# CALIBRATION OF MODELS WITH MICROSHADE – PART II

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## ABSTRACT

This paper deals with the calibration of models capable of simulating the performance of MicroShade$^{TM}$. The function of MicroShade is similar to Venetian blinds, however, MicroShade is a microstructure embedded in a metal foil with a thickness of less than one mm. MicroShade has been modelled using the module in ESP-r for modelling bidirectional transmission through transparent multilayered constructions. Windows with and without MicroShade have been tested in two dedicated test rooms. The measurements from the test rooms have been used to calibrate the MicroShade model. The paper is a continuation of the paper (Jensen, 2009) which summarizes the results from (Jensen, 2008a). The present paper summarizes the results from (Jensen, 2010).

## INTRODUCTION

MicroShade$^{TM}$ is a microstructure of small holes. Figure 1 shows an example of MicroShade. MicroShade consists of many small super elliptically shaped holes manufactured in a thin stainless steel sheet – see figure 1. The holes have a tilting angle and resemble the way Venetian blinds function. However, the appearance is different and so is the view out as seen in figure 2 and 3. The screening off and view out through MicroShade are determined by the shape and tilting angle of the holes in figure 1.

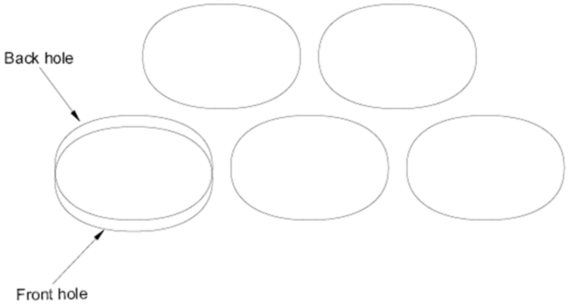

*Figure 1 Example of the holes in MicroShade. The width of the holes are less than 1 mm.*

Figure 3 shows MicroShade embedded in a low-e window. The name of this product is MicroShade$^{TM}$ IG (Insulated Glazing) but in the following it will be referred to as MicroShade windows.

The model of MicroShade is a matrix where the total direct transmission, the absorption in each layer of the window and the enhancement of incoming diffuse radiation due to the scattering of direct radiation in the MicroShade are listed for combinations of the horizontal and vertical incidence angle at steps of $5^o$. The values of the matrix are generated by a special purpose program where the main parameter is the projected hole area seen by the sun at different incidence angles and optical properties of MicroShade and glass. An example of the matrix is included at the end of the paper.

*Figure 2 The view out of a traditional low-e window with solar control coating and external Venetian blinds in test room B.*

*Figure 3 The view out of test room A with a low-e window with MicroShade.*

Figure 4 shows the function of MicroShade. Figure 4 shows the transmittance of direct solar radiation through the window in figure 3 and a traditional low-e window with solar control coating at an azimuth of 0°. During winter at low solar heights when solar heat is valuable the two windows let in almost the same amount of solar heat. But during summer at high solar heights and risk of overheating the MicroShade lets in considerably less solar heat than the traditional window with solar control coating.

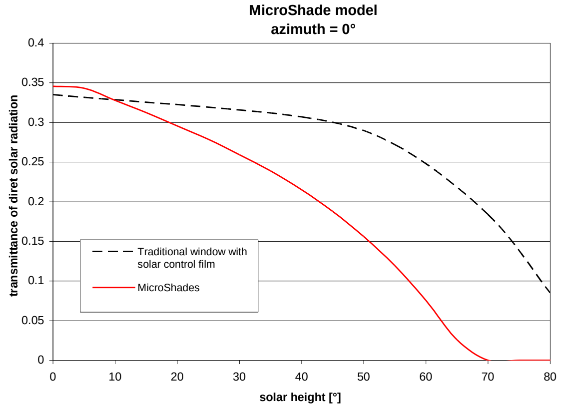

*Figure 4 The transmittance of direct solar radiation through the window in figure 3 and a traditional low-e window with solar control coating at an azimuth of 0°.*

## TEST ROOMS

MicroShade and traditional windows were tested side-by-side in two well-defined and heavily monitored test rooms at Danish Technological Institute, Taastrup, Denmark. The floor area and volume of the test rooms were 6.84 m² and 16.73 m³ respectively. The window of each test room consisted of two transparent areas totalling 1.98 m².

