Proceedings of the 3rd Int. ISES Europe Solar Congress, Copenhagen, Denmark, 19-22 June 2000

THE ALTSET PROJECT
MEASUREMENT OF ANGULAR PROPERTIES FOR COMPLEX GLAZINGS

Werner J. Platzer
Dept. Thermal and Optical Systems, Fraunhofer Institute for Solar Energy Systems, Oltmannsstr. 5, D-79100 Freiburg, Germany, (49-761) 4588 131, (49-761) 4588 132, platzer@ise.fhg.de

Abstract – Within the European project ALTSET (Angular-dependent Light and Total Solar Energy Transmittance) the angular properties of so-called complex glazings (i.e. glazings with special optical properties) and shading devices have been investigated. The paper describes
- the comparison between direct calorimetric measurements and modeling from layer properties
- the important experimental factors for good interlaboratory comparison of results
- error analysis and evaluation procedure
- conclusions for the testing procedure.

The results show that using different approaches for apparatus design one can reach uniform results for well-defined reference conditions and has developed a test procedure for this purpose. Solar calorimetry is an indispensible methodology for all complex glazings like diffusing glazings, transparent insulation, shading lamellae and switchable glazings and can be used for validation of optical-thermal glazing models. But also for conventional glazings the accuracy is comparable with standard testing techniques.

1 INTRODUCTION

The objective of the project ALTSET (**A**ngular-dependent **L**ight and **T**otal **S**olar **E**nergy **T**ransmittance for Complex Glazings) has been the scientific development of European standard test procedures for the determination of angular-dependent total solar energy transmittance g and light transmittance τ_v for complex glazings and integrated shading elements. The emphasis was on harmonizing existing approaches with special regard to so-called complex glazings. These are glazings have innovative features which distinguish them from clear glazings with or without transparent low-e coatings.

Experimental procedures and calculation rules, error analysis and sensitivity studies for experimental conditions have been the main body of the project, as well as exhaustive experimental data for the products investigated. These data as well as the general findings shall serve the public in fenestration and building industry through publication.
The main issues of the project work in short have been:

- evaluation of existing optical and calorimetric test procedures
- development of a standard testing and calculation rule methodology
- generation of a comprehensive data set for complex glazings
- development of component models for complex glazings
- performance evaluation for complex glazings
- preparation of a standardization proposal for the test procedures

The role of the scientific partners was the further development of their individual test procedures and the scientific investigation of possible differences, errors and influences on the measurement result.

ISE	Fraunhofer-Institute for Solar Energy Systems, Freiburg, GERMANY
CSTB	Centre Scientifique et Technique du Bâtiment Saint Martin d'Heres, FRANCE
DBE	Department of Building and Energy, Technical University of Denmark, Lyngby, DENMARK
ENEA	Ente per le nuove tecnologie, l'energia, e l'ambiente, Dipartimento energia, Settore sistemi e componenti per il risparmio energetico S. Maria di Galeria - Roma, ITALY
TNO	TNO - Building and Construction Research, Dept. of Indoor Environment, Building Physics and Systems, Delft, THE NETHERLANDS
UWC	Division of Mechanical Engineering and Energy Studies, School of Engineering, University of Wales College of Cardiff, Cardiff, GREAT BRITAIN

There was a large industry involvement for the provision of samples to the group. The role of industry partners was on the one hand to discuss results and problems during measurements which were related to special samples. Information on glazing components was needed for modelling. The second important part of industry was the delivery of a sufficient number of reference and complex glazings for the measurements.

2 DEFINITION OF TOTAL SOLAR ENERGY TRANSMITTANCE (TSET OR *G*-VALUE)

The normative definition of the total solar energy transmittance g, as described in EN 410, is not useful in this context, as it cannot be traced back to the physical quantities measured in a calorimetric experiment. The definition has to be generalized on the basis of physics in order to make the discussion of the calorimetric test procedure understandable and fruitful.

There are two main driving forces for the net energy flow through a glazing separating inside and outside environment: the temperature difference between inside and outside and the solar irradiation. The total solar energy transmittance g quantifies the effect of solar irradiance, the U-value quantifies the effect of temperature difference. Because of convection and thermal radiation transport the interaction between these two driving forces is non-linear, hence a simple linear superposition is not possible.

The first step is to define a well defined physical quantity, which is valid for a set of arbitrary boundary conditions:

The total solar energy transmittance or g-value of a window system or component is defined as the difference between:

the total net energy flow per unit of area into the internal environment, due to incident solar radiation on the system and heat loss by transmission through the system,

and: the total net energy flow per unit of area into the internal environment, due to heat loss by transmission through the system with the same temperature and wind boundary conditions

i.e. the difference between the total net heat flow of the irradiated and the dark state

$$g = \frac{f(E) - f(E=0)}{AE}$$

where

ϕ transmitted total energy flow

A area of system

The second step is to define useful fixed reference conditions in order to get a unique characteristic value for g. These reference conditions have been chosen in order to guarantee equivalence between this reference value of g with previous normative definitions e.g. in EN 410.

One has to be aware that this reference value is only a special case of a generally defined quantity, which is a function of several environmental boundary conditions in reality.

3 DETERMINATION OF TSET

3.1 Component and calorimetric method

One has to be aware that two main approaches exist to obtain the TSET for any glazing system:

a) **calorimetric method**: direct calorimetric measurement of the solar and thermal gains (indoor and outdoor techniques)

b) **component method**: optical measurements of transmittance, reflectance and absorptance of individual component layers with large integrating spheres, measurement of thermal resistances, and combining these results in a calculation method.

