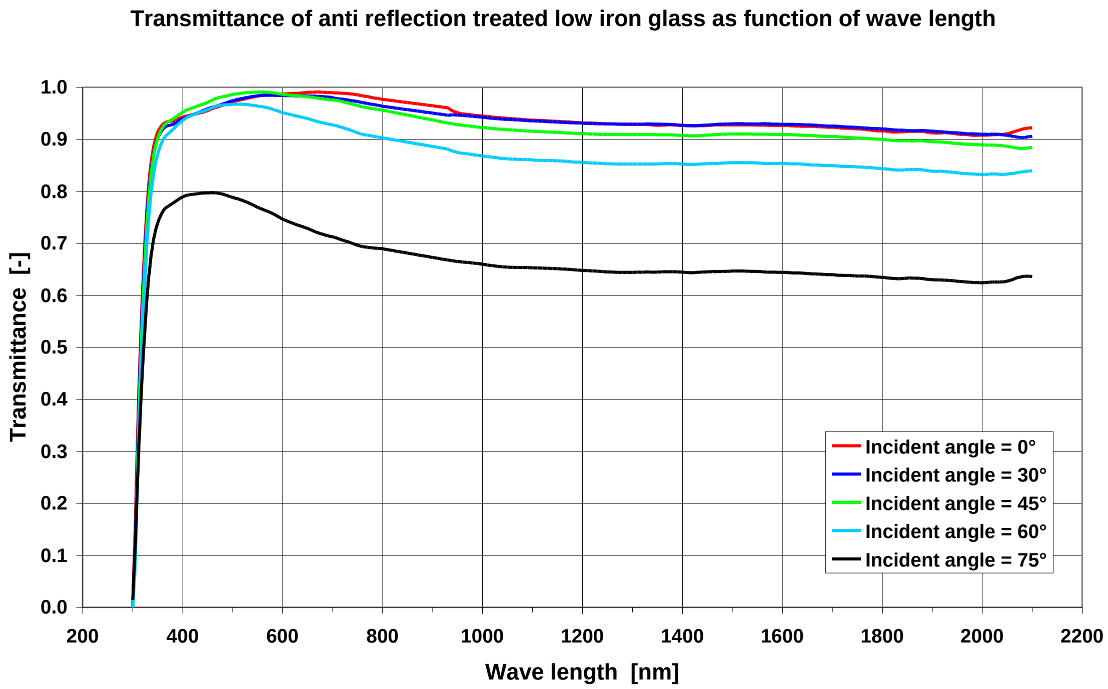

Fig. 2. Transmittance for the antireflection treated glass as functions of the wavelength and the incidence angle.

Table 1. Measured solar transmittance for the two glasses for different incidence angles in the goniospectrometer test facility.

Incidence angle	Normal glass	Antireflection treated glass
0°	0.904	0.960
30°	0.888	0.955
45°	0.893	0.950
60°	0.822	0.909
75°	0.615	0.711

The solar transmittances for the two glasses as functions of the incidence angle are shown in figure 3. Best fits for the solar transmittance of the direct radiation are found to be:

$$\tau_\theta^{dh} / 0.904 = 1 - \tan^{4.3}\left(\frac{\theta}{2}\right) \text{ for the normal glass} \quad (1)$$

$$\tau_\theta^{dh} / 0.960 = 1 - \tan^{5.1}\left(\frac{\theta}{2}\right) \text{ for the glass with antireflection surfaces} \quad (2)$$

where θ is the incidence angle, °

τ_θ^{dh} is the directional-hemispherical transmittance at the incidence angle θ, -