The test rooms, the thermo-physical properties of the materials of the test rooms and the monitoring system are described in detail in (Jensen, 2008b).

## RESULTS FROM THE FORMER PAPER

The matrix shown at the end of the paper was automatically generated by the earlier mentioned special purpose program where the input is the geometry of the holes shown in figure 1. For combinations of vertical and horizontal incidence angles of the sun, the program calculates the total transmittance of direct radiation, the absorption in each layer of the window and the enhancement of the transmitted diffuse radiation due to scattering of direct radiation in the MicroShade.

The matrix was used as input to the ESP-r module for modelling bidirectional transmission through transparent multilayered constructions (developed in the project (Technological Institute, 2005)).

Figure 5 shows an example of the calculated solar radiation through the window compared to the measured incoming solar radiation. Measured global and diffuse solar radiation on horizontal were used as input to ESP-r. Figure 5 shows that the model overpredicts the radiation through the MicroShade window.

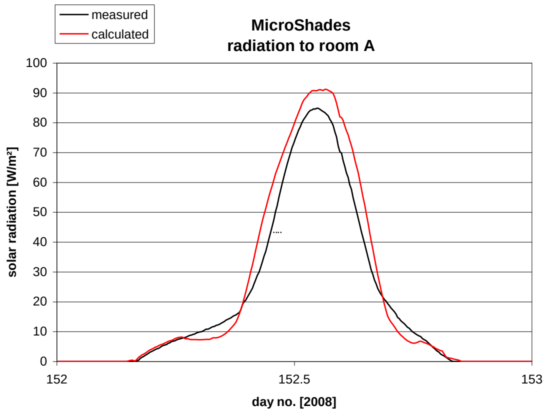

*Figure 5 Measured and calculated solar radiation through the MicroShade window - June 1, 2008.*

The matrix describing the MicroShade window was exposed to an empirical calibration – see (Jensen, 2008a) – which resulted in the calculated result shown in figure 6.

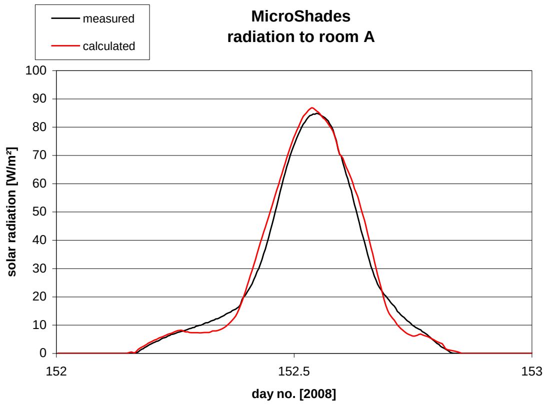

*Figure 6 Measured and calculated solar radiation through the MicroShade window after calibration.*

Figure 6 shows that calibration makes it possible to obtain good agreement between measurements and calculations. But how necessary is such a calibration? Simulations of an office building with MicroShade windows in the south-facing facade show that the difference in calculated cooling load when using the non-calibrated model is 15% higher than when using the calibrated model (Jensen, 2008a).

However, it is time-consuming and expensive to perform an empirical calibration of the MicroShade model each time a new version of MicroShade window is developed. Therefore, based on the result from the empirical validation, a new program for generation of the matrix was developed containing a more refined way to calculate the projected hole area depending on the vertical and horizontal incidence angle of the direct sun.

# CALIBRATION OF THE NEW MODEL

During the above-described calibration the MicroShade window was further developed. The holes in figure 1 were refined and the glazing just behind the MicroShade film (glass no. 2 from outside in figure 10) was omitted.

As in (Jensen, 2008a), the transmittance of diffuse radiation was obtained by using measurements from overcast days. The results from that exercise are shown in figure 7. Based on figure 7 the diffuse transmittance was chosen to be 0.185. Although the diffuse transmittance can be obtained through measurements a method for calculating that value should be developed although it is a complicated task.