ALTSET was concerned with utilizing both approaches for complex glazings, on the one hand developing the calorimetric test procedure, on the other hand developing suitable models for complex glazings.

The **calorimetric method** can be used for glazings without knowledge of their physical behaviour. The sample can be treated as a 'black box' unit. The advantage is the general applicability even for totally new facade elements.

The **component method** based on the principles of prEN 410 needs data on the individual components of glazings and had to be extended to as many glazing families as possible without loss of accuracy. A validation by the calorimetric method is needed for new models. The advantage of the component method is the possibility to combine different components for a series of similar products.

3.2 Principles of calorimetric testing

There are two main types of solar calorimeter test apparatus, both with subclasses:

The **irradiated hot-box** (to some extend comparable with a hot box test for measuring the U-value or thermal resistance, EN-ISO 12576): the test specimen is mounted in a construction separating illuminated (outside) from cooled (inside) environment. The cooling power needed in the cooled box is measured and, after appropriate corrections for heat loss by thermal transmission, is equal to the total solar energy transmitted through the test specimen.

Subclasses refer to the type of calorimeter: there are water and air calorimeters

The **irradiated hot-plate** (to some extend comparable with a hot plate or heat flux meter apparatus for thermal resistance measurements): the test specimen separates the illuminated (outside) from cooled (inside) environment. The heat extracted at the absorber plate is measured either caloricly by measuring the cooling power at the absorber plate or by heat flux sensors in the centre part of the absorber plate. With appropriate corrections for heat loss by thermal transmission, the extracted heat is equal to the total solar energy transmitted through the test specimen.

Subclasses refer to the absorber plate design: liquid cooled absorber plate; plate covered with heat flux meters; guarded hot-plate

With heat flux meter hot-plates local measurements at the centre of glazing far away from edge effects are possible, similarly with liquid cooled absorber plates with guard.

Other calorimeter designs need special experimental precautions to separate thermal and optical edge effects from the centre of glass effects.

4 SCIENTIFIC ACHIEVEMENTS

Within a first phase of the project the target was a validation of the different experimental approaches of the participants. Therefore a limited number of conventional glazings, which can be characterized using standard methods with uncritical extensions. The second phase, the main body of work dealt then with the characterization of the complex glazings either by direct testing or by modeling. From these experience and from theoretical sensitivity studies conclusion were drawen in order to develop a proposal for a testing methodology using solar calorimetry. For optical testing recommendations with respect to angular properties of complex glazings could be developed.

4.1 Comparative testing of conventional glazing products for validation

The objective of this work was to identify possible discrepancies based on methodology or equipment, which are not related to the complexity of a product. Three different glazing types were investigated thoroughly:

a) Float glass DGU U=2.8 W/m2K, τe=70%
b) K-Glass DGU U=1.7 W/m2K, τe =57%
c) Ipasol DGU U=1.1 W/m2K, τe =32%

In a first step the equipment of all partners was described and characterized for the purpose of internal discussion. It was important to characterize the used solar simulators. As well the spectral distribution as the extension of the simulator field have to be known. The latter one is important when one wants to define the incidence angle.

4.1.1 Calorimetric and component testing

An interlaboratory comparison of calorimetric measurements of the three reference samples described above was performed. Every laboratory used its individual test procedure developed to this point in the project. The data were analysed and compared. It turned out that mainly the evaluation procedure of the raw data had to be improved and not the testing procedure itself.

For the component approach the group had to determine optical data for the individual panes. This was done in cooperation with the ADOPT project (coordinator Univ. Uppsala, Dr. Arne Roos, SMT4-CT96-2136). Two sets of spectral angular data for two different polarization states were produced from CSTB (ALTSET/ADOPT) and Oxford Brookes (ADOPT). As expected especially the results for off-normal reflectance did not in all cases agree perfectly. The individual errors for the integrated values were in some cases as large as ±10% (not counted for very small p-reflectance values close to zero were relative errors of 80% could be found). One should acknowledge that the ADOPT programme in the meanwhile improved the procedures and accuracies of these measurements.

The methodology to calculate TSET from individual glass pane data as described in EN410 had to be extended to angular-dependent polarized properties. An Excel sheet for spectral data has been developed to be used for these calculations.

4.1.2 Results

Float Glass Unit

Every laboratory compared modeled data with measurements using the solar calorimeter.There was always good correspondence (Figure 4). The reference spectrum is Global AM1.5 (ISO 9845-1).

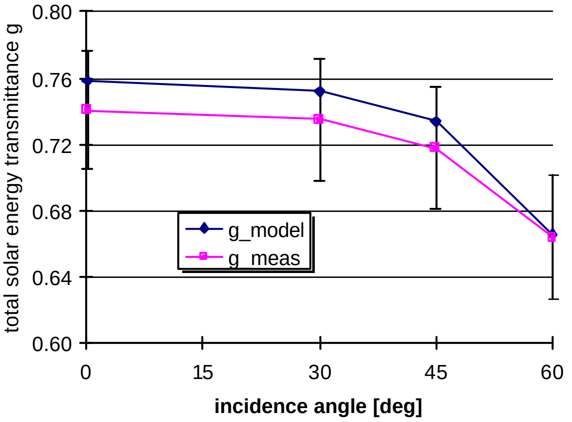


Figure 1: Comparison of calorimetric measurement with model prediction, Fraunhofer ISE Float DGU (error bars for model left out)

Although the experimental error bars taking into account calibration uncertainties and uncertainties of thermal resistance measurements, irradiance level and environmental temperature estimations from few measured data, are in the order of 5%, the deviation from model predictions is in every case within ±2.5%.

