ROUND ROBIN TESTING OF BUILDING COMPONENTS USING THE PASLINK TEST FACILITIES: QUALITY ASSURANCE IN TESTING AND ANALYSIS

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ABSTRACT

The IQ-Test Thematic Network has carried out round robin tests at 10 of the PASLINK outdoor test cell facilities. A round robin test generally produces a clear picture of the overall quality of certain test procedures carried out by the participating organisations. For practical considerations, each organisation constructed its own components according to strict instructions regarding the selection of materials, manufacture and instrumentation. Two components of different levels of complexity were designed: (1) an opaque, homogeneous wall with a removable central section and (2) a window, which is used to replace the central section of the first component. Using recommended dynamic test procedures and appropriate identification methods, each participant determined the thermal performance of the components. Good agreement between sites was achieved for the U-value of the opaque wall. A range of U-values were obtained for the window, however, the variation can be largely accounted for by variations in the boundary conditions between sites, e.g. wind speed and ambient temperature. For future components the test sequence and analysis methods should account for such non-linear behaviour, in order to estimate thermal and solar performance characteristic for appropriate standardised boundary conditions.

Keywords: PASLINK Test Cells, round robin testing, identification methods

1. INTRODUCTION

The aim of the IQ-Test Thematic Network, supported by the European Community under the EESD Programme, was to consolidate the work of the network of the PASLINK [1] outdoor test cell facilities in 10 European countries, involved in the energy performance evaluation of the thermal and solar properties of building components. The objective of IQ-TEST was to further the development of common quality procedures for

- Testing
- Calibration
- Data gathering, processing and analysis
- Interpretation of test results and scaling/replication to real buildings
- Maintenance of the test infrastructure at the test sites.

This should consolidate the network, by integrating the newer test sites and strengthening its common approach of support for new product developments in the field of innovative building components through semi-standardised tests and pragmatic, practicable and affordable but accurate procedures.

As part of the work of the Network, round robin tests were performed as part of a feasibility study for standardisation activities. The objective was to assess both the inter-site quality of testing and analytical procedures of the members, with a view to developing standards for outdoor testing. High quality data for model calibration were also generated.

Two components were designed, incorporating flexibility, in order that the first component could be used as a platform for the second component. The first component is an opaque, homogeneous wall with a removable central section. The thermal properties of the panel are very well defined. The second component is a window, which is used to replace the central section of the first component.

The objective of testing the first component was for each participant to determine the thermal transmission coefficient of the panel by both 1-D heat flux measurements and an energy balance on the test cell. For the second component: the whole wall U-value and solar aperture estimated from the test cell energy balance and the window U-value and solar aperture. This paper presents the results for the window and provides an analysis of the differences between sites in terms of the prevailing boundary conditions.

2. THE TEST COMPONENTS

Given the number of organisations involved in the Thematic Network it was decided at the beginning that it was impractical to circulate one component for testing for the following reasons:

- Variation in the test aperture size of test cells between sites.
- High transportation costs.
- Likely difficulties in keeping to a strict timetable, given the use of the test cells for other tests.

The approach adopted was for each organisation to construct its own component(s) according to strict instructions regarding the selection of materials, manufacture and instrumentation.

2.1. Component 1 – The opaque wall

The first component is an opaque, homogeneous panel consisting of a sandwich of insulation between plywood, with a replaceable central section 1500mm (h) by 1250mm (w). The thermal properties of the panel are well defined and the required materials are available in the locality of each participant. Expanded polystyrene (PS30), with a density of 30kg/m^3 and a nominal thermal conductivity of 0.033W/mK, is used to form an insulating panel of thickness 200mm. A white exterior finish is used on the plywood.

It was agreed that each team should measure the heat flux and temperatures in two profiles through the wall (Figure 1), with one in the centre of the removable section (A) and the other mid-way between the edge of the wall and the removable panel (B). Figure 2 shows the wall installed at BTU Cottbus.

The objective of testing the first component was for each participant to determine the thermal transmission coefficients of the wall as follows.