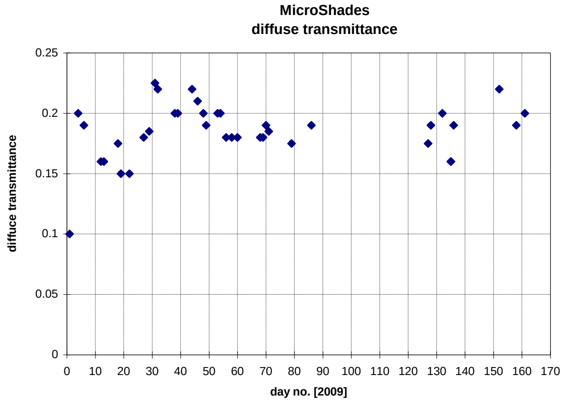

*Figure 7 The transmittance of diffuse radiation dependent on day number.*

As in (Jensen, 2008a) three periods were selected for the calibration exercise:

Winter: 27/1-21/2, 2010 – 26 days
Spring: 4/3-25/4, 2010 – 52 days
Summer: 2/6-17/6, 2010 – 16 days

Figure 8-10 show examples of the calculated solar radiation (with the new model) through the window compared with the measured incoming solar radiation. Figures 8-10 shows good agreement. However, over- as well as under-prediction are now observed.

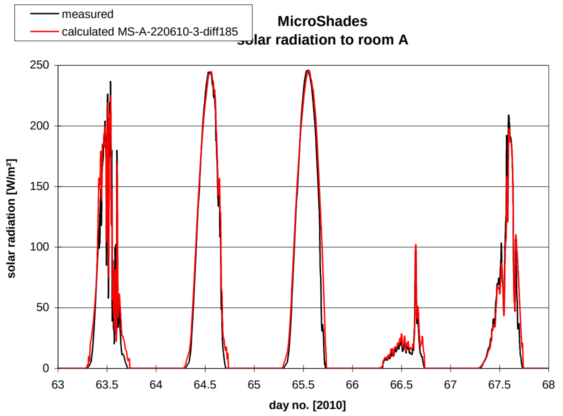

*Figure 8 Measured and calculated solar radiation through the MicroShade window using the new model – March 4-8, 2010*

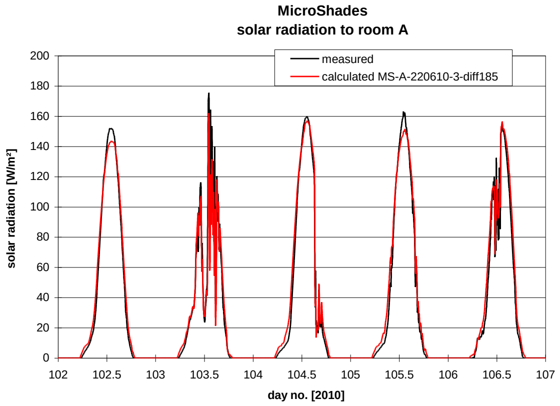

*Figure 9 Measured and calculated solar radiation through the MicroShade window using the new model – April 9-12, 2010.*

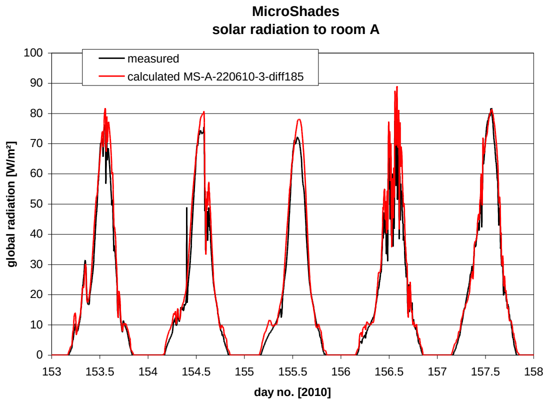

*Figure 10 Measured and calculated solar radiation through the MicroShade window using the new model – June 2-6, 2010.*

The calculations in figures 8-10 were performed with a fixed value for the enhancement of the diffuse radiation due to scattering of direct radiation in the MicroShade. The value was fixed to 3% of the direct solar radiation hitting the window. That value is most certainly angular dependent but no theory for obtaining time varying values has as yet been developed. The value does have a significant impact on the calculated incoming solar radiation as seen in figure 11 where the value was changed from 3 to 0%. On day 157 (figure 10) a perfect match changes to an under prediction of around 15% at noon.