Coated Glass DGU

For coated glass units the measurements without correction showed large result intervalls due to the different solar simulator spectral properties. Because of the different solar simulators in the group measurements without spectral correction differed up to ±30% of the correct value. After correction this was reduced to less than ±8% for the most selective glazing (Figure 2). One can observe that for all incidence angles the difference between modelled and calorimetrically measured results for the very selective Interpane solar control glazing was in the range of ±0.02.

The difference between component and calorimetric testing is shown for a single lab in Figure 3. The specified value from the manufacturer (g=34%) is closer to the calorimeter ("measured") value.

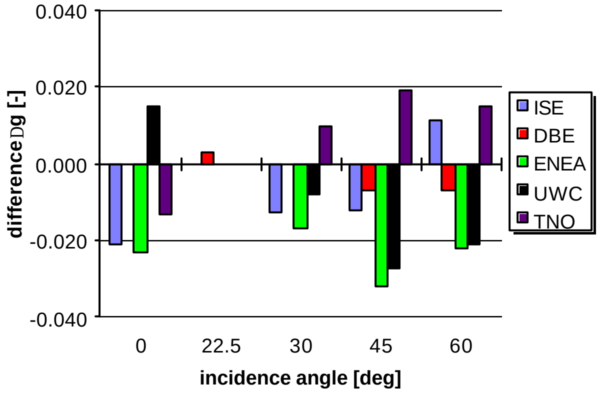


Figure 2: Difference between calorimetric measurements and model prediction for all labs Interpane DGU spectrally corrected

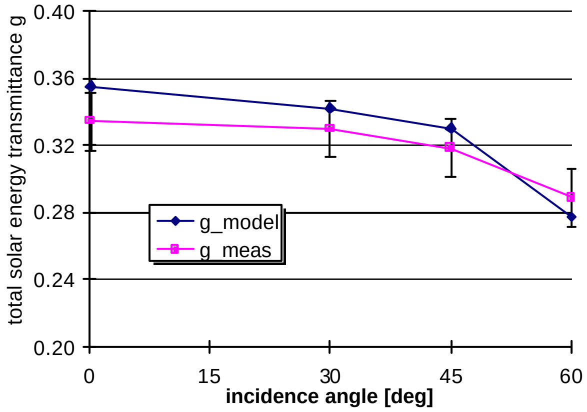


Figure 3: Comparison of calorimetric measurement with model prediction - ISE - Interpane DGU

4.1.3 Conclusion

From the results of this first project phase some implications seemed obvious:

- the idea of taking conventional glazings for calibration needs higher accuracy for the spectral input data; therefore the output of improved test procedures for angular-dependent spectral optical properties of glass pieces from the ADOPT programme is a prerequisite.
- the degree of homogeneity of locally bought glazings is not sufficient for comparison purposes without a careful data treatment; the variation of solar transmittance for a coated glass pane was as large as 0.02 or 3%.
- With state of art spectral measurements the modelled results and the results from calorimetric measurements have the same order of magnitude for the uncertainty. This is certainly a positive result for new method of calorimetric testing.
- Accuracy can be improved for calorimetric measurements specifiying experimental details that have not been observed carefully in the first series of measurements (e.g. mounting details, determination of irradiation level, minimizing simulator divergence, fixing environmental temperatures)
- The work necessary to produce good spectral data sets is quite appreciable; calorimetric testing seems not necessarily imply higher efforts and is therefore not only justified for complex glazings!
- Solar calorimetry is an economic way to test singular glazing prototypes; for a series of similar products testing of few components and a modeling approach (component model) should be preferred.

4.2 Testing of complex glazing products

The conclusions of the first phase led to improvements mainly in the data treatment and evaluation procedure. A common correction model and evaluation method was developed. In the second phase of testing several more complex fenstration products, for which existing standards do not apply in a well-defined way, were investigated. They are described in the following list:

ISOCLIMA (here after shortly referred as IS)		
Layers:	12 mm	Laminated glass / lamellar sheet
	12 mm	gap
	6 mm	float glass (inside)
ANGLIAN (AN)		
Layers:	4 mm	Float
	15.5 mm	gap, filling gas air
	4 mm	Float with frosted film (inside)
OKALUX (OK)		
layers:	5 mm	ESG low-iron Optiwhite
	30 mm	Kapipane (PC capillaries)
	10 mm	gap, filling gas Krypton
	4 mm	low-e coated glass
SAINT GOBAIN (SG)		
Layers:	6 mm	prismatic glass (outside)
	12 mm	gap, filling gas air
	6 mm	float glass
HUNTER DOUGLAS (HD)		
Layers:	4 mm	Float (outside)
	12 mm	gap, aluminum lamellae Thermostop
	4 mm	K-Glass (inside)

All of these samples present complexities, which make it difficult to perform angular light transmittance and TSET value measurements. Similarly the development of models to predict their optical and thermal behaviour is not an easy and straight-forward task. In Tables 1 and 2 a matrix is presented, where for each sample the different characteristics are highlighted that make the glazing "complex" for measurements, as well as for modeling.

