www.windat.org

Windows as Renewable Energy Sources for Europe
Window Energy Data Network

Project supported by DG for Energy and Transport
of the European Commission

contract NNE5-2000-122

Evaluation of Program Calculation Procedures according to Standards EN 673 and EN 410

Werner J. Platzer
platzer@ise.fhg.de
Fraunhofer Institute for Solar Energy Systems
(Fraunhofer ISE)
Heidenhofstr. 2, D-79110 Freiburg, Germany
Tel. ++49-761-4588-5131, Fax ++49-761-4588-9000

WinDat document N3.06 - Public **March 2004**

This document was produced within WinDat, with active contribution by the members of this European Thematic Network. See www.windat.org for more information.

Contact:

On benchmark cases:
The author of this report

On Thematic Network WinDat:
WinDat coordinator: Dick van Dijk, TNO Building and Construction Research, Delft, The Netherlands
Email: H.vanDijk@bouw.tno.nl

Research funded in part by
THE EUROPEAN COMMISSION
in the framework of the Community activities
in the Field of the specific programme for RTD and
demonstration on Energy, Environment and Sustainable
Development

1 Introduction

In the following document the so-called benchmark cases for glazing and shading device configurations are evaluated. Spectral input data for these cases have been provided and cases described in a previous document. In his project the benchmark calculations of different participants serverd two purposes:

Objectives:

- Evaluation of individual routines
- Check of scientific basis and implementation
- sensitivity to extreme situations

Scope:

- optical and thermal algorithms
- preset data input
- CEN and advanced may require different approaches

2 Description of procedures

2.1 EN673

The thermal transport calculations resulting in thermal transmittance L or U-value U or thermal resistance R for the glazing area, which are specified and described in EN673, may split up in several areas which can be checked independenty:
- gas properties of the filling gas ;
- convection and conduction coefficients in the gap(s)
- IR radiation exchange in the gap(s)
- emissivity calculations
- temperature dependance of the heat transport
- boundary conditions

2.1.1 Emissivity calculations

Emissivity calculations can be easily checked when the efective emissivity results from the programm can be seen in a report. In WIS this is not necessary because the user has to specify on its own the correct ed emissivity in the "Pane" definition. Therefore any possible errors converting from measured normal emissivity is not due to the program. For other programs one could check that by comparing several calculated corrected emissivities with a table given in EN673.

2.1.2 Gas filling with convection and conduction

The properties of the gases and the convection-conductive heat transfer coefficients may be checked easily by defining glazings with suppressed infrared radiation transport. If possibly the corrected emissivity zero for the surfaces adjacent to the gas space (gap) may be defined. If not, one has to extrapolate from a series of small emissivities to the value zero.

In a second step using these artificial non-emitting panes on may calculate the U-values depending on gas filling, on gap width and temperatures which are the relevant variables in the EN 673 calculations. It is simple to use the En 673 formulae for the convective heat transport directly within Excel and compare the result with the results of the evaluated program. Of course this should be one for double and triple glazings, because for triple glazings a possible error source could be to use the wrong boundary temperatures for one or both gaps.