In (Jensen, 2008a) and (Jensen, 2009) the calibration was performed by looking at graphs such as in figures 5-6 and 8-10. However, when over- as well as under-prediction is involved as seen in figures 8-10 this method is no longer sufficient. Instead correlation plots were utilized as seen in figures 12-14, where the calculated values are plotted against the measured values for the three periods – again for an enhancement value of 3%.

The values fall nicely around a straight line with a slope close to 1. However, some scattering is seen – especially for the winter period. That is inherited from the calculation of the solar radiation hitting the façade during the winter period as shown in figure 15. As the scattering in figure 12 is mostly re-found in figure 15, this can be disregarded and it is possible to concentrate only on the regression line. The scattering is mostly caused by an occasionally slight time shift between measured and calculated values during cloudy conditions (with drifting clouds) and is therefore not very important.

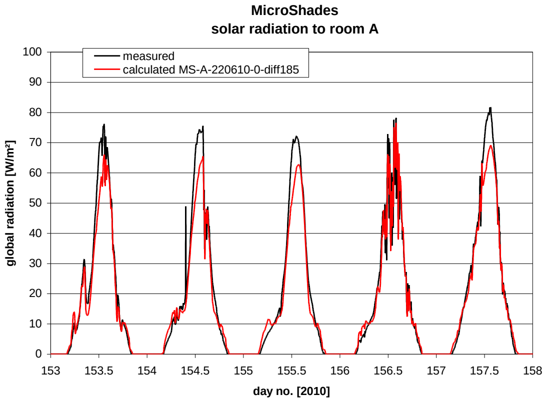

*Figure 11 As figure 10 but with an enhancement factor of 0 instead of 3%.*

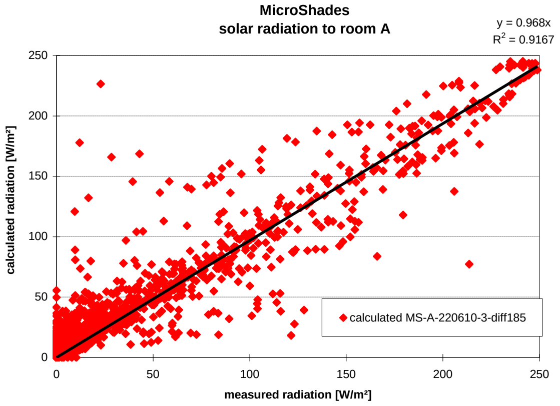

*Figure 12 Correlation plot for the winter period with an enhancement factor of 3%.*

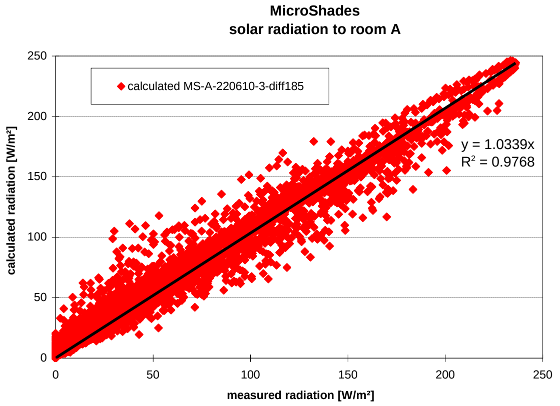

*Figure 13 Correlation plot for the spring period with an enhancement factor of 3%.*

