NPL Report CBTM 2

SM&T Project 3032 - Contract MATI-CT 940063

# FINAL SUMMARY REPORT -

# DESIGN AND VALIDATION OF GLAZED CALIBRATION PANELS REQUIRED FOR THE MEASUREMENT OF THERMAL TRANSMITTANCE OF GLAZED ASSEMBLIES

Ray Williams & David Hall

September 1997

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# Design and validation of glazed calibration panels required for the measurement of thermal transmittance of glazed assemblies

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## Abstract

Draft CEN (and ISO) standards for hot-box U-value measurements of windows and insulated glazing units, require calibration measurements to be carried out with glazed calibration-panels of known thermal conductance. In this report a suitable design and construction procedure for these panels has been specified. This panel design has been validated by five partner laboratories (NPL, BBRI, EMPA, IFT and TNO) who each made panels to this specification and carried out the calibration procedures, specified in prEN 12412-1. The panels were then circulated to the other partner laboratories who measured their U-value using the CEN procedure. This report shows that the panel design selected produced panels that were robust and that the thermal conductances could be calculated to an estimated uncertainty of ±6%. The work also demonstrated that the uncertainty of the subsequent U-value measurements made using the calibration data, were within ±7%. The sensitivity of the CEN measurement procedures to the calculated conductance and temperature measurement accuracy is discussed and some improvements are suggested for the draft standards.

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# 1 INTRODUCTION

## 1.1 Objectives of the project

The objective of the project is to establish a precise method for the construction, characterisation and application of glazed calibrated reference panels for hot-box use. These panels are a vital requirement of two draft CEN standards prEN 12412 -1[1] and prEN1098[2] and an ISO draft standard, ISO/CD 12567[3] , which specify procedures for carrying out U-value measurements of window systems and insulated glazing units. The method requires the measurement laboratory to carry out hot-box measurements on at least two glazed calibration panels of known thermal conductance. This work will provide the basis of a technical supplement to those standards that will specify how the panels should be designed and constructed.

The project involved five laboratories from different countries (see section 10) fabricating the calibration panels and carrying out thermal measurements. An additional participant, from Pilkingtons, was involved as an advisor, for his specialist knowledge of the original standards.

## 1.2 Deliverables

- Report detailing the design specification for producing glazed calibration panels with a thermal conductance known to an uncertainty of ±7%.
- Report on the comparison of guarded hot-plate thermal conductivity measurements.
- Report comparing the hot-box measurements made by different laboratories on glazed calibration panels made to the same design.
- Four sets of well characterised, glazed calibration panels for use within the Community.

# 2 DECISIONS TAKEN AT THE PROJECT MEETINGS

## 2.1 Decisions taken at the 1st project meeting (26/1/95)

At the first project meeting, held at the NPL (UK) on the 26th January 1995, the following issues were decided:

- the type of panel to fabricate
- the materials to be used in the calibration panels
- the fabrication method for the calibration panels
- the details of how to carry out the thermal conductivity measurements on the insulation material.

The first phase of the project was to purchase the expanded polystyrene (EPS) insulation material and the toughened glass. The thermal conductivity of the EPS then had to be measured over the temperature range required by the standards. Lastly, each laboratory was to send its 12 mm thick EPS thermal conductivity specimens to one laboratory and its 50 mm thick EPS thermal conductivity specimens to another. The details and findings of this first stage of the project are given in NPL Report QM 122.

## 2.2 Decisions taken at the 2nd project meeting (21/11/95)

### 2.2.1 Panel fabrication method

TYPE OF PANEL - • Both to be non-instrumented

PANEL SIZE - • Both panels:- 1198 ± 2 mm x 1198 ± 2 mm

CORE MATERIAL - • White expanded polystyrene (EPS) with a density of approximately 28 $kg/m^3$. The core of both panels to be made from the same sheets of EPS from which the thermal conductivity specimens were taken.

CORE THICKNESS - • Panel 1 approximately 12 mm thick EPS core
• Panel 2 approximately 50 mm thick EPS core

GLAZING MATERIAL - • 4 mm thick toughened glass for both panels

### 2.2.2 Panel construction details

- Toughened glass to be glued to EPS using Dow Corning 7091 compound in a 4 x 4 array of glue points, centres located as shown below:

  |< 70 > * < 353 > * < 353 > * < 353 > * < 70 >| (mm)

- Suggested method of applying the adhesive

The panel will be made by fixing the toughened glass to the EPS core material using Dow Corning 7091 silicone compound in a 4 x 4 array of glue points about 35 mm diameter. The 16 points will be evenly distributed as shown above so as to avoid the surface thermocouples.

The method used at the NPL to produce an even adhesive "spot" about 35 mm in diameter is as follows. Metal "washers" (see sketch below) with a 28 mm diameter hole and 0.5 mm thick are placed in the required array on the EPS surface. The holes are filled flush to the top surface with Dow Corning 7091 compound and then the washers are removed.

The glass is put in position, ensuring that the edges are square to the EPS material. The joint is put under pressure by placing a 1.2 m x 1.2 m piece of 19 mm thick plywood on top of the glass and weighting with buckets filled with sand.

The adhesive to be approximately 35 mm final diameter.

**IT IS VERY IMPORTANT THAT THE GLASS IS THOROUGHLY CLEANED WITH A SOLVENT SUCH AS ACETONE, PRIOR TO APPLYING THE ADHESIVE.**

- Tape the edges of panel, to reduce moisture pick-up.

- Always keep the panels in a dry environment.

2.2.3 Panel thickness determination

The accurate determination of the EPS sheet thickness and the average overall panel thickness is one of the most critical stages in the fabrication of the calibration panels.

a) Determine the EPS sheet thickness and the average glazed panel thickness as precisely as practically possible. NB an uncertainty of ± 0.1 mm in 12 mm leads to an uncertainty of ± 0.8% in conductance.

b) Each laboratory can use their own method to measure the panel thickness at a minimum of 25 places uniformly spread over the panel surface.

c) For the purpose of calculating the thermal conductance of the calibration panel the thickness of the core will be assumed to be the average gap between the inner surfaces of the two glass sheets. A correction can be made for the air gap if required. The effect of the air gap and adhesive on the calculated conductance are shown in the enclosed spreadsheet printout.

Note The thickness of glass is very uniform and can be assumed to be the thickness as measured at the edges.

## 2.3 Thermal transmittance measurements

2.3.1 Method of mounting surface thermocouples

- Thermocouples shall be made of wire with a maximum diameter of 0.25 mm
- The insulation shall be stripped back a minimum of 15 mm from the hot junction
- The thermocouple should be taped to the glass surface for a minimum of 100 mm
- The tape should be of the paper "masking tape" type.

2.3.2 U-value measurements of the laboratory's own panels

The full CEN calibration measurement schedule should be carried out. Which means that each panel should be measured at three mean temperatures of 5, 10, and 15°C, keeping the hot-box air temperature constant. Each laboratory should ensure that it has the latest version of prEN 1098 (the glazing standard) and prEN 12412 - 1 "Windows, Doors and Shutters - Determination of Thermal Transmittance by Hot Box Method - Part 1: Windows and Doors. Care should be taken to ensure that the procedures described in these two standards are followed exactly.

As the panels are 1.2 m x 1.2 m the requirements of the glazing standard prEN1098 should be met. That includes using 50 mm beading around the specimen edges on both the hot and cold sides.