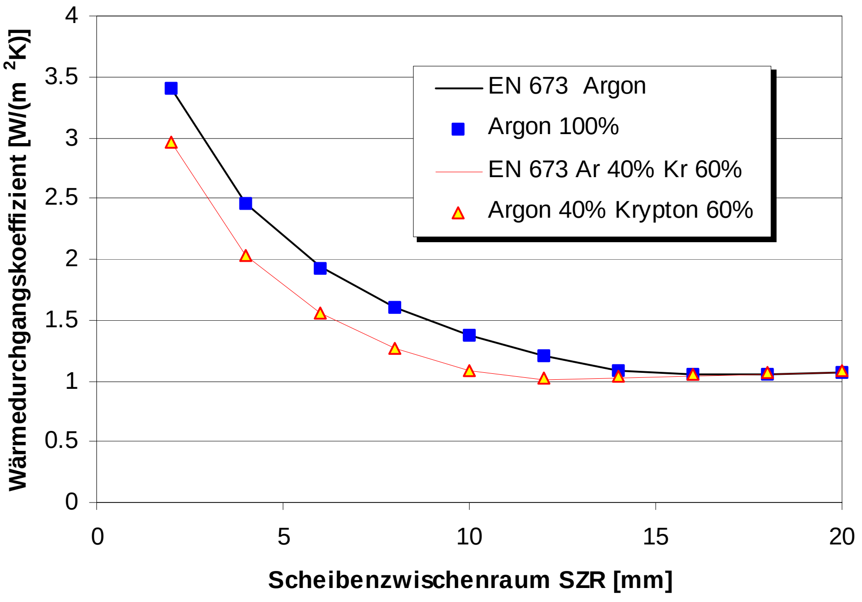

Figure 2-1: Example of convection heat transfer check using program output and direct calculation according to EN 673 for some gases and a range of gap widths (double glazing)

2.1.3 IR radiation exchange

When convective heat transport has been proven to be correct, the next step is to look at infrared radiation. Here we use panes with variable emissivities, calculate the complete glazing heat transport (U-value), and subtract the convective part. This can be done by subtracting the - already checked result - for zero emissivity. As the En 673 here just adds the two parts, this procedure yields the IR-transport, which again can be plotted versus corrected emissivity for program output and direct calculation.

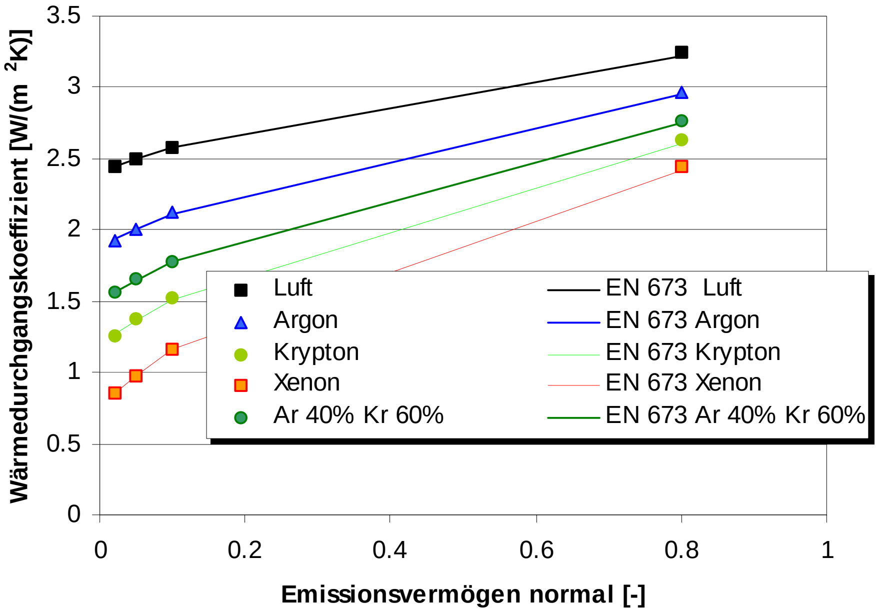

Figure 2-2: Example of infrared radiation check using a double glazing with panes of variable normal emissivity

It has to be clear that several varaitions must be checked:
- variation of lefthand emissivity of gap
- variation of righthand emissivity of gap
- possibly variation of both simultaneously
- double and triple glazing calculations
- for non-CEN mode calculations it is advisable to check also temperature variations using different boundary temperatures

2.1.4 Boundary conditions

If CEN mode only has to be evaluated there is only one specific boundary condition which has been used in all checks defined above. Thus there is no need of an additional evaluation step. A problem would have turned up in the comparison of probably bith, convective and infrared transport. However, when in an expert mode conditions can be varied, the dependence on temperature, slope, external and internal surface coefficients for example should be checked as well.

2.2 EN410

The standard EN 410 describes several algorithms working together which are used within the software WIS. There are several key issues which have to be checked in an evaluation.