1. By 1-D heat flux measurements to determine the U-value of the central removable panel (U_A).

2. By an energy balance on the test cell to determine the whole wall U-value (U_{opaque}).

These measurements enable the thermal performance of the wall to be estimated for subsequent tests with the second component mounted in the aperture. The UA-value of the surrounding opaque part is

$$U_{opaque} A_{TOTAL} - U_A A \qquad (1)$$

where A_{TOTAL} is the area of the whole wall, A is the area of the aperture.

The whole wall value includes edge effects, which vary depending on the test cell and installation of the test wall at each site.

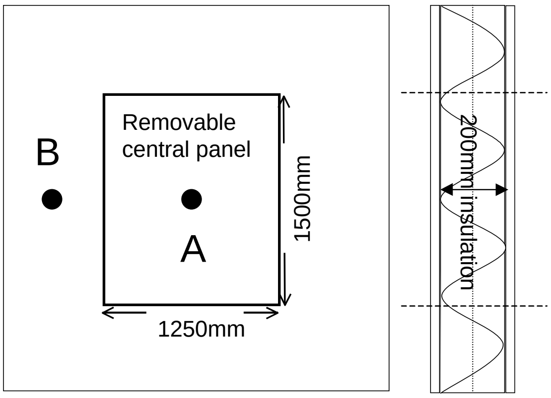

Figure 1. Schematic diagram of opaque wall with removable central panel and location of heat flux and temperature measurement profiles.

Figure 2. Opaque wall installed in PASLINK test cell at BTU Cottbus, Germany.

2.2. Component 2 – The window

The objective of the second component is to introduce a greater degree of complexity by using a window to replace the central section of the first component. The window design incorporates double glazing using ordinary clear float glass in a timber frame. The frames for each participant were produced centrally. Each participant obtained glass from a local supplier and samples were tested centrally to ensure consistency. The spectrophotometric tests have shown that there are differences between the samples in their infrared transmittance, which may give variations in the g-value (solar energy transmittance) of the double glazing between 73.2 and 77.3 %. Figure 3 shows the window installed in the opaque surround.

Figure 3. The window installed in the opaque surround at BRE, Scotland, and CRES, Greece.

The objectives of the test were to determine

The whole wall UA-value (UA_{TOTAL}) and solar aperture (gA-value) estimated from the test cell energy balance.

The window U-value (U_w) which includes edge effects:

$$U_w = \frac{UA_{TOTAL} - \left(U_{opaque}A_{TOTAL} - U_A A\right)}{A} \qquad (2)$$

3. THE TEST PROCEDURES

The procedures are based on the COMPASS Measurement and Data Analysis Procedures [2]. The procedures were design to maximise the information available for analysis using a suitable identification method, whilst reducing the duration of the test. A heating or cooling regime may be chosen, depending on the local climatic conditions. The basic test procedure consists of an eight day heating or cooling sequence with

- 3 days low power
- 1.5 days high power
- 3.5 days dynamic sequence with on/off control

An optional six day validation sequence may be applied following the above procedure.

The maximum power levels were calculated to ensure that the mean test room temperature difference between the low and high power parts of the test sequence should be at least 10K, but preferably 20 K, without exceed the safe operational limits of the test cell. In a “heating” climate a maximum power level of about 250W is satisfactory for the window test: an example of a typical heating sequence is shown in Figure 4, which includes a Randomly Ordered Logarithmically distributed Binary Sequence (ROLBS).

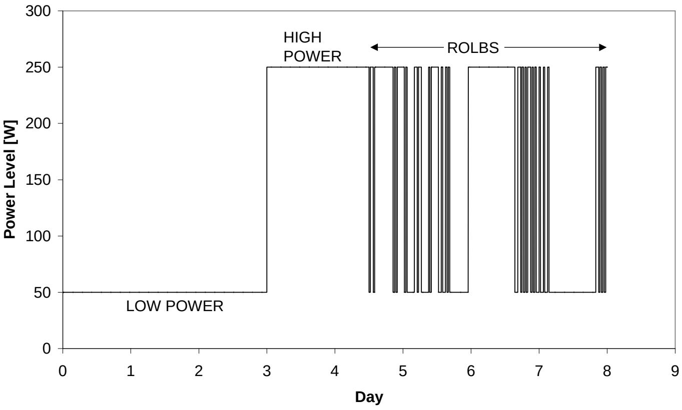

Figure 4. A typical heating power sequence with low power = 50W air circulation fan; high power = 50W fan power + 200W resistance heater.