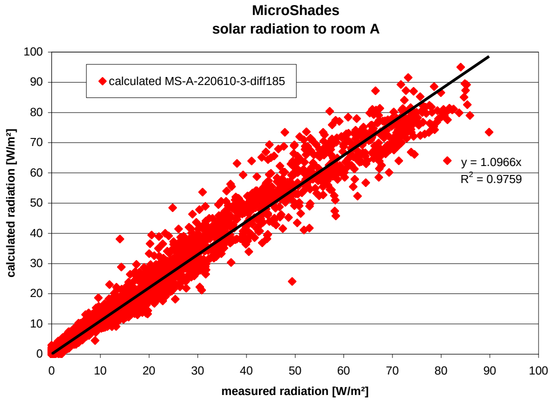

*Figure 14 Correlation plot for the summer period with an enhancement factor of 3%.*

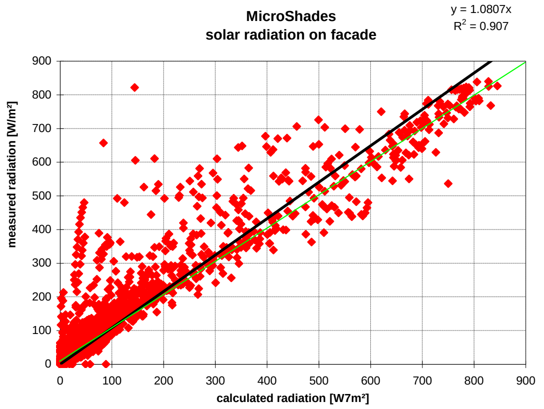

*Figure 15 Correlation plot for the radiation on the façade for the winter period.*

Table 1 shows how much the slope of the regression lines from the correlation plots differs from 1. The first row is for the radiation on the façade while the four other rows are for the solar radiation through the MicroShade window with different enhancement values (or scattering factors) in the matrix. The red oval-shaped rings show at which scattering factors the difference of the slope from 1 is identical with the difference of the slope from 1 for the radiation hitting the façade. From table 1 it seems as though a scattering factor of 2-3% should be preferred.

*Table 1 Comparison of the difference from 1 of the slope of the regression equations. Positive values mean that the calculations give higher values than measured.*

| | winter % | spring % | summer % |
|---|---|---|---|
| on facade | -7.5 | 7.4 | 3.5 |
| scattering: 0% | -8.7 | -7.1 | -6.1 |
| scattering: 1% | -6.2 | -3.6 | -0.8 |
| scattering: 2% | -3.6 | -0.1 | 4.4 |
| scattering: 3% | -3.2 | 3.4 | 9.7 |

However, the comparison in table 1 favours large irradiation levels as the regression line is forced to start in 0.0. Instead of regression lines, one could also look at integrated energy. Table 2 shows the integrated measured and calculated solar radiation hitting the façade. The scattering in figure 15 results in an over prediction of 25% for the winter period, while the over-prediction is more or less in agreement with table 1 for the spring and summer periods. Table 3 compares the integrated measured and calculated solar radiation through the MicroShade window. The measured energy is in table 3 both shown as measured and as enhanced with the percentage found in table 2 – the latter are the values in brackets. The red oval-shaped rings show where there is agreement between measurements (values in brackets) and calculations. Blue oval-shaped rings show where there is agreement between real measurements and calculations

*Table 2 Integrated measured and calculated solar radiation on the facade for the three periods.*

| solar ra, diation on the facade | winter kWh/m$^2$ | spring kWh/m$^2$ | summer kWh/m$^2$ |
|---|---|---|---|
| measured | 23,805 | 142,919 | 42,578 |
| calculated | 29,810 | 156,271 | 45,258 |
| difference | 25 % | 9,3 % | 6,3 % |

*Table 3 Integrated measured and calculated solar radiation through the window for the three periods.*

| solar radiation through the window | winter kWh/m$^2$ | spring kWh/m$^2$ | summer kWh/m$^2$ |
|---|---|---|---|
| measured | 6,096<br>(7,620) | 26,501<br>(28,955) | 5,428<br>(5,770) |
| scattering: 0% | 6,458 | 23,648 | 5,385 |
| scattering: 1% | 6,592 | 24,441 | 5,622 |
| scattering: 2% | 6,725 | 25,233 | 5,860 |
| scattering: 3% | 6,819 | 26,025 | 6,098 |

Table 3 shows that a scattering factor of 1.5 % gives a good agreement for the summer period when comparing with the value in brackets while a scattering factor of 0.5 % is best when comparing with the real measurements, while a scattering factor of above 3 % in both cases is necessary for the spring period. For the winter period a scattering factor below 0 % is necessary when comparing with the real measurements, while a scattering factor of above 3% is necessary when comparing with the value in brackets.