Table 1: Measurement complexities of selected samples

Complexity	IS	AN	OK	SG	HD
Scattering/Diffusing		X	X		
Light Redirection			X	X	X
Shading Elements	X				X
Spectral Selective		X			X
Angular Selective	X			X	X

Table 2: Main model complexities of selected samples

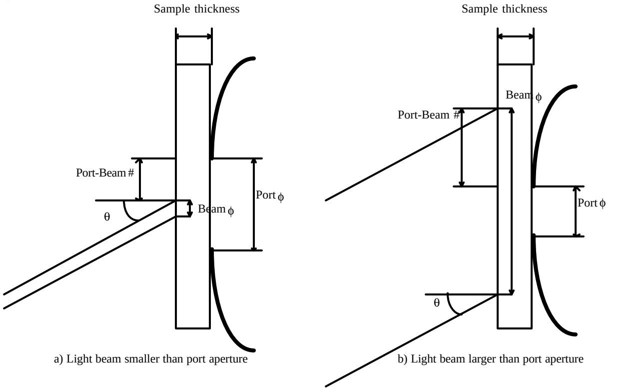
Complexity	IS	AN	OK	SG	HD
Geometry			X	X	
Internal Heat Exch.			X		X
Diffusing Layers		X			
Angular Variations	X			X	X

4.2.1 Optical testing

Table 3: Laboratories performing optical measurements

LABS	FACILITIES
ENEA	Integrating Sphere
CSTB	Integrating Sphere
ISE	Integrating Sphere and Spectrophotometer
UWCC	Goniophotometer

Due to the special properties of the selected glazings the equipment has to meet advanced specifications. Large integrating spheres were generally used for this purpose. All the devices were single-beam devices due to the large irradiation area required. In order to detect all light transmitted two different approaches were followed in the group for irradiation:



a) Light beam smaller than port aperture

b) Light beam larger than port aperture

Figure 4: Small-area and broad-area irradiation of sample

The partner CSTB was the only laboratory using method a) which requires for complex samples (diffusing layer, thickness in the order of several centimeter, internal structures) a large aperture and thus a huge integrating sphere. The Megasphere of CSTB has a diameter of close to 4m. For the other partners using broad-area irradiation (method b) a sphere size of approximately 0.6m to 1.0m diameter has been sufficient.

In order to be able to correct for the difference of reference spectrum and simulator spectrum the optical properties of the complex glazings were also determined spectrally using e.g. diode-array-spectrometers attached to the large integrating spheres.

Measurements were usually performed at 0, 15, 30, 45 and 60 angle of incidence on the five complex glazings. In Figure 5 an example for the spectral results obtained by CSTB, the reference laboratory for optical measurements, is reported. In Figure 6 the light transmittance values obtained on the Isoclima shading product by all labortatories have been compared. The comparison shows very good correspondence. In other cases with diffusing samples (Okalux and St. Gobain, Figure 7) the results were similar except that one laboratory deviated from all others. This was due to the measurement methodology, as a new technique with an photogoniometer was tried, measuring the transmitted light distribution angularly resolved. The integration over the hemisphere should yield the transmittance value to be compared with the other results. However, due to geometry reasons not the complete hemisphere can be scanned with this special instrument. Therefore especially for light-diffusing and redirecting glazing a part of the intensity is escaping and light transmittance is underestimated.

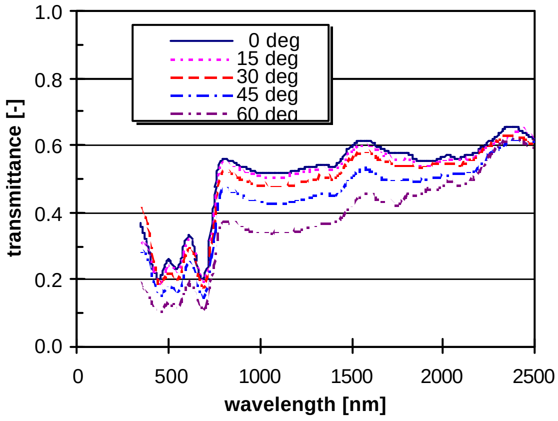


Figure 5: Spectral Transmittance of Anglian Sample (AN)

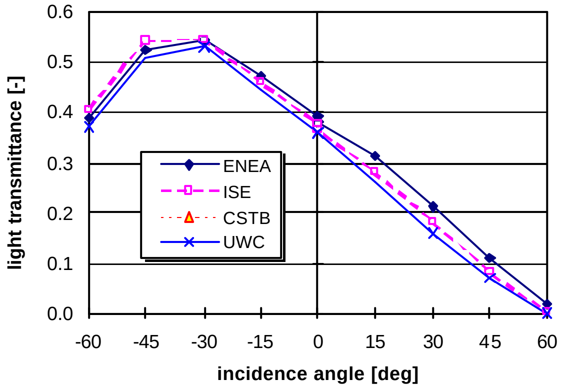


Figure 6: Light Transmittance comparison of Isoclima Sample (IS)