The air leakage of the test room should also determined by pressurisation testing before and after the test to ensure that the test cell meets a requirement of <0.5 air changes per hour (ac/h) at 50Pa. If the air leakage exceeds 0.5 ac/h at 50Pa, it is recommended that the air leakage be monitored continuously during the test by tracer gas measurements. A target value of 0.025 ac/h should be achieved throughout the test, corresponding to a maximum heat loss due to ventilation of 4% of the total heat loss through the test room envelope, based on the average test conditions.

4. RESULTS

The choice of analysis method was open to each team; however the identification program LORD, developed for the PASLINK EEIG, was generally used. Two teams also used MATLAB IDENT. Error estimates were also determined using a pragmatic method, which has since been incorporated into the latest version of LORD (version 3.0).

The results of the round robin tests as provided by each team performing the tests are summarised below.

4.1 Opaque wall results

The results are summarised in Table 1 and Figure 5. The whole wall U-value is obtained by dividing the UA-value by the area of the test cell aperture.

Table 1. Summary of results for opaque wall

Team	Whole Wall UA-value [W/K]	Error [W/K]	Area of Test Cell Aperture [m^2]	Whole Wall U-value [W/m^2K]	Error [W/m^2K]	Profile A U-value [W/m^2K]	Error [W/m^2K]
BBRI	1.28	0.10	6.25	0.20	0.02	0.17	0.01
BRE	1.37	0.19	7.16	0.19	0.03	0.18	0.02
CIEMAT	2.02	0.17	6.13	0.33	0.03	0.17	0.01
CRES	1.59	0.02	7.63	0.21	0.00	0.18	0.01
EMPA	1.06	0.10	6.73	0.16	0.01	0.16	0.01
FGUP	1.12	0.02	6.10	0.18	0.00	0.17	0.01
JRC	4.40	0.34	7.45	0.59	0.05	0.18	0.01
TNO	2.06	0.16	7.58	0.27	0.02	0.19	0.01
UoB Cottbus	1.40	0.10	7.43	0.19	0.01	0.18	0.01
VTT	1.25	0.14	7.32	0.17	0.02	0.17	0.01

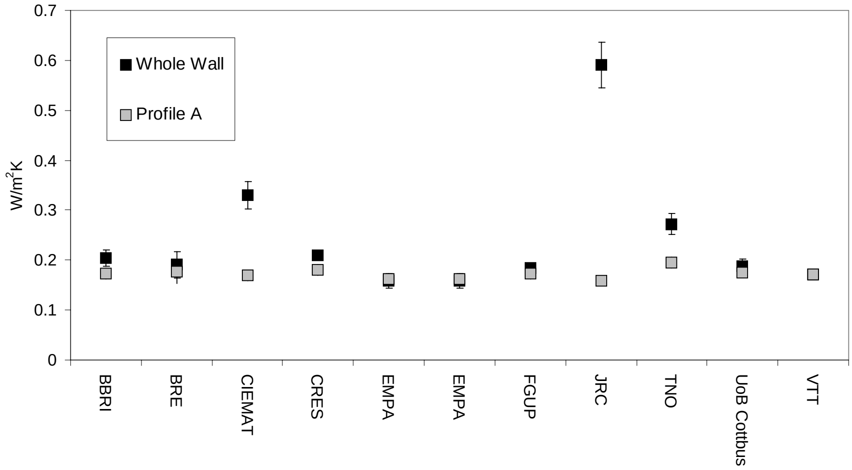

Figure 5. Whole wall and 1-D centre of panel (Profile A) U-values.

The results indicate that satisfactory agreement between sites was achieved for the centre of panel U-values.

The difference between the whole wall and the centre of panel U-values at each site indicates the magnitude of the edge effects of the wall together with unidentifiable heat losses such as that due to air leakage. These effects vary from site to site.

4.2 Window component results

The results are summarised in Table 2.

Table 2. Summary of results for the window component.