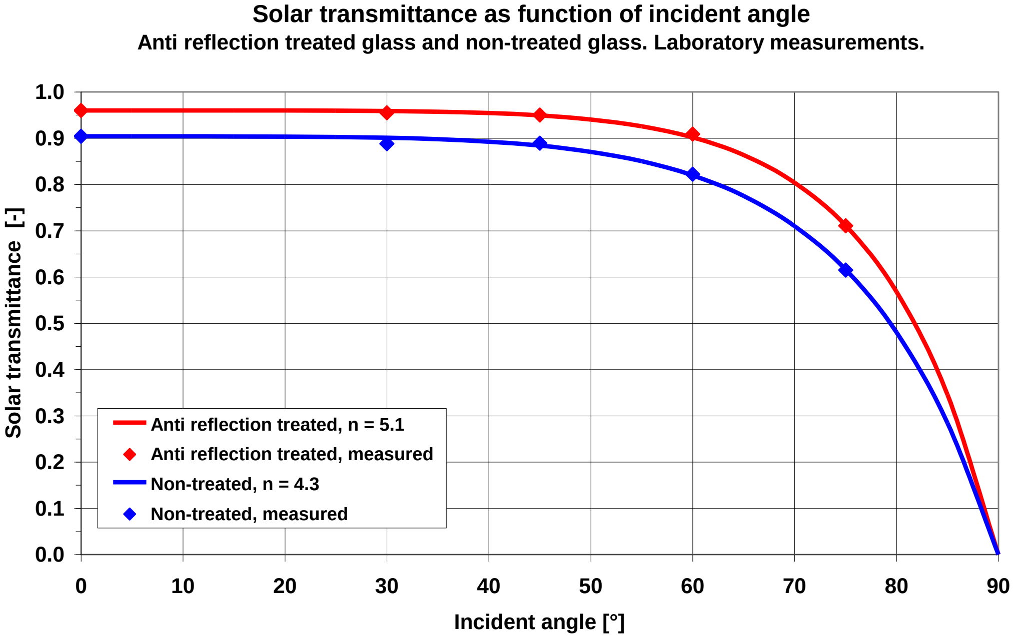

Fig. 3. Solar transmittance as a function of the incidence angle for the normal glass and the antireflection treated glass.

The diffuse-hemispherical transmittance τ^{dif-h} was measured in an outdoor laboratory test facility under weather conditions without direct solar radiation for the two clean glasses. The test facility is placed at the Technical University of Denmark, Kgs. Lyngby, Denmark. τ^{dif-h} is the ratio between the transmitted radiation and the total radiation on the glass under these conditions.

Fig. 4. Test facility used to measure the solar transmittance of two glasses. Left: Antireflection treated glass. Right: Normal glass.

The measurements were carried out in the test facility with four calibrated pyranometers, type CM 5 and CM11 from Kipp and Zonen. Before the tests started all 4 pyranometers were tested against each other after they have been put into position, but before the shadow ring and the glasses were installed to be sure they all gives the same output signal for the same solar irradiance. During the tests the pyranometers are measuring the total irradiance on the glasses, the diffuse irradiance on the glasses and the irradiances transmitted through the two glasses. The accuracies of the measured irradiances are estimated to be within 2%. The glasses are placed side-by-side on a 45° tilted surface facing 10° towards west from south, see figure 4.

Table 2 shows the measured results. The antireflection treatment increases the diffuse-hemispherical transmittance by 8 % points.

Table 2. Measured diffuse-hemispherical transmittance for the two glasses.

Glass	Total irradiance	Transmitted irradiance	τ^{dif-h}
Normal glass	167 W/m²	142 W/m²	0.85
Antireflection treated glass	167 W/m²	155 W/m²	0.93

3. Long-term measurements of transmittance

Long-term measurements of the solar transmittance of the two glasses were carried out in the outdoor test facility mentioned in section 2. Measurements were carried out in the test period April 30, 2008 – August 8, 2008. Due to problems with the measuring equipment measurements were not carried out in the period May 23 – June 2, 2008. Measured daily values for the total and diffuse radiation on the glasses are shown in figure 5. The daily rain amounts are shown as well. Figures 6 and 7 show daily transmittances for the normal glass and for the glass with the antireflection treated surfaces. The daily transmittances are the ratios between the daily radiation transmitted through the glass and the daily radiation on the glass surface.