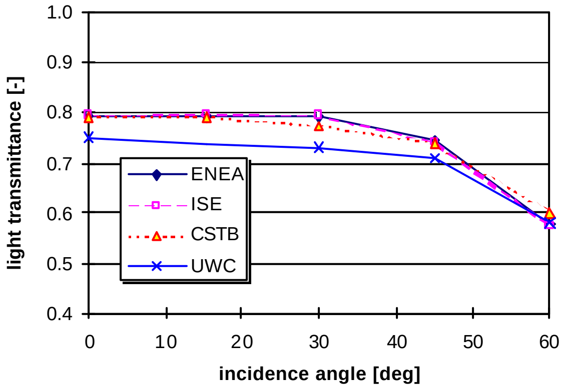


Figure 7: Light Transmittance comparison of the St. Gobain Sample (SG)

4.2.2 *Calorimetric testing*

Table 4: Laboratories performing calorimetric measurements

LABS	FACILITIES
ENEA	Hot Plate
TNO	Hot Plate (with fluxmeters)
ISE	Hot Plate (with fluxmeters)
DBE	Hot Box
UWCC	Hot Plate

The results of this comparison were elaborated using a common evaluation method. In such a way eventual differences, due to not homogeneous calculation and correction procedures, were avoided.

The resulting g-values of the Isoclima sample (IS) mentioned above as well as the Okalux sample (OK), are plotted in Figure 8 and Figure 9. In the graphs also the error estimation declared by each lab is reported. These two samples types showed relative large variations of results to be analysed whereas for the samples from Anglian and Saint. Gobain good agreement was obtained. The shading product of Hunter-Douglas can be discussed in a similar way as Isoclima.

In most of cases it was possible to find an overlapping area that shows congruence among all measurements. In that case upper and lower limits of existence are plotted as lines.

Where this is not the case (Figure 8), such remarkable discrepancies can be due to several facts in principle:

a) systematic problems of the measurements
b) wrong estimation of error band.
c) differences among samples.

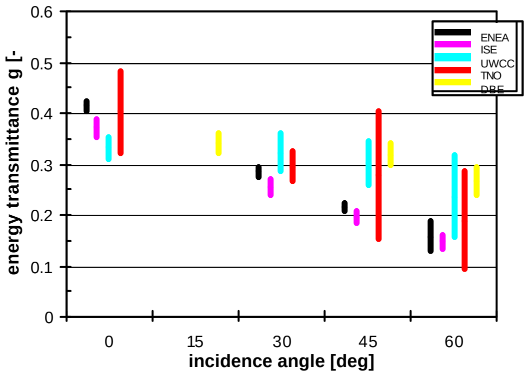


Figure 8: TSET error analysis of Isoclima Sample (IS)

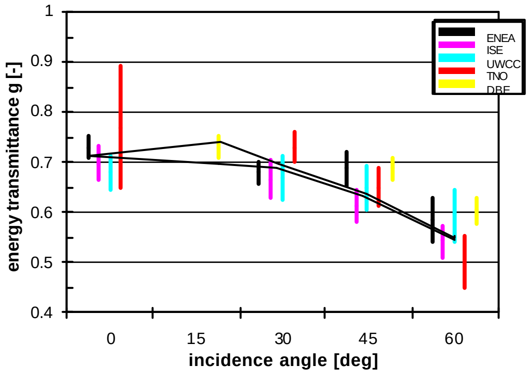


Figure 9:TSET error analysis of Okalux Sample

Especially the results for Isoclima and Hunter-Douglas, the solar shading products are remarkable. There are relatively large discrepancies between individual labs that cannot be explained by the usual experimental error. Although inspection of the products showed some variations of the slat tilt angle locally this cannot be the reason for the large differences in results - otherwise the light transmittance should show similar discrepancies (case c). It is obvious that the error bands given by the labs do not include systematic problems (case b). However, a systematic problem turns up in these cases (case a). The different lamp fields of the laboratories produce divergent irradiation around an average incident angle. For labs with a large field (UWC, DBE) the divergence is large and therefore especially for incidence angles around cut-off the transmittance is overestimated (as a part of the solar simulator field still shines through the slats, see illustration Figure 10). For the Hunter-Douglas product an additional source of uncertainty is the tilt angle of the lamellae or slats - there is a setting error of about 3 degree for horizontal slats and about 5 degree for tilted slats.

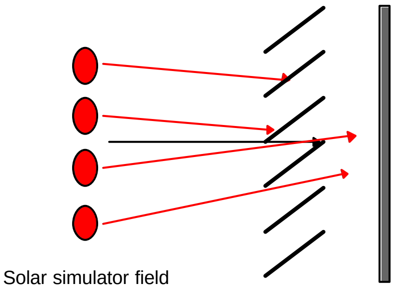


Figure 10: Impact of divergent irradiation by extended solar simulator for cut-off position for nominal incidence angle

In general for large fields the divergence of the source is larger than for small fields which means that the angle is not very well defined. Especially for situations where the transmittance curve has a large second derivative, errors due to divergence are introduced (Figure 11).