2.3.3 U-value measurements of the panel(s) from other laboratories

This should be measured at a mean temperature of 10°C, with the hot air temperature at the same temperature as that used for when measuring the laboratory's own panels, and with the same air flow. The surface of the specimen should be instrumented with thermocouples.

The thickness of this calibration panel should be measured using the same technique used with the laboratory's own panels.

The results should be used to compare directly with those obtained using our own panel as well as to measure its U-value and conductance using the CEN technique.

## 2.4 The panel intercomparison schedule

- For the 20 mm panel

| | | |
|---|---|---|
| TNO | to | BBRI |
| BBRI | to | IFT |
| IFT | to | EMPA |
| EMPA | to | NPL |
| NPL | to | TNO |

- For the 60 mm thick panel

| | | |
|---|---|---|
| IFT | to | NPL |
| NPL | to | BBRI |
| BBRI | to | EMPA |
| EMPA | to | TNO |
| TNO | to | IFT |

An additional measurement was agreed. The thin panel made by EMPA or the thin panel made by NPL would continue around the circuit of laboratories so that all laboratories would have measured it. Which panel, will be decided nearer the time. This means that three of the laboratories will be making one additional measurement.

## 2.5 Safe transportation of the calibration panels

This is a critically important issue. All panels MUST be transported in a box made from a frame of approximately 50 mm x 50 mm wood covered with stout plywood. The panel should be surrounded by EPS material, including the edges and should be in a plastic bag to ensure it stays dry.

Use a box with triangles of plywood fixed to the sides to ensure that the box will stand only upright and the use of "Fragile-this way up" labels will encourage people to keep the panels upright. No effort should be spared to ensure that the panels are packaged soundly.

## 3 HOT-BOX DETAILS

### 3.1 Description of the Hot-boxes used

The apparatus used by the different laboratories to carry out the thermal conductance/transmittance measurements are described in detail in the individual test reports; NPL [4], IFT [5], TNO [6], EMPA [7], and BBRI [8]. A summary is given below in Table 1.

Table 1 Hot box apparatus used by the different laboratories

| Laboratory | Type of apparatus | Size of metering box (m) | Measurement uncertainty claimed for calibration panels (%) |
|---|---|---|---|
| NPL | Wall Guarded Hot Box | 1.95 x 1.95 | ± 6% |
| BBRI | Wall Guarded Hot Box | 1.6 x 1.6 | ±4% |
| IFT | Guarded Hot Box | 1.25 x 1.98 | Unknown |
| EMPA | Calibrated Hot Box | 2.0 x 1.5 | ± 5% |
| TNO | PASSYS Cell + Cold box operated as a Guarded Hot Box | 2.75 x 2.75 | ± 6% |

### 3.2 Surround-panel details

The surround panel heat transfer coefficient will depend on the thickness and thermal conductivity of the holder panel and the thickness and thermal conductivity of the calibration panel. A summary of the details for each laboratory's surround panel is given below in Table 2.

Table 2 Surround Panel details

Surround panel details at 10°C

| Laboratory | **Thickness (m)** | **Thermal Conductivity (W/m.K)** | **Thermal Conductance (W/m².K)** |
|---|---|---|---|
| **NPL** | 0.1490 | 0.0340 | 0.2283<br>(calculated) |
| **EMPA** | 0.1000 | 0.0335<br>(calculated) | 0.3354 |
| **TNO** | 0.2240 | 0.0383<br>(calculated) | 0.1710 |
| **IFT** | 0.2000 | 0.0260 | 0.1440 |
| **BBRI** | unknown | unknown | unknown |

## 4 GLAZED CALIBRATION PANEL THICKNESS MEASUREMENTS

The method used by each laboratory to measure the thickness of the glazed calibration panels is described in detail in their own report. A summary of those methods is given below in Table 3.

Table 3 Thickness measurement methods

| Laboratory | Thickness measurement method |
|---|---|
| NPL | Purpose-made micrometer using a dial gauge as the indicator, calibrated with slip gauges. |
| EMPA | Gauge table with electronic contact sensor<br>(the measured thickness contains the thickness of the sample itself and the gap between sample and table, if any) |
| TNO | Purpose-made micrometer using a dial gauge as the indicator, calibrated at zero distance. |
| BBRI | Purpose-made free-standing micrometer, using a dial gauge as the indicator and calibrated using slip gauges. |
| IFT | Purpose-made micrometer using a dial gauge as the indicator, calibrated using slip gauges. |

Table 4 Summary of the glazed calibration panel thickness measured by the different laboratories

| Lab. | **NPL Thin (m)** | **panel Thick (m)** | **EMPA Thin (m)** | **panel Thick (m)** | **BBRI Thin (m)** | **panel Thick (m)** | **TNO Thin (m)** | **panel Thick (m)** | **IFT Thin (m)** | **panel Thick (m)** |
|---|---|---|---|---|---|---|---|---|---|---|
| **NPL** | 0.02034 | 0.0683 | 0.02023 | | | | | | | 0.05806 |
| **% diff** | - | - | -0.1% | | | | | | | -0.4% |
| **EMPA** | | | 0.02020 | 0.0588 | | 0.0568 | | | 0.01752 | |
| **% diff** | | | - | - | | 0.25% | | | -1.27% | |
| **TNO** | 0.02034 | | 0.02023 | 0.0589 | | | 0.02242 | 0.0580 | | |
| **% diff** | 0.00% | | -0.15% | -0.17% | | | - | - | | |
| **IFT** | | | 0.0202 | | 0.02018 | | | 0.05696 | 0.0173 | 0.05781 |
| **% diff** | | | 0.00% | | 0.64% | | | 1.79% | - | - |
| **BBRI** | | 0.06816 | 0.02023 | | 0.02031 | 0.05694 | 0.02238 | | | |
| **% diff** | | 0.20% | -0.15% | | - | - | 0.18% | | | |

**NB** % Diff. ((Owner thickness - Laboratory thickness)/Owner thickness) x 100

# 5 CALCULATION OF CALIBRATION PANEL THERMAL CONDUCTANCE

## 5.1 Conductance values and calculation method used

To derive the three sets of graphs specified in the CEN measurement procedure, each laboratory had to calculate the thermal conductance of their two glazed calibration panels at the three temperatures established in the hot box during the calibration measurements. The method of doing this was specified at the second project meeting (see section 2.2.3c). The glue and the air gap between the glass and the EPS material was to be ignored. This therefor assumes that the gap between the two sheets of glass was completely filled with EPS material. This removes the need to measure the thickness of the EPS material separately . The effect of this simplification on the calculated conductance of the NPL panels was 1.2% for the thin panel and 0.5% for the thick panel. The values calculated by each laboratory are given in Table 5.