- As WIS works only with optical data of glass panes with definite thickness we do not have to check the correct extrapolation to other substrate thickness for a specific coating. This is an issue which is possible within EN 410.

- Similarly we do not have to check the properties of a laminated glass consisting of layers of glass panes and a laminate film.

- It has to be checked wether the combination of a transparent system consisting of several glass panes is being calculated correctly from the individual constitutent properties. This concerns the spectral properties transmittance, reflectance and layer absorptance of the multiple glazing. This is called „spectral algebra“.

- From the spectral properties of the transparent system integrated solar and light values are calculated. These integrations have to be checked. This part is called „spectral integration“.

- The thermal transport due to convection and thermal radiation with in the gaps between the glass layers has to be determined according to EN 673

2.2.1 Spectral algebra

The formulae which are used for calculation of the spectral properties of the transparent glazing system are described in EN 410. They are used for each wavelength. Thus it seems to be sufficient to check the algorithm for a specific wavelenght. However, due to the different ranges of the spectrum (UV, light, solar) with different wavelength resolution there might be within a real program a case selection. Therefore it seems to be more safe to check each wavelength range individually. It is proposed to calculate some cases with different transmittance and reflectance values (e.g. because a reflectance of 0.0 does not reveal a problem with multiple reflections whereas a larger value for the reflectance does), using a “constant” spectrum. A different treatment of a certain spectral range leading to an error would be detected by a spectral step in the results. More advanced, piecewise constant spectra can be used when can be assured that the resulting steps are not occuring at the limits between the ranges UV, light and solar. The Figure 2-3 shows an example of such a test.

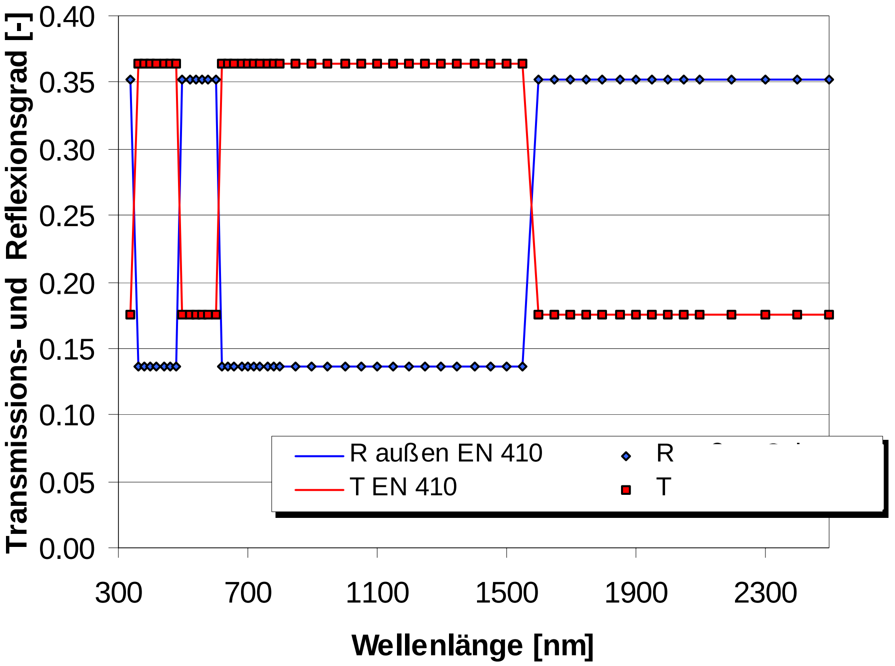

Figure 2-3: Example of spectral algebra with piecewise constant optical functions of the constituent glass layers showing constant results in between. The numerical value can be calculated for each constant piece of the spectrum manually (by pocket calculator) and compared to the result of the software.

2.2.2 Spectral integration

Spectral integration has several possible error sources. Firstly the mathematical numerical integration (a summation of product pairs of optical property times weighting function) may be wrong (e.g. wrong running indices). Secondly the used weighting function may be tabulated with errors.Thirdly in principle the input of spectral properties uses different sampling points than the tabulated weighting function. Therefore there has to be some method to interpolate the spectrum at the sampling points of the weighting function. From the standpoint of EN410 it is not specified how this spectrum point has to be interpolated from the measured input data.