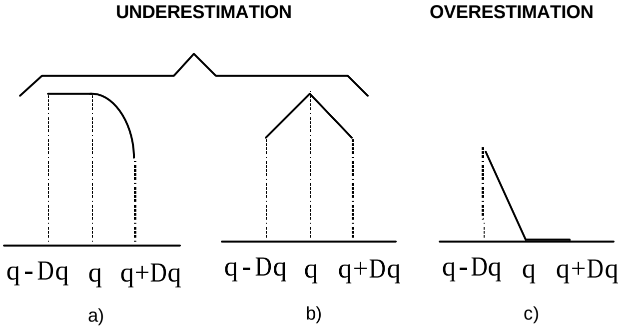


Figure 11: Situations where the light source divergence will introduce not negligible errors

For Isoclima situation c) should have a maximum effect for incidence angle 45 degree. Here the relative differences between labs with large simulator fields and those with smaller divergence indeed are prominent. As a consequence we may say that simulator divergence should be minimized for angular selective samples. But even then some overestimation according to situation c) in Figure 11 can be expected. A possibility for correcting this effect is currently under investigation.

5.2.7 Conclusions

From the section on optical measurements with integrating spheres the following considerations can be inferred:

- The mean deviation is in most of the cases is around a tisfactory 2-3%, even at high angles of incidence.

The research on light transmittance on complex glazings highlights a good agreement of results among the participant labs. Higher discrepancies are found out for a goniophotometer when dealing with scattering samples.

From the section on calorimetric measurements one is led to the following conclusions. Taking into account that the matter was the measurement on complex glazings, the results can be considered satisfactory.

One important conclusion regards the used facilities, and as a matter of fact the final results are not related to a specific set up (hot box, hot plate with or without fluxmeters). Concerning the results, the standard mean deviation is not greater than 5% (apart from the slat product, where the discrepancy is traced back to slightly different slat angles).

The analysis of the influence of the two terms solar transmittance and secondary heat gain factor on the final TSET value suggest the following considerations:

- q_i is the effective parameter to be determined, since the utilisation of the same solar transmittance does not reduce the discrepancies
- The control of experimental conditions is a crucial aspect, in particular, the corrections due to the spectrum of light sources influence the final TSET results. Checking the spectral distribution of the lamp during testing is important for an accurate correction of the experimental results.
- Different divergence of solar simulator fields is critical for angle-selective products, e.g. solar shading with slats

4.3 Development of test procedures for the angular-dependent properties of complex glazings

The starting point for the development of a common solar calorimetric test procedure was the fact that every single device was developed and constructed with a different background and technology. The question was whether a common procedure for evaluating the measured quantities could be developed, that could guarantee - provided the experiments were performed with sufficient care - that the final results were identical. From our results we can conclude that this can only be achieved, if common reference conditions for the target value of g are agreed (see Table 5).

4.3.1 Common evaluation procedure

After a common analysis of individual test equipment and procedures in a project meeting we harmonized the evaluation process by developing a common evaluation procedure and implemented that in a electronic sheet. The quantities to be filled in were experimental values from different equipment. We had to make sure that all quantities were understood in a common sense and thus had to describe the variables in a more detailed way in the written test procedure. All the results shown here were elaborated according to this procedure. In such way eventual differences, due to not homogeneous calculation and correction procedures, were avoided.

The evaluation procedure consists of two main parts. The first part shows the transformation of the primary measured variables within the calorimetric measurement (e.g. temperatures, heat flux) into a experimental g-value for laboratory specific conditions. In the second part this result will be corrected taking into account small deviations from the reference conditions. Here data from optical measurements and calibration experiments (e.g. on heat transfer coefficients) are needed. This two-step procedure is documented and described in detail in an internal working document.

Table 5: Reference conditions (summer)

Property	Target value	Remark
α_{abs}	1	ideal absorber
E [W/m^2]	783	irradiance on plane normal to irradiance direction
$I_{\lambda sim}$	I_λ [ISO 9845]	reference spectrum global solar irradiance AM1.5
$T_s = T_a$		air and radiative temperatures should be identical
h_i[W/m^{2}K]	$h_{e,c}$=3.6 $h_{e,r}$=4.4 $\varepsilon_g/\varepsilon_0$ [EN 673]	conv. and rad. standard internal film coefficient (h_i = 8 W/(m^{2}K) for uncoated inner surface of the glazing)
h_e[W/m^{2}K]	$h_{e,c}$ = 18.6 $h_{e,r}$ = 4.4 $\varepsilon_g/\varepsilon_0$ [EN 673]	conv. and rad. standard external film coefficient (h_e = 23 W/(m^{2}K) for uncoated inner surface of the glazing)
T_i [°C]	24	room temperature
T_e [°C]	24	outdoor conditions

NB: ε_0 =0.837 is the emiitance of uncoated glass

4.3.2 Development of Black-Box-model for corrections

For the development of the correction procedure a general black-box model was of great use, the γ-model by Rosenfeld (Rosenfeld, 1997).

The thermal part of g, the secondary internal heat transfer factor†, q_i can be written according to this model, without loss of generality as

$$q_i(\vartheta) = \frac{[R_e + R_s\gamma(\vartheta)]\alpha_s(\vartheta)}{R_e + R_s + R_i}$$

where R_i, R_s R_e are interior, sample and exterior heat resistance and α is the sample absorptance

The parameter γ describes the position-weighted absorption and ranges between 0 (absorption on inside surface) to 1 (absorption on outside surface).

4.3.3 Development of component models

In order to investigate the possibility to use a component approach for the different complex glazings, laboratories associated to individual industrial partners developed glazing models. These models are documented in a working document and published (Rosenfeld, 2000).

In general good agreement could be found for all glazings and only examples are given here.