Table 5 Calculated thermal conductance values

Calculated Conductance

| Laboratory | **Thin calibration panels** | | **Thick calibration panels** | |
|---|---|---|---|---|
| | **Mean Temp. (°C)** | **Calc. Conductance (W/m².K)** | **Mean Temp. (°C)** | **Calc. Conductance (W/m².K)** |
| **NPL** | 17.28 | 2.460 | 16.35 | 0.575 |
| | 11.17 | 2.436 | 10.82 | 0.564 |
| | 4.16 | 2.361 | 4.38 | 0.554 |
| **EMPA** | 14.39 | 2.583 | 14.75 | 0.677 |
| | 9.70 | 2.539 | 9.96 | 0.667 |
| | 3.63 | 2.482 | 4.50 | 0.655 |
| **TNO** | 12.67 | 2.220 | 12.69 | 0.680 |
| | 8.49 | 2.200 | 9.88 | 0.670 |
| | 5.30 | 2.180 | 6.54 | 0.670 |
| **IFT** | 14.02 | 3.430 | 14.99 | 0.654 |
| | 10.04 | 3.420 | 11.47 | 0.653 |
| | 5.79 | 3.430 | 7.64 | 0.653 |
| **BBRI** | 12.32 | 2.499 | 15.01 | 0.669 |
| | 7.96 | 2.462 | 9.15 | 0.669 |
| | 3.57 | 2.424 | 5.05 | 0.66 |

These values are plotted in Figures 1 and 2.

Figure 1 Calculated conductance of the thin panels

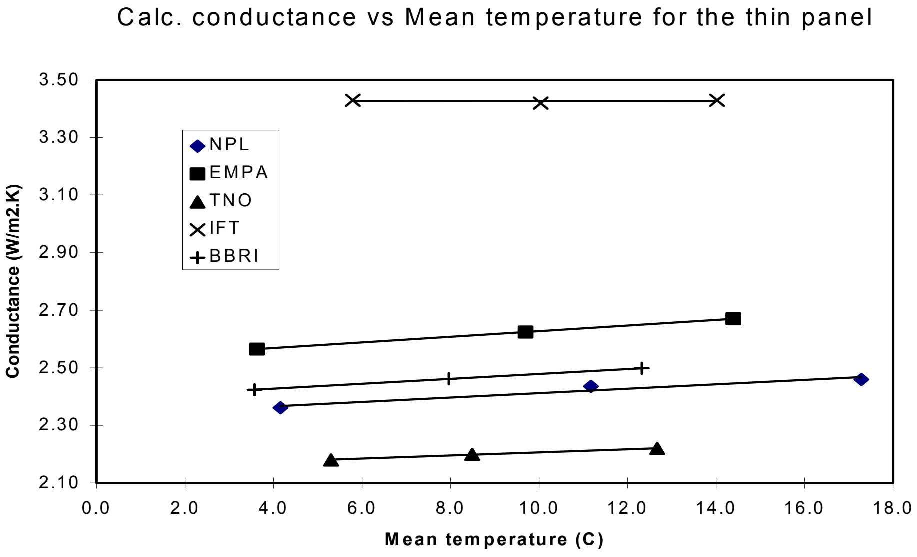
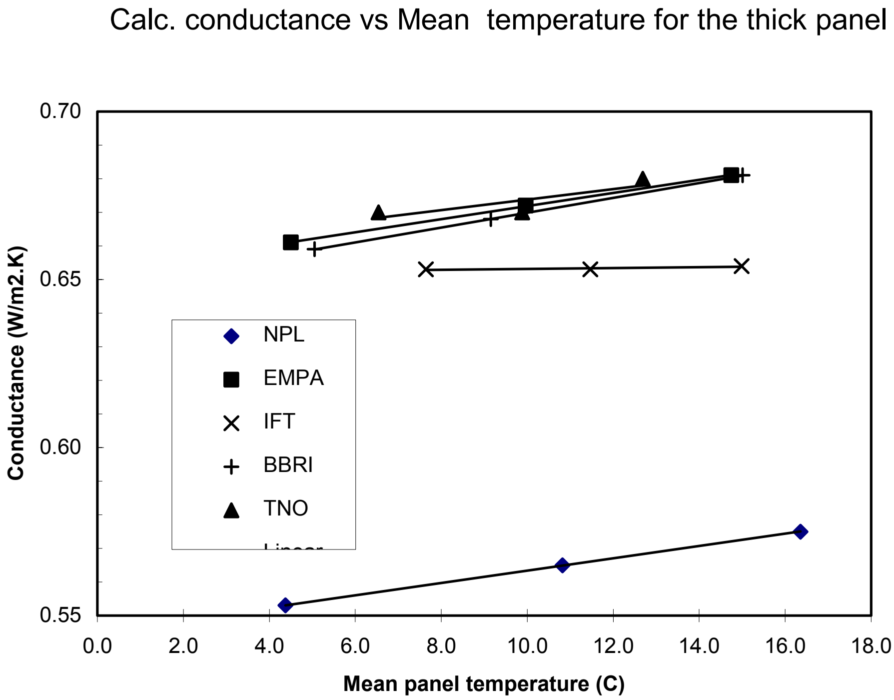


Figure 2 Calculated conductance of the thick panels



### 5.2 Uncertainty of the calculated conductance values

The uncertainty in the calculated conductance value is due to the following causes:

| | | **Worst case taken for both panels** |
|---|---|---|
| i. | Uncertainty in the thermal conductivity value | ± 4.0% |
| ii. | Uncertainty in the thickness measurement | ± 2.0 % |
| iii. | Thermal conductivity of EPS in calibration panel being different to the sample measured. | ± 1.0% |
| iv. | Total uncertainty (summed in quadrature) | ± 4.6% |
| v. | Uncertainty due to assuming no air gap and no adhesive | -1.2%<br>+0.0% |
| Total uncertainty in the calculated conductance of the calibration panel | | - 5.8 % to<br>+4.6 % |

## 6 RESULTS OF THE HOT-BOX MEASUREMENTS

### 6.1 Measurements by the laboratories of their own calibration panels

Each laboratory has written a report describing this phase of the project {[4],[5],[6],[7], [8]}. A summary of the hot box measurement data required to produce the three graphs needed to implement the procedures specified in prEN 12412-1, ISO/CD 12567 and prEN 1098 are given below in Tables 6, 7, 8, 9 and 10. The contents of those tables are as specified in the draft standards.

The procedures given in prEN 12412-1 Annex A were used to calculate the environmental temperatures, the surround panel heat transfer coefficient, the total surface resistance values and the convective fractions.