The first items can be checked with the program by defining optical step functions e.g. a "transmittance" function with value 1.0 for all sampling points below a certain wavlenght and 0.0 above. The braod band solar integration of this spectrum is identical to the cumulative integrated spectral distribution provided by the standard. Thus any combination of the first two errors - either a wrong spolar spectrum or a numerical problem - would lead to a difference of these two quantities. In Figure 2-4 an example of a successful check for an inhose program is shown: all integrated "solar transmittance" results of all the step functions are on the cumulative spectral solar distribution curve.

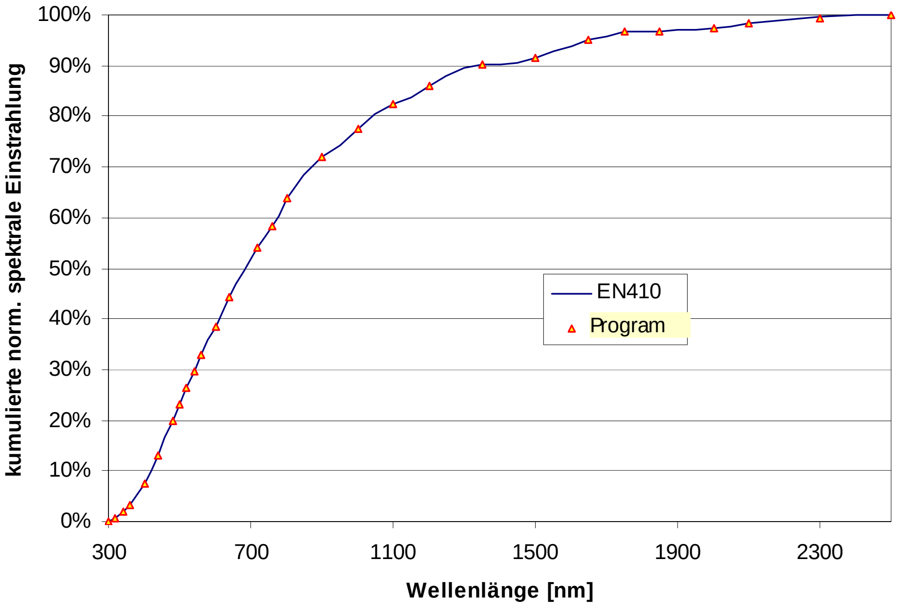

Figure 2-4: Example of check of spectral integration by plot of cumulative spectral solar distribution versus integrated broadband result of a program for spectral step function (step at the specified wavelength)

Following the generation of the EN 410 solar spectrum weighting function from the original data of Bird and Hulstrom, it is obvious that the weighting points at selected wavelengths for EN410 represent the energy content of the symmetrical wavelengtht intervall around this sampling point. The consequence is that from the optical function a value in this intervall should be taken representing best the transmittance or reflectance within this intervall. For an equally spaced subdividion of the intervall this is the arithmetic average of all the values in the intervall. In Figure 2-5 the import algorithm has been varied from "point sampling" to "intervall average" for a optical step function. One can see that there is a big local difference for the "representative" value - in one case it is still 100% whereas as average it would result in 50%. This would lead to errors in the order of +-0.02 for the class of step functions. In Figure 2-6 one can see the integrated solar transmittance of optical step functions with the step within 800nm to 900nm. When the step varies between 800 and 849nm the integrated result for pointwise sampling import would be identical. Only for the next small change 849nm to 850 nm, suddenly the result changes by +0.04! Obviously this isnot correct. Due to this problem the standard ASTM 893 explicitly defines the integration from spectra with high resolution wavelength steps in a way ensuring this intervall averaging. In the standard EN410 this is omitted.