Team providing data	Whole Wall UA-value: Opaque+ Window [W/K]	**Window UA-value [W/K]**	**gA-value [m^2]**	**Window U-value [W/m^2K]**	Error [W/m^2K]	**g-Value [-]**	Error [-]
BBRI	4.70	**3.75**	**0.97**	**2.00**	0.16	**0.52**	0.08
BBRI with cold box	4.69	**3.75**	**-**	**2.00**	-	**-**	-
BRE	5.74	**4.74**	**1.12**	**2.53**	0.20	**0.60**	0.08
CIEMAT	6.89	**5.20**	**1.07**	**2.77**	0.11	**0.57**	0.02
CRES	5.94	**4.74**	**0.96**	**2.53**	0.19	**0.51**	0.03
EMPA	5.59	**4.84**	**0.98**	**2.58**	0.29	**0.53**	0.01
FGUP	5.28	**4.50**	**0.67**	**2.40**	0.06	**0.36**	0.01
JRC	8.65	**4.55**	**0.97**	**2.43**	0.16	**0.52**	0.04
TNO	7.21	**5.51**	**1.17**	**2.94**	0.20	**0.62**	0.04
UoB Cottbus	5.51	**4.43**	**1.02**	**2.36**	0.14	**0.54**	0.02
VTT	5.19	**4.26**	**1.06**	**2.27**	0.15	**0.57**	0.04

Calculations using WINDOW4 and WIS both gave a U-value estimate for the window of 2.65W/m^2K. g-value estimates of 0.66 and 0.69 at normal incidence were obtained using WINDOW4 and WIS, respectively.

4.3. U-values

The test results show a range of U-values between 2.00 and 2.94W/m^2K. The following analysis indicates that variation in local climate conditions between the test sites may explain most of the differences between the values.

The U-value of the window is influenced by

- Indoor and outdoor temperatures:
  - Variation of the physical properties of the air in the gap of the double glazing: density, dynamic viscosity and conductivity (Figure 6).

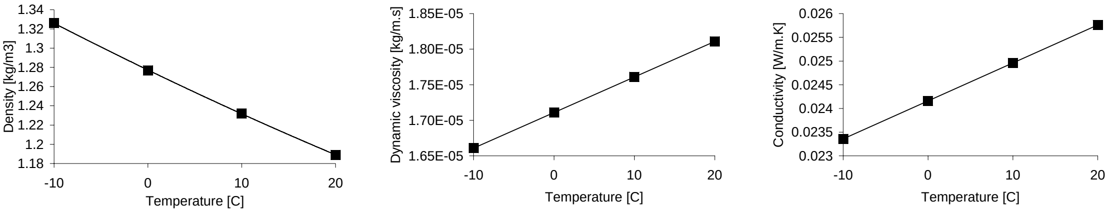

Figure 6. The variation in the density, dynamic viscosity and thermal conductivity of air with temperature

  - Radiative and convective heat exchange in the gap of the double glazing.

- Wind velocity and air velocity:
  - Variation in the convective heat exchange coefficients at internal and external surfaces.

- Long-wave exchange with the environment.

The European Standard EN 673:1997 [3] gives the calculation method for determining the centre of pane thermal transmittance of glazing. The U-value of a glazing is given by:

$$\frac{1}{U} = \frac{1}{h_e} + \frac{1}{h_t} + \frac{1}{h_i} \tag{3}$$

where

h_e and h_i	are the external and internal heat transfer coefficients;
h_t	is the total thermal conductance of the glazing.

$$\frac{1}{h_t} = \sum_{1}^{N} \frac{1}{h_s} + \sum_{1}^{M} d_j \cdot r_j \tag{4}$$

where

h_s	is the thermal conductance of each gas space;
N	is the number of spaces;
d_j	is the thickness of each material layer;
r_j	is the thermal resistivity of each material;
M	is the number of material layers.

$$h_s = h_r + h_g \tag{5}$$

where

h_r	is the radiation conductance;
h_g	is the gas conductance.

The radiation conductance is given by:

$$h_r = 4\sigma \left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1 \right)^{-1} T_m^3 \tag{6}$$

where

σ	is Stefan-Boltzmann's constant;
T_m	is the mean absolute temperature of the gas space;
ε_1 and ε_2	are the corrected emissivities of the material surfaces bounding the gas space.