Table 6 NPL Measurement data for their own panels

| NPL Calibration Panels | | TT105 | | | TT106 | | |
|---|---|---|---|---|---|---|---|
| d[m] thickness | [m] | 0.02034 | | | 0.0683 | | |
| A Area of panel | [$m^2$] | 1.221 | | | 1.218 | | |
| Test number | | 1 | 2 | 3 | 1 | 2 | 3 |
| θsur {Surround mean temp.} | [°C] | 17.79 | 12.43 | 6.14 | 16.68 | 11.32 | 5.06 |
| Δθsur {Surround temp. diff. } | [°C] | 9.67 | 19.33 | 30.81 | 13.61 | 23.21 | 34.88 |
| $\theta_m$ {mean panel temperature} | [°C] | 17.28 | 11.17 | 4.16 | 16.35 | 10.82 | 4.38 |
| Cold temperatures - measured | | | | | | | |
| θa.e {air} | [°C] | 12.73 | 2.30 | -9.97 | 9.66 | -0.67 | -12.93 |
| θb.e {baffle} | [°C] | 12.75 | 2.37 | -9.87 | 9.68 | -0.62 | -12.87 |
| θc.e {cal panel} | [°C] | 13.58 | 4.03 | -7.32 | 10.00 | -0.07 | -12.08 |
| θsur.p.e {reveal - estimated} | [°C] | 12.95 | 2.76 | -9.27 | 9.87 | -0.29 | -12.38 |
| θsur.e {surround temp.} | [°C] | 12.95 | 2.76 | -9.27 | 9.87 | -0.29 | -12.38 |
| Hot temperatures - measured | | | | | | | |
| θa.i {air} | [°C] | 23.75 | 23.26 | 22.83 | 23.96 | 23.67 | 23.56 |
| θb.i {baffle} | [°C] | 23.25 | 22.41 | 21.63 | 23.60 | 23.11 | 22.79 |
| θc.i {cal panel} | [°C] | 20.98 | 18.32 | 15.64 | 22.70 | 21.71 | 20.83 |
| θsur.i {reveal} | [°C] | 22.36 | 20.70 | 19.53 | 22.50 | 21.94 | 21.60 |
| θsur.i {surround temp.} | [°C] | 22.62 | 22.09 | 21.54 | 23.48 | 22.92 | 22.50 |
| Φm {Measured hot box power} | [W] | 29.87 | 57.43 | 89.39 | 17.46 | 30.18 | 44.11 |
| v.i {air flow hot} | [m/s] | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| v.e {air flow cold] | [m/s] | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| Λcal {Calc conductance} | W/$m^2$.K | 2.460 | 2.436 | 2.361 | 0.575 | 0.564 | 0.553 |
| Φcal {power cal panel - calc.} | [W] | 22.21 | 42.51 | 66.18 | 8.90 | 14.97 | 22.16 |
| hr.i {radiant sur coef- hot} | W/$m^2$.K | 4.632 | 4.548 | 4.466 | 4.669 | 4.634 | 4.605 |
| hr.e{radiant sur coef- cold} | W/$m^2$.K | 4.205 | 3.781 | 3.318 | 4.060 | 3.637 | 3.174 |
| ha.i{convective coef- hot} | W/$m^2$.K | 3.005 | 3.540 | 4.027 | 2.875 | 3.219 | 3.545 |
| ha.e{convective coef- cold} | W/$m^2$.K | 17.22 | 16.56 | 17.32 | 17.65 | 17.32 | 18.39 |
| Fa.i {Convective fraction - hot} | | 0.393 | 0.438 | 0.474 | 0.381 | 0.410 | 0.435 |
| Fa.e {Convective fraction - cold} | | 0.804 | 0.814 | 0.839 | 0.813 | 0.826 | 0.853 |
| Rtc {Total res. cal.panel} | $m^2$.K/W | 0.178 | 0.173 | 0.166 | 0.179 | 0.175 | 0.169 |
| Hsur {Surround panel coef} | W/K | 0.791 | 0.772 | 0.753 | 0.630 | 0.655 | 0.629 |

Table 7 EMPA Measurement data for their own calibration panels.

| EMPA Calibration Panels | | Panel 1 | | | Panel 2 | | |
|---|---|---|---|---|---|---|---|
| d[m] thickness | [m] | 0.020 | | | 0.059 | | |
| A Area of panel | [m$^2$] | 1.44 | | | 1.44 | | |
| Test number | | 2 | 1 | 3 | 5 | 4 | 6 |
| θsur {Surround mean temp.} | [°C] | 14.82 | 10.57 | 4.87 | 14.76 | 9.59 | 4.60 |
| Δθsur {Surround temp. diff. } | [°C] | 9.61 | 19.23 | 28.43 | 9.49 | 18.21 | 28.11 |
| $\theta_m$ {mean panel temperature} | [°C] | 14.39 | 9.70 | 3.63 | 14.75 | 9.96 | 4.50 |
| Cold temperatures - measured | | | | | | | |
| θa.e {air} | [°C] | 9.86 | 0.54 | -9.95 | 9.86 | 0.58 | -9.98 |
| θb.e {baffle} | [°C] | 9.91 | 0.70 | -9.74 | 9.84 | 0.56 | -9.93 |
| θc.e {cal panel} | [°C] | 10.98 | 2.73 | -6.77 | 10.34 | 1.40 | -8.80 |
| θsur.p.e {reveal - estimated} | [°C] | 10.36 | 1.58 | -8.48 | 10.12 | 1.02 | -9.37 |
| θsur.e {surround temp.} | [°C] | 10.01 | 0.95 | -9.35 | 10.01 | 0.88 | -9.46 |
| Hot temperatures - measured | | | | | | | |
| θa.i {air} | [°C] | 19.99 | 20.93 | 20.23 | 19.85 | 19.89 | 19.91 |
| θb.i {baffle} | [°C] | 19.61 | 20.24 | 19.22 | 19.66 | 19.55 | 19.40 |
| θc.i {cal panel} | [°C] | 17.80 | 16.66 | 14.02 | 19.17 | 18.51 | 17.80 |
| θsur.i {reveal} | [°C] | 18.78 | 18.55 | 16.82 | 19.27 | 18.76 | 18.20 |
| θsur.i {surround temp.} | [°C] | 19.62 | 20.18 | 19.08 | 19.50 | 19.09 | 18.65 |
| Φm {Measured hot box power} | [W] | 30.43 | 60.59 | 87.99 | 13.84 | 26.25 | 39.23 |
| v.i {air flow hot} | [m/s] | 0.07 | 0.07 | 0.06 | 0.11 | 0.13 | 0.12 |
| v.e {air flow cold] | [m/s] | 1.61 | 1.56 | 1.49 | 1.55 | 1.49 | 1.43 |
| Λcal {Calc conductance} | W/m$^2$.K | 2.583 | 2.539 | 2.482 | 0.677 | 0.667 | 0.655 |
| Φcal {power cal panel - calc.} | [W] | 25.39 | 50.91 | 74.29 | 8.61 | 16.43 | 25.07 |
| hr.i {radiant sur coef- hot} | W/m$^2$.K | 4.518 | 4.505 | 4.419 | 4.540 | 4.521 | 4.501 |
| hr.e{radiant sur coef- cold} | W/m$^2$.K | 4.135 | 3.765 | 3.371 | 4.120 | 3.735 | 3.328 |
| ha.i{convective coef- hot} | W/m$^2$.K | 4.730 | 4.640 | 4.741 | 5.599 | 4.968 | 3.886 |
| ha.e{convective coef- cold} | W/m$^2$.K | 11.893 | 12.655 | 13.092 | 8.144 | 10.241 | 11.514 |
| Fa.i {Convective fraction - hot} | | 0.497 | 0.507 | 0.518 | 0.552 | 0.524 | 0.520 |
| Fa.e {Convective fraction - cold} | | 0.742 | 0.771 | 0.795 | 0.664 | 0.733 | 0.776 |
| Rtc {Total res. cal.panel} | m$^2$.K/W | 0.174 | 0.170 | 0.170 | 0.180 | 0.177 | 0.174 |
| Hsur {Surround panel coef} | W/K | 0.524 | 0.503 | 0.482 | 0.552 | 0.539 | 0.504 |

Table 8 TNO Measurement data for their own calibration panels.