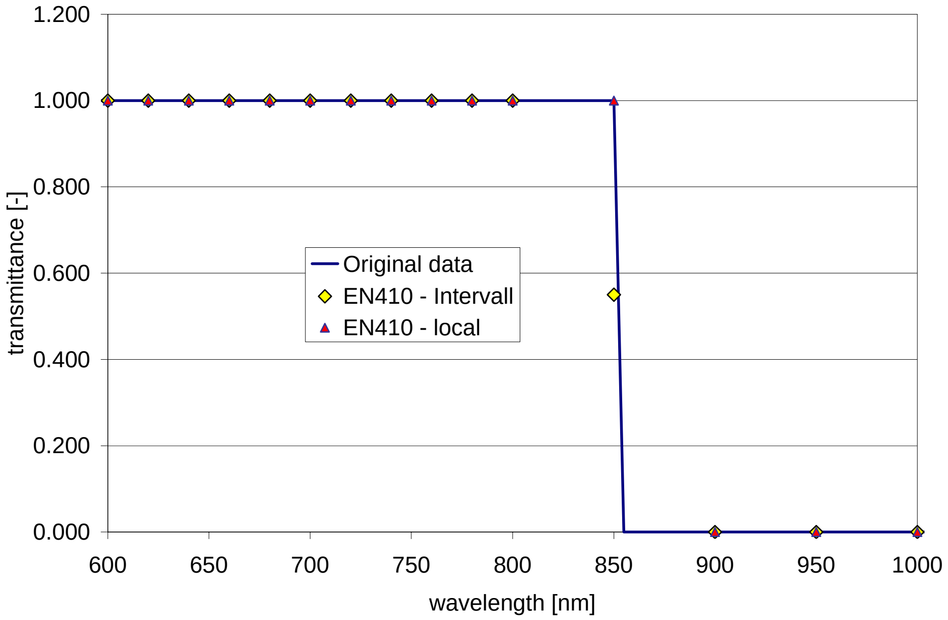

Figure 2-5: Example of spectral averaging check (check at wavelength 850 nm): Imported spectrum with step function having a step at 850 nm shows different values at 850 nm depending on import algorithm (a-taking interval average of [825nm, 875nm], b-taking value at wavelength 850nm)

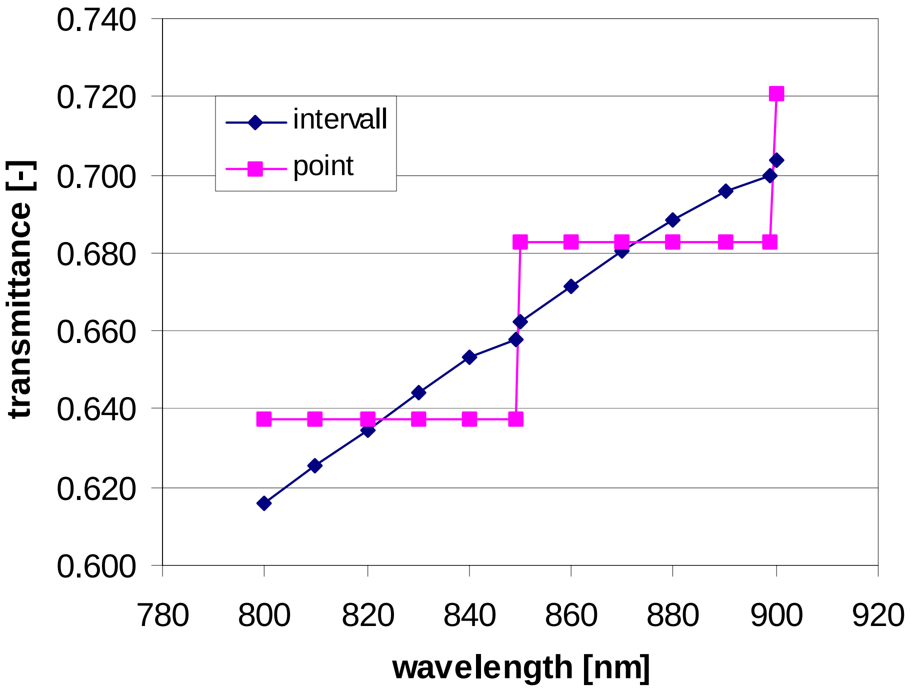

Figure 2-6: Resulting deviations of resulting solar integrated transmittance for step functions with specified wavelength depending on importing algorithm (pointsampling versus intervall averaging)

However, in practice, for smooth functions as they exist for glass substrates and coatings, without pronounced absorption peaks of polymer materials, the linearly interpolated value at the sampling point is sufficient. The difference in result is below +-0.002 in practical cases. This has been checked with samples of the WP2 round robin test.