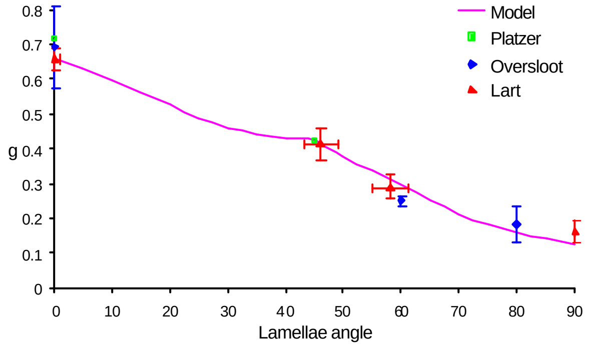


Figure 12: Hunter Douglas DGU.Total solar energy transmittance as a function of lamellae angle, for normal incidence.Model predictions, compared to measurements

For lamellae systems usually discrepancies could be attributed to unprecise lamellae rotation angle. Especially for off-normal incidence the so-called cut-off position (the lamellae position where the direct parallel light is just "cut-out" from transmittance without projected overlap of the lamellae) very critical and the change in transmittance large. Thus measurements due to small misalignments and product variations in lamellae angle can give rather different results. This could be inferred from model calculations. The advice is not to use the cut-off angle when testing solar shading products.

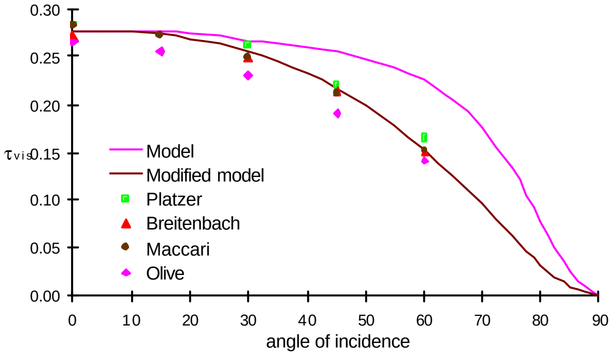


Figure 13:Anglian DGU.Luminous transmittance as a function of angle of incidence.Model predictions compared to measurements

In some cases too simple models could be excluded by comparison to measurements (Figure 13).

It should be noted that some models do not use the parametric formulation of the γ-model. On the contrary, these physically based models, describing the heat transport within the glazings in more detail, can be used to determine this parameter γ, for instance the one on transparent insulation glazings. (Platzer, 1992)

4.3.4 Sensitivity analysis

Using the sophisticated model describing the nonlinear heat transport phenomena in transparent insulation a sensitivity study was performed to find out, how g can be influenced by different temperature or irradiation levels.

Other (linear) effects can be described quite general using the mentioned γ-model (see above 4.3.2).The non-linear effects were investigated for a case where large effects were expected to exist (Figure 16).

Due to variations in irradiation levels beween 0 W/m^2 and 1000 W/m^2 and temperature levels (negligible and large temperature gradients between inside and outside air) the relative variations in g were ±5% in extreme cases (opaque sample with middle pane black absorber, q_i only!). However, in most cases variations were less than ±1%. It has to be noted that the γ-model would predict identical values for all cases, i.e. it is not sensitive to irradiation and temperature levels.

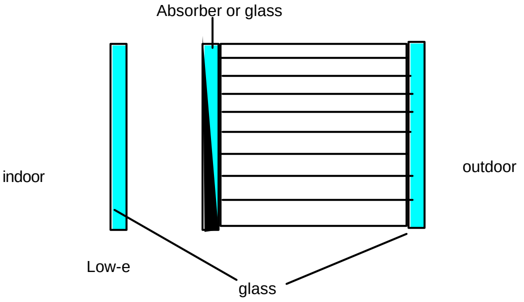


Figure 14: Schematic layers of fictitious glazing used for investigation of non-linear phenomena

4.3.5 Test procedures

The final result of all theoretical analysis was the development of two internal documents with proposals and recommendations for the testing of angular properties, one for optical measurement (light transmittance), one for calorimetric measurements. It is planned to publish these results in near future.

- Working Document ALTSET-4-99
  Procedures and recommendations for the use of large integrating spheres
- Working Document ALTSET-3-00:
  Thermal Performance of Windows and Glazings – Direct Determination of the Total Solar Energy Transmittance by Laboratory Measurement

Whereas for optical measurements with large integrating spheres a lot of experience and testing precautions are published in literature and relevant standards, solar calorimetry needed the development of a completely new test procedure. Therefore in the first document only recommendations and procedures which are special to more complex samples are given. It was not necessary to develop a complete test procedure in this case.

4.3.6 Conclusion

Within the project practical and theoretical investigations led to a knowledge basis which enabled the group to present a proposal for a solar calorimetry test procedure suitable for indoor testing. The interesting feature of the test procedure is that it does not require completely prescribed equipment. Using the precautions and the correction algorithm described, laboratories with different equipment such as a irradiated heat-flux plate apparatus and a irradiated hot-box should be able to determine the same reference values of the total solar energy transmittance. This procedure is applicable to all kinds of glazings and facade elements, even opaque ones. Of, course special samples need always special attention and a physical understanding of the energy transport processes. For example time periods of testing cannot be given a priori, but the thermal capacity of building elements (time constant) influences the required time to reach stationarity.

From theoretical investigations we learned that strictly speaking the total solar energy transmittance is not a constant but dependent on many environmental conditions. Therefore it is absolutely necessary to define reference conditions for product comparison. On the other hand, variations are usually small enough so that simple and linear correction procedures are valid.