| TNO Calibration Panels | | TNO 3A | | | TNO 4A | | |
|---|---|---|---|---|---|---|---|
| d[m] thickness | [m] | 0.02242 | | | 0.058 | | |
| A Area of panel | [m$^2$] | 1.21 | | | 1.21 | | |
| Test number | | 1 | 2 | 3 | 1 | 2 | 3 |
| θsur {Surround mean temp.} | [°C] | 13.85 | 10.29 | 7.42 | 13.21 | 10.53 | 7.35 |
| Δθsur {Surround temp. diff. } | [°C] | 12.96 | 20.09 | 24.86 | 14.25 | 19.24 | 25.20 |
| $\theta_m$ {mean panel temperature} | [°C] | 12.67 | 8.49 | 5.30 | 12.69 | 9.88 | 6.54 |
| Cold temperatures - measured | | | | | | | |
| θa.e {air} | [°C] | 6.94 | 0.14 | -4.85 | 5.97 | 0.79 | -5.46 |
| θb.e {baffle} | [°C] | 7.40 | 0.21 | -5.08 | 6.03 | 0.86 | -5.35 |
| θc.e {cal panel} | [°C] | 7.94 | 1.09 | -3.94 | 6.24 | 1.16 | -4.92 |
| θsur.p.e {reveal - estimated} | [°C] | 7.66 | 0.67 | -4.48 | 6.16 | 1.03 | -5.09 |
| θsur.e {surround temp.} | [°C] | 7.37 | 0.24 | -5.01 | 6.08 | 0.91 | -5.25 |
| Hot temperatures - measured | | | | | | | |
| θa.i {air} | [°C] | 20.52 | 20.44 | 20.15 | 20.68 | 20.55 | 20.45 |
| θb.i {baffle} | [°C] | 20.22 | 20.07 | 19.64 | 20.48 | 20.34 | 20.21 |
| θc.i {cal panel} | [°C] | 17.41 | 15.88 | 14.54 | 19.15 | 18.61 | 18.01 |
| θsur.i {reveal} | [°C] | 18.87 | 18.05 | 17.19 | 19.74 | 19.38 | 18.98 |
| θsur.i {surround temp.} | [°C] | 20.33 | 20.23 | 19.85 | 20.33 | 20.15 | 19.95 |
| Φm {Measured hot box power} | [W] | 32.67 | 50.38 | 63.49 | 19.05 | 26.09 | 33.43 |
| v.i {air flow hot} | [m/s] | - | - | - | - | - | - |
| v.e {air flow cold] | [m/s] | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| Λcal {Calc conductance} | W/m$^2$.K | 2.220 | 2.200 | 2.180 | 0.68 | 0.67 | 0.67 |
| Φcal {power cal panel - calc.} | [W] | 25.42 | 39.28 | 48.71 | 10.60 | 14.23 | 18.55 |
| hr.i {radiant sur coef- hot} | W/m2.K | 4.59 | 4.55 | 4.50 | 4.64 | 4.63 | 4.61 |
| hr.e{radiant sur coef- cold} | W/m2.K | 4.10 | 3.80 | 3.59 | 4.03 | 3.82 | 3.57 |
| ha.i{convective coef- hot} | W/m2.K | 3.09 | 3.42 | 3.55 | 2.24 | 2.46 | 2.70 |
| ha.e{convective coef- cold} | W/m2.K | 18.77 | 30.42 | 39.80 | 30.16 | 28.79 | 25.64 |
| Fa.i {Convective fraction - hot} | | 0.40 | 0.43 | 0.44 | 0.33 | 0.35 | 0.37 |
| Fa.e {Convective fraction - cold} | | 0.82 | 0.89 | 0.92 | 0.88 | 0.88 | 0.88 |
| Rtc {Total res. cal.panel} | m$^2$.K/W | 0.174 | 0.155 | 0.147 | 0.174 | 0.172 | 0.171 |
| Hsur {Surround panel coef} | W/K | 0.56 | 0.56 | 0.59 | 0.59 | 0.62 | 0.59 |

Table 9 IFT Measurement data for their own calibration panels.

| IFT Calibration Panels | 20mm | | | 60mm | | |
|---|---|---|---|---|---|---|
| d[m] thickness [m] | 0.0173 | | | 0.05781 | | |
| A Area of panel [$m^2$] | 1.21 | | | 1.21 | | |
| Test number | 1 | 2 | 3 | 1 | 2 | 3 |
| θsur {Surround mean temp.} [°C] | 15.45 | 12.01 | 7.93 | 15.49 | 12.22 | 8.55 |
| Δθsur {Surround temp. diff. } [°C] | 14.89 | 21.21 | 29.05 | 15.65 | 21.89 | 28.99 |
| $\theta_m$ {mean panel temperature} [°C] | 14.02 | 10.04 | 5.79 | 14.99 | 11.47 | 7.64 |
| Cold temperatures - measured | | | | | | |
| θa.e {air} [°C] | 7.74 | 0.92 | -6.32 | 7.50 | 0.98 | -6.37 |
| θb.e {baffle} [°C] | 7.78 | 1.06 | -6.11 | 7.44 | 1.02 | -6.26 |
| θc.e {cal panel} [°C] | 9.13* | 2.92* | -3.69* | 7.10* | 0.45* | -5.63* |
| θsur.p.e {reveal - estimated} [°C] | 8.00 | 1.41 | -6.60 | 7.66 | 1.27 | -5.95 |
| θsur.e {surround temp.} [°C] | 8.00 | 1.41 | -6.60 | 7.66 | 1.27 | -5.95 |
| Hot temperatures - measured | | | | | | |
| θa.i {air} [°C] | 23.13 | 22.98 | 22.86 | 23.36 | 23.21 | 23.17 |
| θb.i {baffle} [°C] | 24.09 | 24.42 | 24.72 | 23.69 | 23.70 | 23.84 |
| θc.i {cal panel} [°C] | 19.21* | 17.63* | 16.16* | 21.77* | 21.12* | 22.08* |
| θsur.i {reveal} [°C] | 22.89 | 22.62 | 22.45 | 23.31 | 23.16 | 23.04 |
| θsur.i {surround temp.} [°C] | 22.89 | 22.62 | 22.45 | 23.31 | 23.16 | 23.04 |
| Φm {Measured hot box power} [W] | 45.83 | 65.52 | 85.30 | 16.06 | 21.36 | 27.94 |
| v.i {air flow hot} [m/s] | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| v.e {air flow cold] [m/s] | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |
| Λcal {Calc conductance} W/$m^2$.K | 3.43 | 3.42 | 3.43 | 0.654 | 0.653 | 0.653 |
| Φcal {power cal panel - calc.} [W] | 41.85 | 60.97 | 82.27 | 11.56 | 16.24 | 21.72 |
| hr.i {radiant sur coef- hot} W/$m^2$.K | 4.734 | 4.696 | 4.655 | 4.783 | 4.767 | 4.755 |
| hr.e{radiant sur coef- cold} W/$m^2$.K | 4.035 | 3.764 | 3.489 | 4.002 | 3.733 | 3.447 |
| ha.i{convective coef- hot} W/$m^2$.K | 2.807 | 3.243 | 3.602 | 1.814 | 1.991 | 2.249 |
| ha.e{convective coef- cold} W/$m^2$.K | 20.79 | 21.39 | 22.42 | 18.80 | 22.78 | 20.96 |
| Fa.i {Convective fraction - hot} | 0.373 | 0.409 | 0.436 | 0.314 | 0.289 | 0.272 |
| Fa.e {Convective fraction - cold} | 0.838 | 0.832 | 0.850 | 0.845 | 0.865 | 0.859 |
| Rtc {Total res. cal.panel} $m^2$.K/W | 0.173 | 0.166 | 0.160 | 0.196 | 0.187 | 0.186 |
| Hsur {Surround panel coef} W/K | 0.267 | 0.215 | 0.108 | 0.288 | 0.234 | 0.215 |

(*) These are the values measured by the thermocouples mounted on the outside surface.