The gas conductance is given by:

$$h_g = Nu \frac{\lambda}{s} \tag{7}$$

where

s	is the width of the gas space;
λ	is the thermal conductivity;
Nu	is the Nusselt number.

$$Nu = A(Gr\,Pr)^n \tag{8}$$

where

A	is a constant (for vertical glazing A=0.035);
Gr	is the Grashof number;
Pr	is the Prandtl number;
n	is an exponent (for vertical glazing n=0.38).

$$Gr = \frac{9.81 s^3 \Delta T \rho^2}{T_m \mu^2} \qquad (9)$$

$$Pr = \frac{\mu c}{\lambda} \qquad (10)$$

where

ΔT	is the temperature difference between glass surfaces bounding the gas space;
ρ	is the gas density;
μ	is the dynamic viscosity of the gas;
c	is the specific heat capacity of the gas.

Therefore, there is a non-linear dependence of the U-value on both the temperature difference across the gas space and the mean gas space temperature (Figure 7). The influence of the external heat transfer coefficient on the U-value is also non-linear (Figure 8).

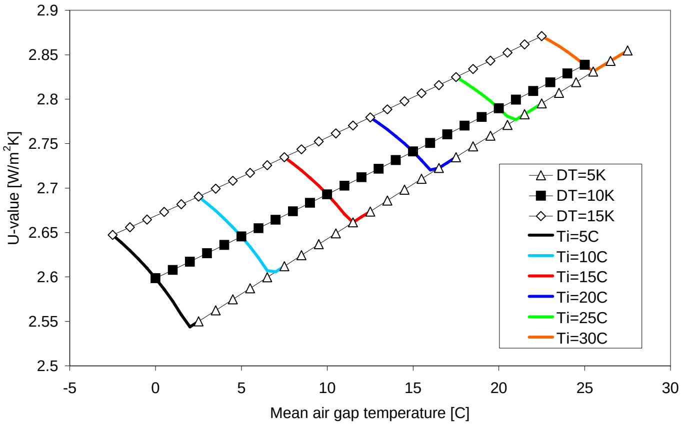

Figure 7. The variation of the U-value of double glazing with a 20mm air gap with mean temperature and temperature difference across the gap. Standardised internal and external heat transfer coefficients were used for the calculations: hi = 8 W/m^{2}K; he = 23 W/m^{2}K.

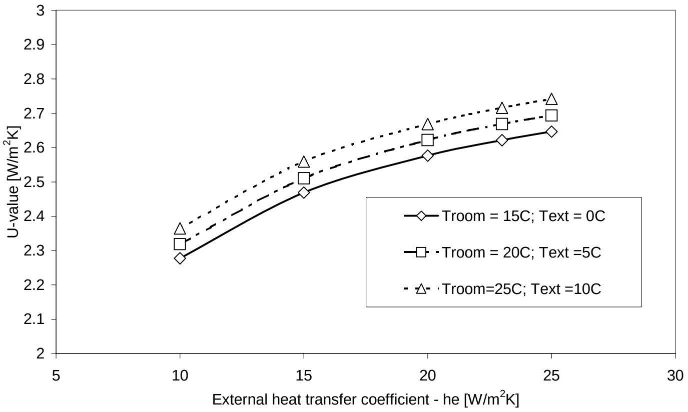

Figure 8. The variation of the U-value of double glazing with a 20mm air gap with external heat transfer coefficient, for a range of boundary temperatures and a fixed internal heat transfer coefficient of 8 W/m^{2}K.

The average boundary conditions from seven test sites, which were able to provide wind speed data for the calculation of external heat transfer coefficients, are shown in Figures 9-11.

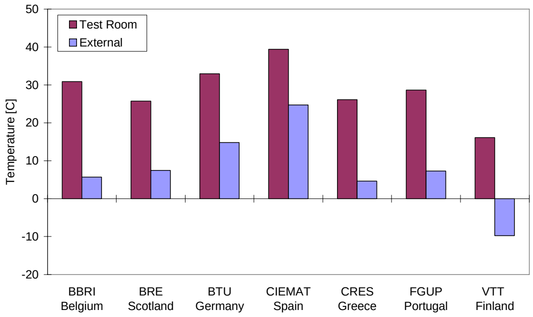

Figure 9. Average test room and external ambient temperatures for seven test sites measured during the window tests.