4.4 Impact of angular data on building application fields

The group has investigated the impact of improved input data for light and total solar energy transmittance on heating load, cooling load and daylighting calculations, either with specialised computer programs or within existing or emerging CEN calculation methodologies.

4.4.1 Definition of case studies

Two exemplary case studies were defined to cover a broad range. The first case study is on heating, cooling and light demand of a highly glazed office building in a cooling dominated climate (Rome, Italy). In the second case study the heating demand of a typical dwelling (single family house) in a heating dominated climate (Germany, average weather data) was investigated.

4.4.2 Results

For the cooling loads the largest impact of angular data was observed. The simulations show that the difference between the simulation result with angular data and the one with constant value g_n (for normal incidence) can be as large as 100% - depending on the glazing type!

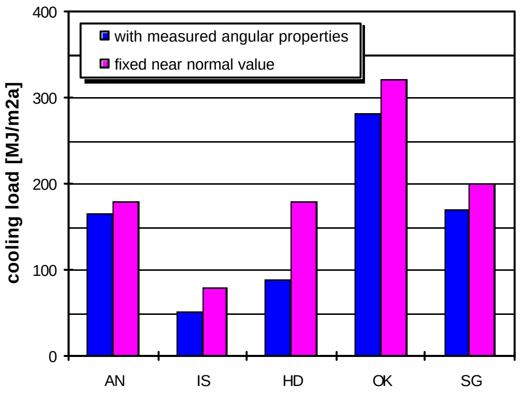


Figure 15:Cooling load comparison (Case study Rome)

Table 6: Energy load variations without any angular decay (Office building, Rome)

Sample	Cool [%]	Heat [%]	Light [%]
Anglian	+8	0	-14
Isoclima	+49	-17	-17
Hunter Douglas	+100	-30	-8
Okalux	+14	0	-2
Saint Gobain	+18	-1	-2

4.4.3 Conclusion

The importance of the measured angular functions for complex glazing samples on building energy could be demonstrated. It could be shown that the assumption of a constant total solar energy transmittance g (for normal incidence as it is usual practice) does produce large errors in the simulated results.

The assumption of a constant diffuse-hemispherical value g_h for simulation did produce very good results for the yearly heating consumption in the case of the dwelling in Germany. This cannot be extrapolated to buildings with very low heating demand and/or with high glazing area. For the calculation of the constant hemispherical value one needs the angular function. The simple estimation of g_h from the normal incidence value (as proposed e.g. by EN 832) is not appropriate: The factor proposed by EN 832 is 0.85 whereas for our glazings these values differ between 0.52 and 0.85!

This means that in future - as more and more "targeted" complex glazing developments shall meet specialized requirements of the building industry and designers, the possibility to determine angular data will be even more important.

Planning tools and procedures have to be adapted as well in order to cope with the improved data basis. Tools nowadays cannot cope very well with the measured angular data.

5 OUTLOOK

The ALTSET project has achieved its main objectives and was fully successful as well in technical aspects as in implanting the test methodology already in advanced building planning practice and tools.

The aim of further work can be to extend and validate the applicability of the general methodology to other product groups, to further improve accuracy and to establish quality reference materials for solar calorimetry testing. It is highly desirable for laboratories having not participated in the project to be able to calibrate and check their own equipment on a regular and validated basis. Therefore calibration panels and reference panels shall be developed in future.

The ALTSET participants created within the project a network of expertise, which can be used for further work. The project served industrial partners and scientific partners in their specific needs.

6 ACKNOWLEDGEMENTS

The results presented here were extracted from the common work of the whole group. I want to thank my colleagues Francois Olive (CSTB), Karsten Duer (DBE), Augusto Maccari (ENEA), Henk Oversloot and Dick van Dijk (TNO), Jean Rosenfeld (UWC) and Rick Marshall (previously UWC) as well as Tilmann Kuhn (ISE) for the excellent cooperation and the superb working atmosphere. The ALTSET project could only come about because the work was funded by the European Commission, DG XII within the Standards, Measurements and Testing Program under the project number SMT4-CT96-2099. I would like to thank also Mr. Paolo Salieri for the good cooperation as project officer during the period.

7 SYMBOLS AND UNITS

Symbol	Quantity	Unit
E	Irradiance	W/m^2
g	Total solar energy transmittance	-
h	Surface coefficient of heat transfer	W/(m^{2}K)
q	Heat flux density	W/m^2
R	Thermal resistance	m^{2}K/W
T	Temperature	°C
U	Thermal transmittance	W/(m^{2}K)
a	absorption coefficient	-
e	Emissivity (hemispherical)	-
r	Reflectance	-
t	Transmittance (for radiation)	-

8 REFERENCES

Rosenfeld, J.L.J., Platzer, W.J., van Dijk H., Maccari, A. (2000). Modelling the optical and thermal properties of advanced glazing overview of recent developments. *To be presented at Eurosun 2000*, Copenhagen, Denmark.

Platzer, W.J. (1992). Calculation procedure for collectors with a honeycomb cover of rectangular cross-section, Sol. Energy, Vol. 48/6, pp. 381-394

Rosenfeld, J.L.J. (1997) On the calculation of the total solar energy transmittance for complex glazing systems, Proceedings of the 8th Int. Meeting on Transparent Insulation, Freiburg 16th Sept. 1996, Germany