Table 10 BBRI Measurement data for their own calibration panels.

| BBRI Calibration Panels | | 20mm | | | 60mm | | |
|---|---|---|---|---|---|---|---|
| d[m] thickness | [m] | 0.0203 | | | 0.0569 | | |
| A Area of panel | [m$^2$] | 1.219 | | | 1.216 | | |
| Test number | | 1 | 2 | 3 | 1 | 2 | 3 |
| θsur {Surround mean temp.} | [°C] | 14.07 | 10.31 | 6.35 | 15.54 | 9.96 | 6.04 |
| Δθsur {Surround temp. diff. } | [°C] | 20.49 | 28.43 | 36.57 | 16.65 | 27.65 | 35.44 |
| $\theta_m$ {mean panel temperature} | [°C] | 12.32 | 7.96 | 3.57 | 15.01 | 9.15 | 5.05 |
| Cold temperatures - measured | | | | | | | |
| θa.e {air} | [°C] | 3.63 | -4.23 | -12.33 | 7.02 | -4.18 | -12.07 |
| θb.e {baffle} | [°C] | 3.92 | -3.90 | -11.90 | 7.18 | -3.97 | -11.83 |
| θc.e {cal panel} | [°C] | 5.19 | -2.04 | -9.39 | 7.49 | -3.43 | -11.09 |
| θsur.p.e {reveal - estimated} | [°C] | n/a | n/a | n/a | n/a | n/a | n/a |
| θsur.e {surround temp.} | [°C] | 3.82 | -3.91 | -11.94 | 7.21 | -3.87 | -11.66 |
| Hot temperatures - measured | | | | | | | |
| θa.i {air} | [°C] | 24.28 | 24.36 | 24.44 | 24.11 | 24.18 | 24.22 |
| θb.i {baffle} | [°C] | 23.34 | 23.16 | 22.97 | 23.77 | 23.64 | 23.56 |
| θc.i {cal panel} | [°C] | 19.45 | 17.96 | 16.52 | 22.53 | 21.72 | 21.19 |
| θsur.i {reveal} | [°C] | 20.92 | 20.08 | 19.19 | 22.66 | 21.75 | 21.20 |
| θsur.i {surround temp.} | [°C] | 24.31 | 24.52 | 24.63 | 23.86 | 23.78 | 23.74 |
| Φm {Measured hot box power} | [W] | 52.25 | 72.51 | 92.18 | 19.22 | 31.34 | 39.51 |
| v.i {air flow hot} | [m/s] | - | - | - | - | - | - |
| v.e {air flow cold] | [m/s] | 3.09 | 3.36 | 2.93 | 3.08 | 3.20 | 2.99 |
| Λcal {Calc conductance} | W/m$^2$.K | 2.50 | 2.46 | 2.42 | 0.680 | 0.670 | 0.660 |
| Φcal {power cal panel - calc.} | [W] | 43.14 | 59.57 | 76.00 | 12.39 | 20.33 | 25.75 |
| hr.i {radiant sur coef- hot} | W/m$^2$.K | 4.90 | 4.85 | 4.81 | 4.99 | 4.96 | 4.95 |
| hr.e{radiant sur coef- cold} | W/m$^2$.K | 4.86 | 4.47 | 4.10 | 5.00 | 4.44 | 4.06 |
| ha.i{convective coef- hot} | W/m$^2$.K | 3.88 | 4.19 | 4.45 | 3.24 | 3.67 | 3.89 |
| ha.e{convective coef- cold} | W/m$^2$.K | 18.63 | 18.50 | 17.70 | 18.40 | 18.78 | 18.35 |
| Fa.i {Convective fraction - hot} | | 0.442 | 0.463 | 0.480 | 0.394 | 0.425 | 0.440 |
| Fa.e {Convective fraction - cold} | | 0.793 | 0.805 | 0.812 | 0.786 | 0.809 | 0.819 |
| Rtc {Total res. cal.panel} | m$^2$.K/W | 0.156 | 0.154 | 0.154 | 0.164 | 0.159 | 0.158 |
| Hsur {Surround panel coef} | W/K | 0.421 | 0.436 | 0.427 | 0.406 | 0.394 | 0.384 |

The CEN procedure specified in prEN 12412-1 requires three graphs to be plotted from the data given in these tables. They are:

- The calculated total surface resistance versus the heat flux density.

  This graph is used to normalise the measured U-value of a test element to include the standard surface resistance value of 0.17 $m^{2}.K/W$. This is achieved by reading the total surface resistance off the graph at the same heat flux density as established with the test element . This value is deducted from the reciprocal of the measured U-value; the 0.17 $m^{2}.K/W$ is added; then the reciprocal of that value gives the standardised U-value.

- The Surround panel heat transfer coefficient versus the Surround panel mean temperature.

  This graph is used to derive the power through the surround panel. The heat transfer coefficient is assumed to dependent linearly with test element thickness. The heat transfer coefficient for the thickness of the test element is interpolated at the temperature of the surround panel that was established when measuring the test element. The power through the surround is then calculated by multiplying that coefficient by the temperature across the surround panel determined when measuring the test element. This value includes:

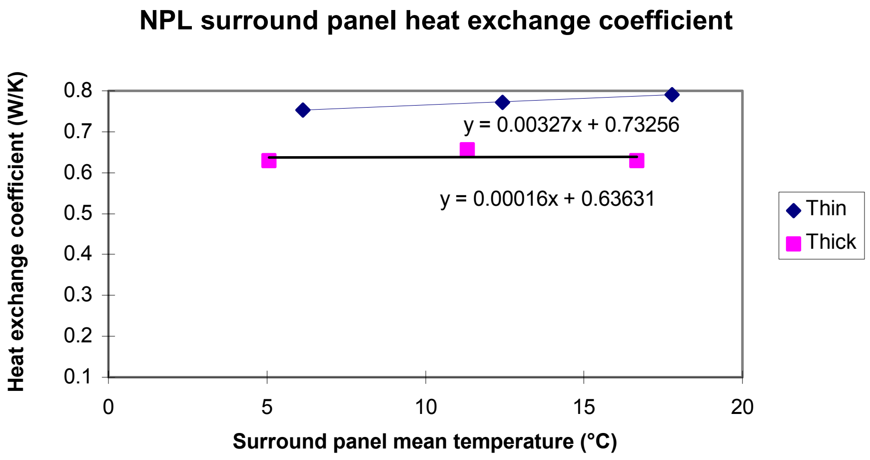
  i) the one dimensional heat flow through the surround panel
  ii) the heat flow around the test element through the reveal
  iii) other systematic errors

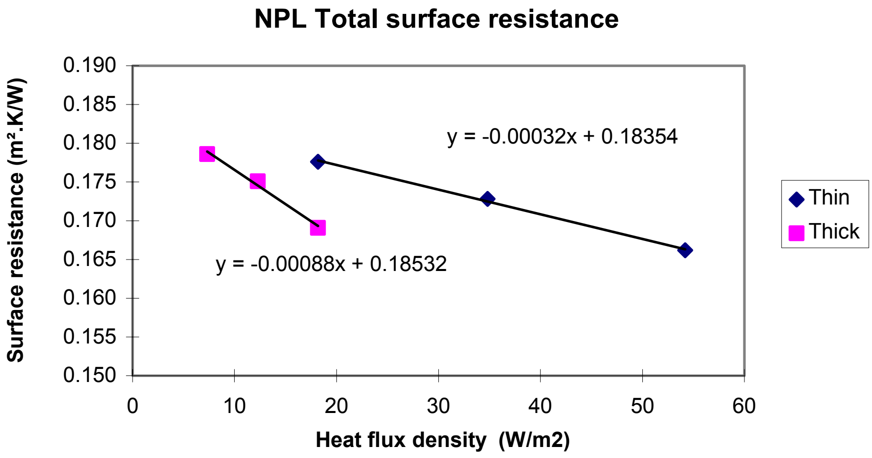
- The Convective fraction for the Hot and Cold boxes versus heat flux density.