As a large part of the excess calculated radiation on the facade occurs in the morning and in the afternoon where large part of the radiation is reflected at the outer glass and screen off by the MicroShade it is believed that the right difference is somewhere in between the blue and red oval-shaped rings in table 3.

Using a scattering factor of 3 % gives then a mean difference between calculated solar radiation and the measured values and the enhanced measurements (in brackets) in table 3 of:

| | |
|---|---|
| Winter period: | 0.7% |
| Spring period: | -6.0 % |
| Summer period: | 9.0 % |

During winter, solar radiation is low where as a large part of solar radiation during summer is cut off by the MicroShade – see table 3. Therefore, focus should first be on fitting the scattering value for the spring period and secondly for the summer period - especially if mechanical cooling is necessary in a building.

Based on the above considerations it is concluded that when using a fixed scattering factor, 3 % is the best choice. A better agreement would probably be obtained if the scattering factor was made angular dependent. Although the agreement in table 3 is acceptable one may consider for future work to investigate the angular dependency of the scattering factor.

## CONCLUSION

The described work shows that via calibration using measured data from test rooms it is possible to obtain a model that represents the complex optical performance of MicroShade very well.

Two steps of calibration were performed. Initially the matrix describing the optical properties created by an special purpose program was calibrated in order to fit the calculations to the measurements. To achieve a better agreement between measurements and calculations it was decided to develop an improved program containing a more refined way of calculating the projected area of the holes in the MicroShade depending on the vertical and horizontal incidence angle of the direct sun. The use of the improved description of MicroShades revealed the need for calibration of the scattering factor. The scattering factor is describing how much of the direct solar radiation that is scattered in the Microshade.

Good agreement appeared for a scattering factor of 3%. However, that factor is most likely angular dependent so if a method for determination of the angular dependency of the scattering factor was developed it might be possible to reach even better agreement.

However, that raises the question: how far should one go when calibrating models? Calibration for perfection is very time-consuming and often impossible. And most often “good enough” is sufficient due to uncertainties we cannot control.

## ACKNOWLEDGEMENT

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#HorizontVertical, Transmittance, Absorb, Absorb, Absorb, Absorb, Absorb, Direct-diffuse
#Degrees, Degrees
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-90 -85 0 0 0 0 0 0 0
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```

diffuse transmittance

1th column: azimuth
2th column: solar height
3th column: total direct transmittance
4th column: absorption in the outer layer of glass
5th column: absorption in the PowerShade foil
6th column: absorption in the in the glass behind the PowerShade foil
7th column: absorption in the air gab of the window
8th column: absorption in the inner layer of glass
9th column: enhancement of diffuse radiation due to scattering of direct radiation in the PowerShade

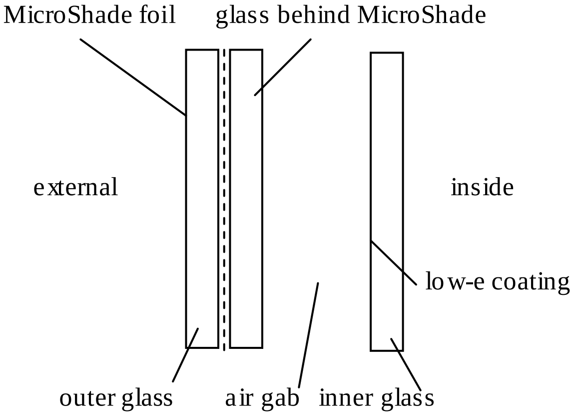

*Figure 10 Example of a MicroShade matrix. The matrix covers azimuths and solar heights from -90 to 90 ° with steps of 5 °.*