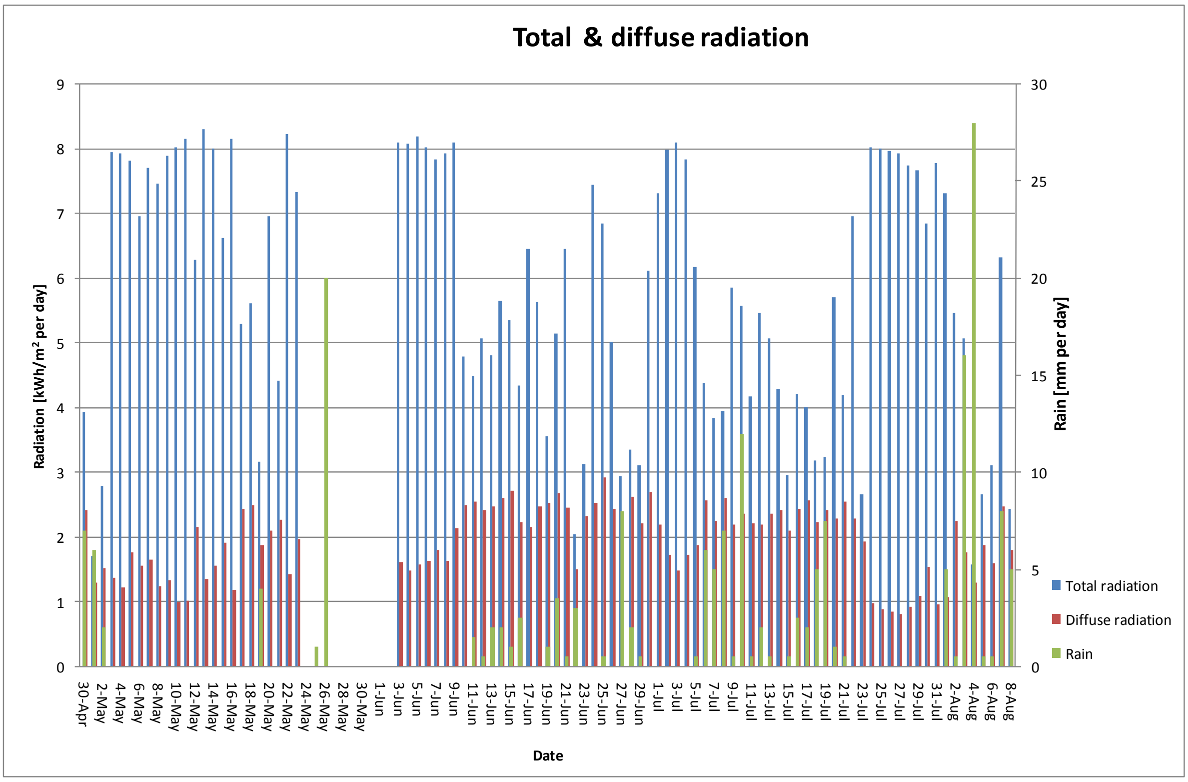

Fig. 5. Measured daily total and diffuse radiation on the glasses and daily rain amounts.

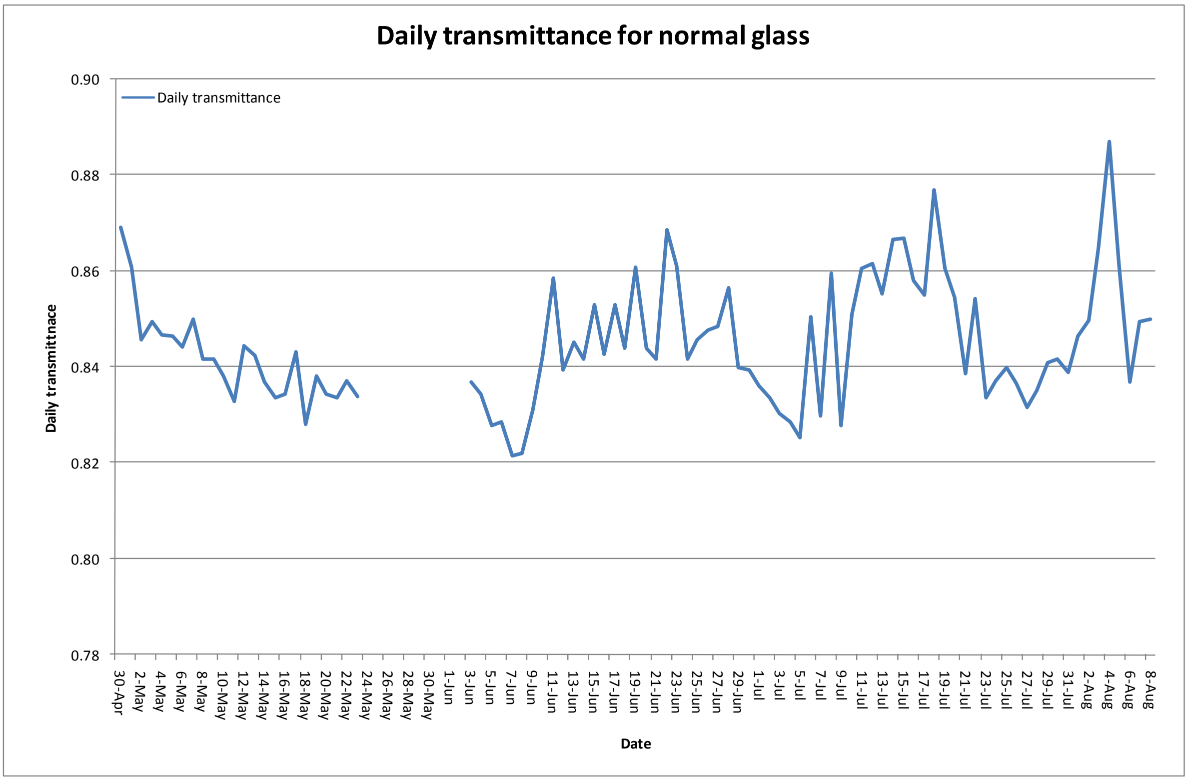

Fig. 6. Measured daily transmittance for the normal glass.