  These graphs are used to calculate the hot and cold environmental temperatures. The convective fraction is read off the graphs, at the heat flux density that was established during the hot box measurement of the test element. This is done for both the hot and cold sides. The environmental temperatures are then calculated by multiplying the convective fraction by the air temperature and the radiant temperature by one minus the convective fraction and then adding the two together.

The set of three graphs, produced by each laboratory from the data in Tables 6, 7, 8, 9 and 10, are shown in Figures 3, 4 , 5, 6 and 7.

Figure 3 Three CEN graphs from the NPL Results





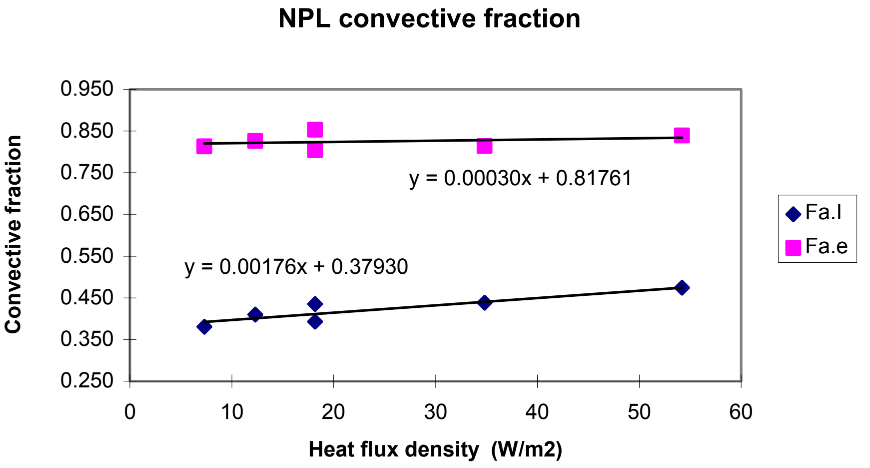
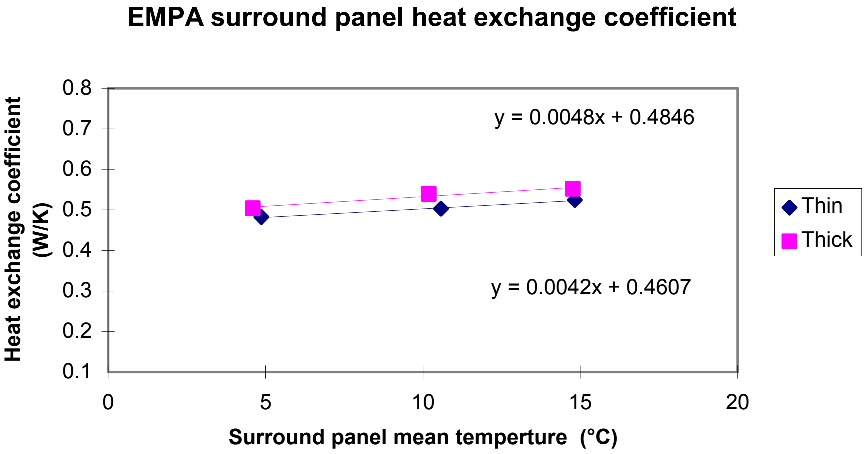
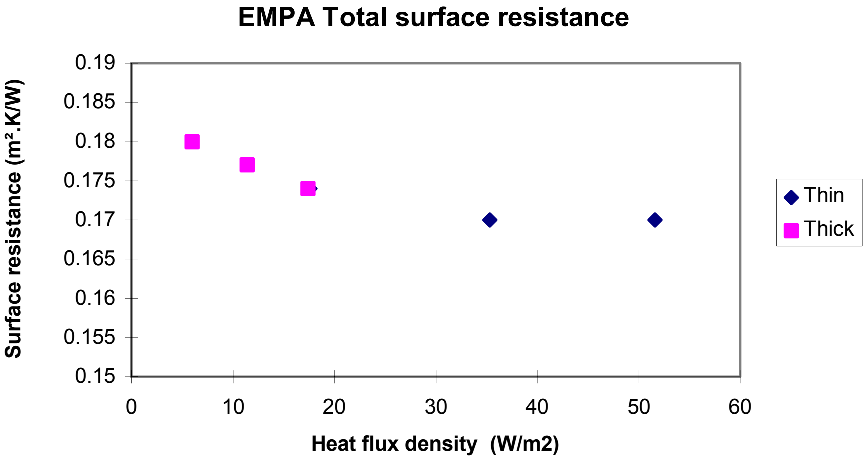