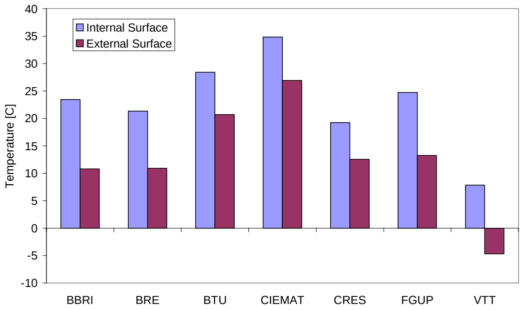

Figure 10. Average glazing surface temperatures for seven test sites measured during the window tests.

The external heat transfer coefficient, h_e, was estimated for each of the seven sites (Figure 12) using the following relationship:

For wind speed, $V < 5\text{m/s}$: $h_e = 5.82 + 3.96 \times V$ (11a)

For wind speed, $V \geq 5\text{m/s}$: $h_e = 7.68 \times V^{0.75}$ (11b)

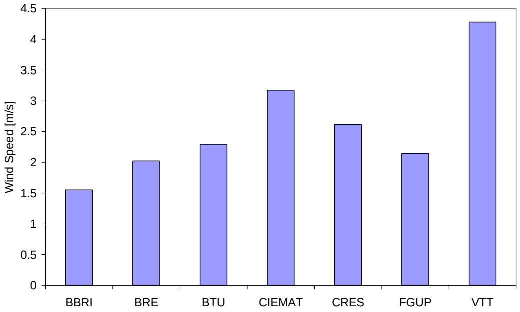

Figure 11. Average wind speed for seven test sites measured during the window tests.

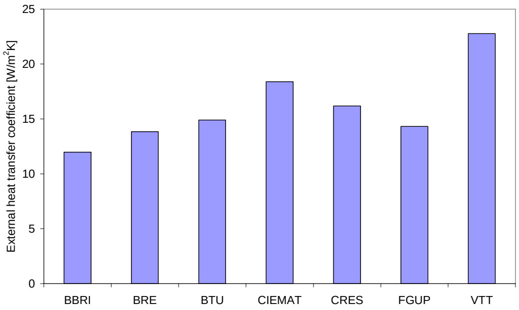

Figure 12. The external heat transfer coefficient for seven test sites estimated from the wind speed measured during the window tests.

There is a considerable variation in temperatures between the sites. For example, the estimate of the mean glazing temperature, from the surface temperature measurements, ranges from 1.6°C at VTT to 30.9°C at CIEMAT. The estimates of the external heat transfer coefficient range from 12 $\text{W/m}^2\text{K}$ at BBRI to 23 $\text{W/m}^2\text{K}$ at VTT.

Each test result has been compared with a model of the complete window, i.e. frame and glazing, for the boundary conditions at each site (Figure 13). The centre of glazing U-value was estimated as above using EN 673:1997. The program FRAME [4] was used to calculate the U-values for the frame and a defined edge region. For modelling purposes an internal heat transfer coefficient of 8 $\text{W/m}^2\text{K}$ was assumed for each site. The conductivity of the air space for the FRAME calculation was determined using Equations 5-10. The comparison is shown in Figure 14.

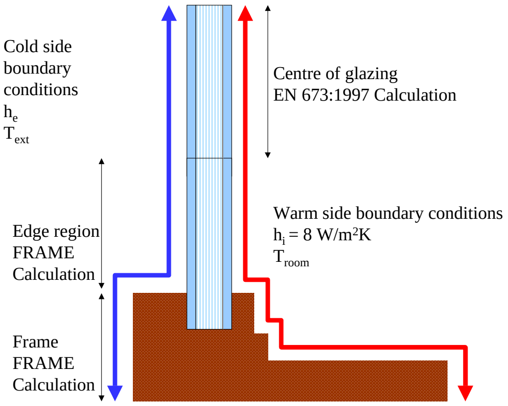

Figure 13. Window model for FRAME and EN 673:1997 Calculations.