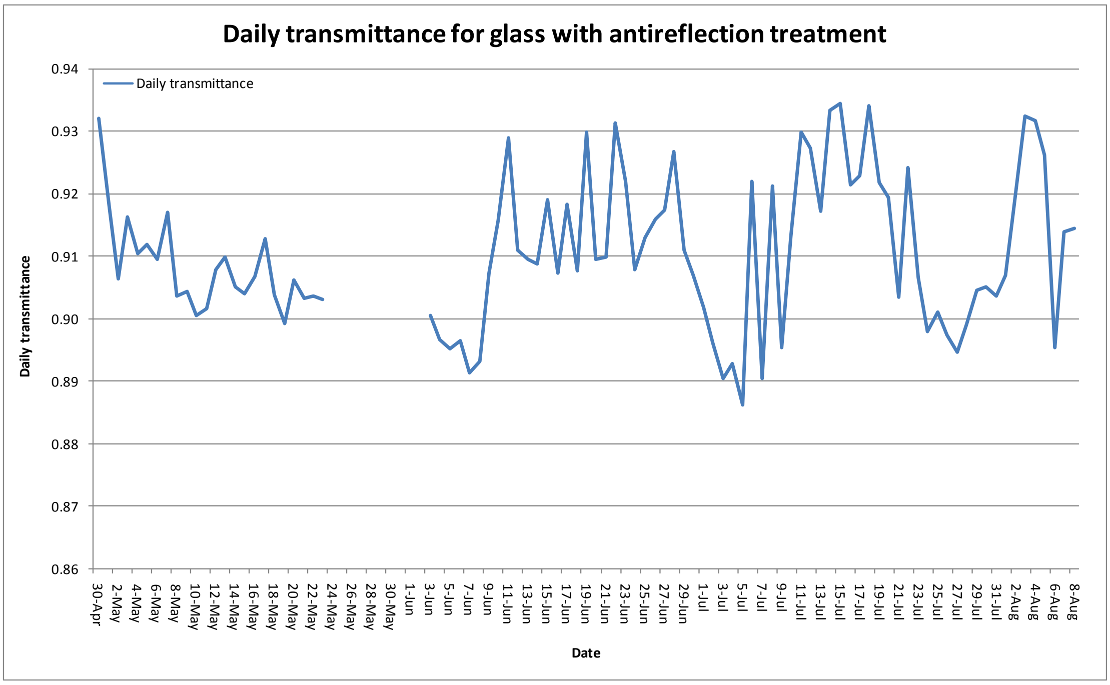

Fig. 7. Measured daily transmittance for the glass with the antireflection treated surfaces.

The measured daily transmittance for the normal glass is varied between 0.82 and 0.88, and the measured daily transmittance for the antireflection treated glass is varied between 0.89 and 0.93. For the whole test period the transmittances are 0.84 for the normal glass and 0.91 for the glass with the antireflection treated surfaces. The transmittance is for the whole test period increased by 8%, corresponding to 7 % points, by the antireflection treatment. The daily transmittance for both glasses is relatively low in sunny days without rain. This might be caused by dirt attached to the glass surfaces. The daily transmittance for both glasses is relatively high in rainy days and in days after rainy days. This might be caused by the fact that the glasses are washed clean during rainy periods.

The measured transmittances are compared to calculated transmittances based on the measurements for the clean glasses, that are the indoor measurements of the transmittances for direct radiation and the outdoor measurements of the transmittances for diffuse radiation.
The calculated hemispherical-hemispherical transmittances at a specific time are found by:

$$\tau^{hh} = ((E_d \cdot 0.85) + ((E - E_d) \cdot 0.904 \cdot (1 - \tan^{4.3}\left(\frac{\theta}{2}\right)))/E \text{ for the normal glass} \quad (3)$$

$$\tau^{hh} = ((E_d \cdot 0.93) + ((E - E_d) \cdot 0.960 \cdot (1 - \tan^{5.1}\left(\frac{\theta}{2}\right)))/E \text{ for the glass with antireflection surfaces} \quad (4)$$

where E is the total irradiance on the glass, W/m²
E_d is the diffuse irradiance on the glass, W/m²
θ is the incidence angle, °

Measured and calculated daily transmittances for the two glasses are seen in figure 8. The measured daily transmittances are up to 4% lower than the calculated daily transmittances for both glasses. The difference between the measured and calculated daily transmittances is relatively large in sunny periods and relatively small in periods with and after rain. The reason is as mentioned, most likely that the glasses are washed clean during rain showers.