EN410 does not explicitly specify integration procedure. For spectra of polymers the problem might be more severe due to the pronounced absorption peaks. Also for spectral experimental data with a relatively high white noise on the spectral measurement (e.g. for a measurement with low intensity and therefore low signal to noise ratio) an intervall averaging would filter out better this noise than the pointwise definition. We recommend therefore an addendum to EN410 saying that the correct treatment of imported optical spectra is that one should

-> produce the average value of spectra $X(\lambda)$ with N measured points within the wavelength intervall $[\lambda-\Delta\lambda, \lambda+\Delta\lambda*]$ symmetrical around the solar spectrum sampling wavelength λ by :

$$X[\lambda] = \Sigma X(\lambda) / N$$

and use that average for calculation of energy / light properties:

$$X_e = \Sigma X[\lambda] S_\lambda d\lambda$$

2.2.3 Thermal calculations g

When we have reached the point that optical calculations can be trusted on the spectral laevel and on the integration level, the remaining part is to bring that together with the thermal transport calculation and check the simple g-value formulae for single, double and triple glazings if EN 410 with integrated intermediate values of some benchmark cases. The formula can then be used directly with the input data solar layer absorptance and transmittance in conjuction with known heat trasnfer coefficients repsectiv resistances. This is a ratehr simple exercise.

2.3 Shading EN 13363-2

Shading: EN 13363
- calculation of blind optical data
- spectral calculations ?
- combination shading + glazing
- ventilation algorithms ?

Comparison of different tools?
- specular and diffuse blinds

3 General considerations

Some general considerations should round off an evaluation of a specific program. The general program operation should be a part of the evaluation. Do for example pull-down menus work properly? Are changes in glass properties reflected in the program output? Is it possible to define unphysical properties? The most important part here is to check the following two issues:
- is it possible to define a glass with negative internal transmittance?
- is it possible to define a glass violating the Kirchhoff law, with the sum of transmittance, reflectance and absorptance larger than unity?

One has to be aware that these sources of errors should be minimized by program operation rather than trusting the expertise of the experienced user of the program!

When there are different calculation modes, it should be verified that the CEN mode does only CEN calculations and gives warnings or no output at all when other properties are requested (e.g. in the CEN mode boundary temperatures or surface coefficients should not be variable).

Another feature of a program is the output. Of course it is possible to restrict output only to the main requested parameters like U-value or g-value. However the standards EN673 and EN410 require certain information on the calculated case. Moreover, for transparency of the results other information should also be available:

- nominal width of individual layers an gaps
- type of gas filling
- position of low-e coatings
- slope of glazing
- corrected emissivities of all layers
- internal surface coefficient h_i for low-e internal coatings
- U-value and total heat transport coeficient h_t of the glazing

- optical broadband properties of the individual layers (transmittance, reflectance fronat and back, absorptance within stack)
- total optical broadband results for complete glazings
- boundary conditions where different from standard

4 Conclusions

A general methodology for evaluating program operation according to standards EN410 and EN 673 has been presented. Mainly these checking procedures operate on isolating individual algorithms within the standards, and compare these with direct calcuations using the same input data (which might be intermediate results).

Using this approach a black box program operation can be analysed and correct operation gives confidence in the overall credibilty also in other cases. However, whenever a problem turns up, the analysis of the error source in most cases will need access to the computer code and has to be done in cooperation with the programmers.

5 Literature

[1] R.E. Bird, R.L. Hulstrom, Additional solar spectral data sets, Solar Cells 8 (1983), pp. 85-95