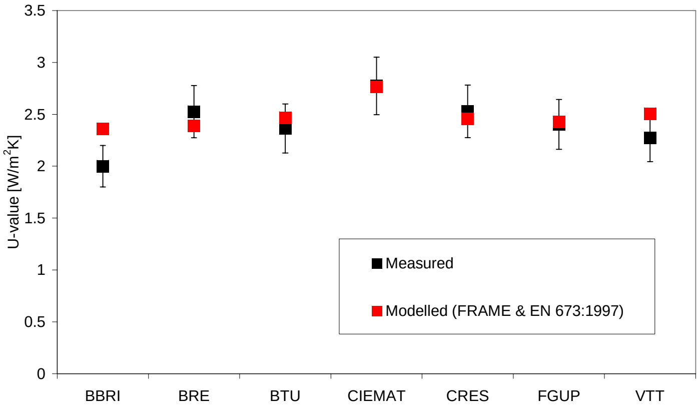

Figure 14. Comparison of measured results and model estimates for IQ-Test window U-values at seven test sites.

Generally there is good agreement between the measured results and the model. The analysis explains most of the variation between sites in terms of the prevailing boundary conditions. Additional factors influencing the window U-value are the internal heat transfer between the room and the window, and longwave exchange with the external environment. However, generally (1) the test room regime is unknown in terms of the convective and radiative exchanges between the wall under test and the test room environment; and (2) longwave radiation measurements were not available.

In order to normalise the results from each site to a set of standardised boundary conditions it will necessary to improve the identification method to allow for the non-linear behaviour of the component with respect to varying boundary conditions. The use of the existing or an improved dynamic test sequence to produce a range of boundary conditions is also necessary to aid identification.

4.4 g-values

The g-values obtained are in reasonable agreement, in terms of their error bands, if the FGUP result is excluded (a site inspection revealed that the solarimeter used to measure the incident radiation on the test wall was misaligned). Treating the latter as an outlier, the range of g-values obtained was 0.51 to 0.62, with a mean of 0.56 and standard deviation 0.04, i.e. 7% (Figure 15). The results were obtained throughout the year, and the CIEMAT result was determined with the window facing north, in order to prevent overheating within the test room. No obvious seasonally dependent behaviour was observed. The results are lower than the theoretical value for normal incidence. The variation in the g-values cannot be explained by differences in the glazing properties measured by spectrophotometry.

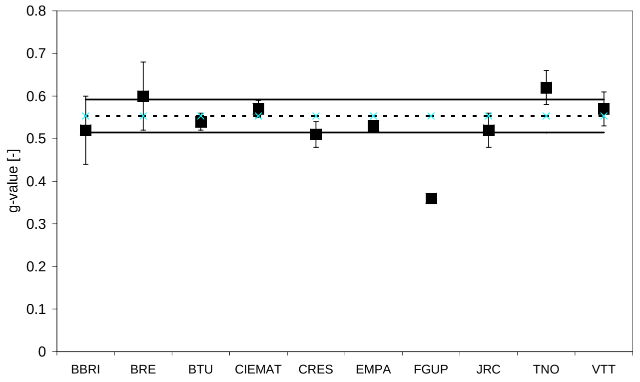

Figure 15. Measured g-values with mean and standard deviation, treating the FGUP result as an outlier.

5. CONCLUSIONS

Two round robin test components have been designed and tested to assess the inter-site quality of testing and the analytical abilities of the participating organisations. The first component is an opaque, homogeneous wall with a removable central section The second component is a window, which is used to replace the central section of the first component.

Satisfactory agreement was achieved across the sites in identifying the 1-D U-value of the opaque insulated panel.

The window test results showed a range of U-values between 2.00 and 2.94W/m^{2}K. However, the variation can be largely accounted for by variations in the boundary conditions between sites, particularly the wind speed (thus the external heat transfer coefficient) and ambient temperatures. The variation of the U-value with these parameters is non-linear.

For future components the test sequence and analysis methods should account for non-linear behaviour, in order to estimate thermal and solar performance characteristic for appropriate standardised boundary conditions.

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