The ratio between the measured solar radiation transmitted through the glass and the calculated solar radiation transmitted through the glass for the whole test period is 0.98 for the normal glass and 0.97 for the glass with the antireflection treated surfaces. That is: The transmitted solar radiation is reduced by 2% for the normal glass and by 3% for the glass with the antireflection treated surfaces due to dirt and water on the glass surfaces.

Considering the measuring accuracy it is concluded that the antireflection treatment has no significant influence on how much dirt and water attached to the glass surfaces reduce the solar transmittance during a Danish summer period.

The weather might influence the conditions and therefore the measurements will be continued during the autumn 2008 and winter 2008-2009.

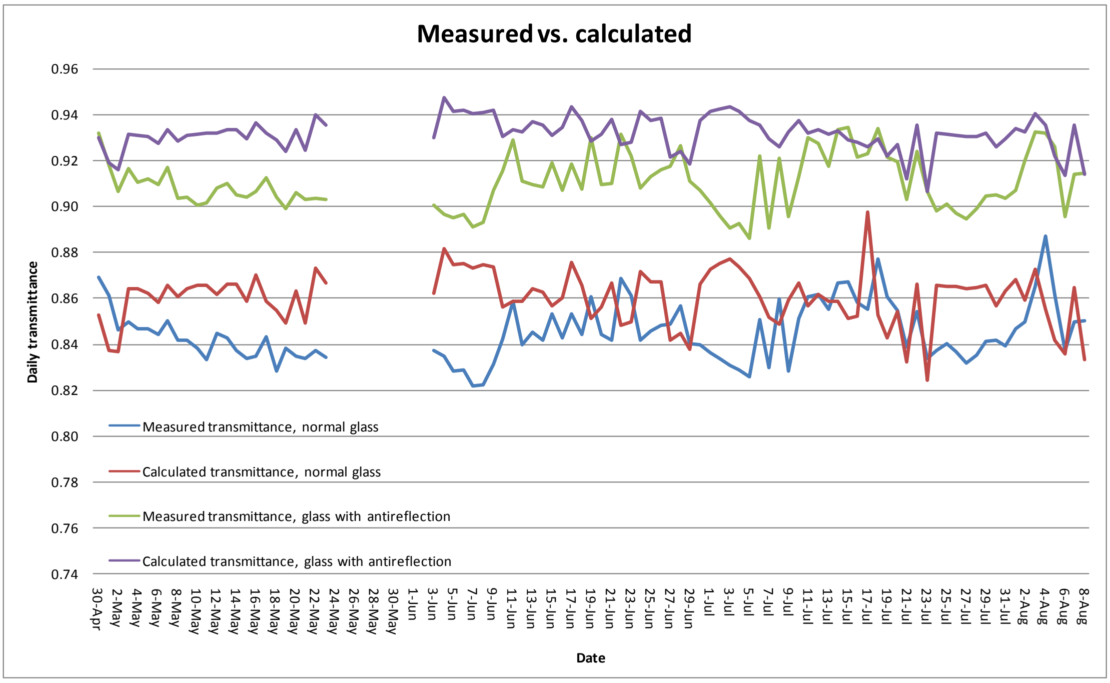

Fig. 8. Measured and calculated daily transmittances for the normal glass and for the glass with the antireflection treated surfaces.

4. Conclusion

Long-term side-by-side measurements of the solar transmittance for a normal glass and a glass with antireflection treated surfaces show that the solar transmittance is increased by 8% by antireflection treatment in a Danish summer period.

The measured transmittances in the summer period is 2-3% lower than the calculated transmittances based on measurements for the clean glasses. The antireflection treatment has, in the Danish summer no significant influence, negative or positive on the transmittance reduction caused by dirt and water attached to the glass surfaces.

Nomenclature

τ_θ^{dh} is the directional-hemispherical transmittance at the incidence angle θ, -

τ^{hh} is the hemispherical-hemispherical transmittance, -

E is the total irradiance on the glass, W/m²

E_d is the diffuse irradiance on the glass, W/m²

θ is the incidence angle, °

References

[1] S. Furbo & L.J. Shah (2003). Thermal advantages for solar heating systems with a glass cover with antireflection surfaces. Solar Energy 74, pp 513-523.

[2] J. Birck Laustsen & K. Johnsen (2008). Udvikling af værktøjer til at fremme energieffektiv anvendelse af solafskærmninger. Slutrapport for ELFORSK-projekt 337-094. Department of Civil Engineering, Technical University of Denmark, report no. R-187.