Figure 4 Three CEN graphs from the EMPA Results





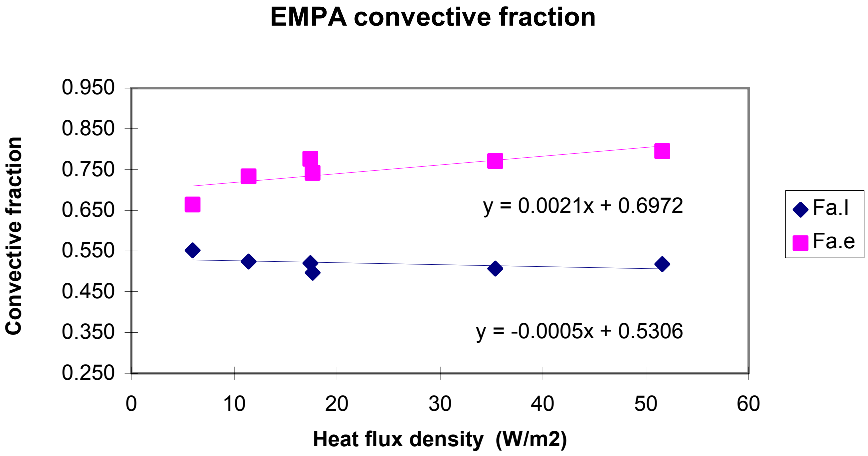


Figure 5 Three CEN graphs from the TNO Results

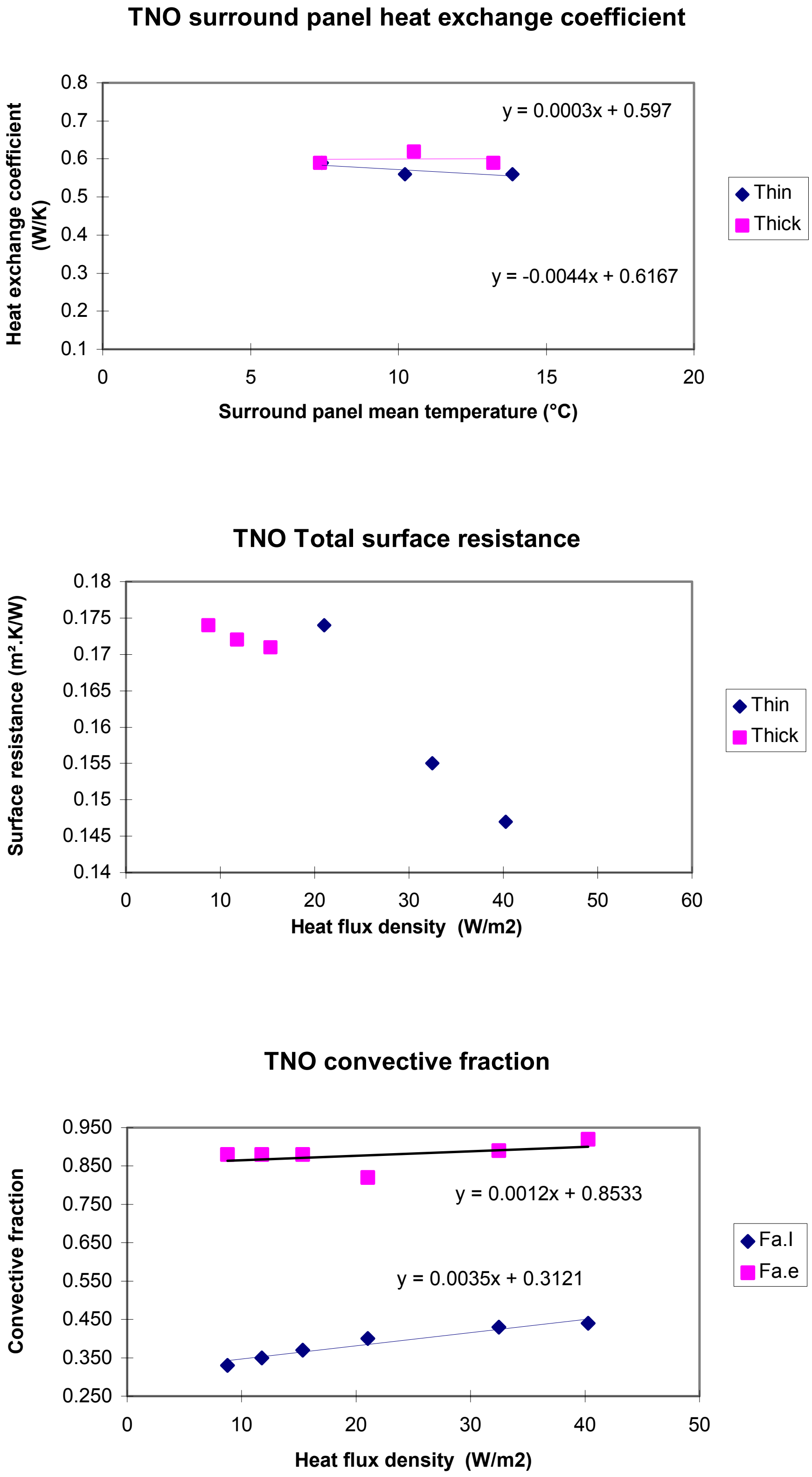
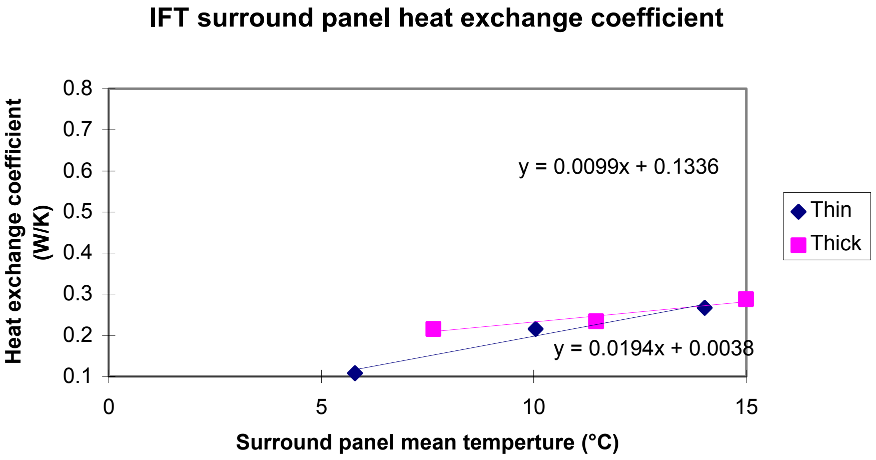
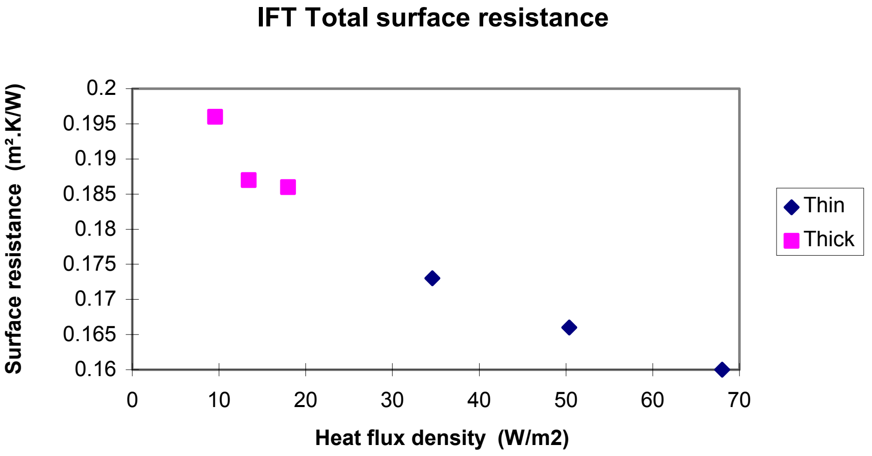


Figure 6 Three CEN graphs from the IFT results


IFT surround panel heat exchange coefficient


IFT Total surface resistance

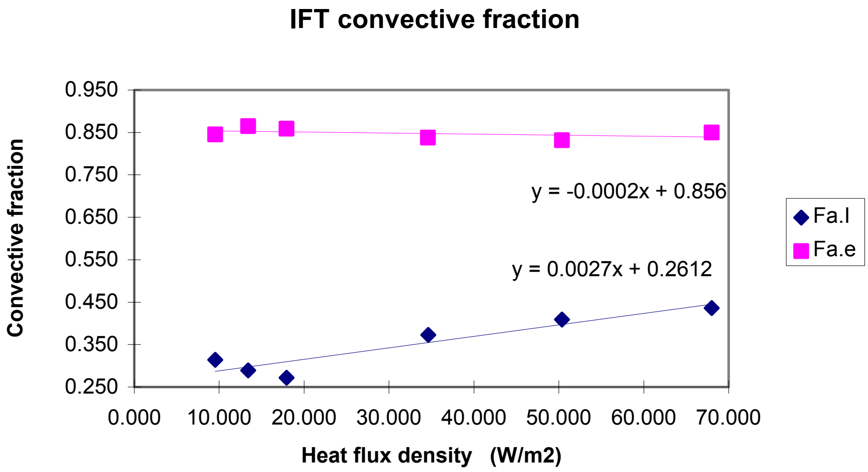
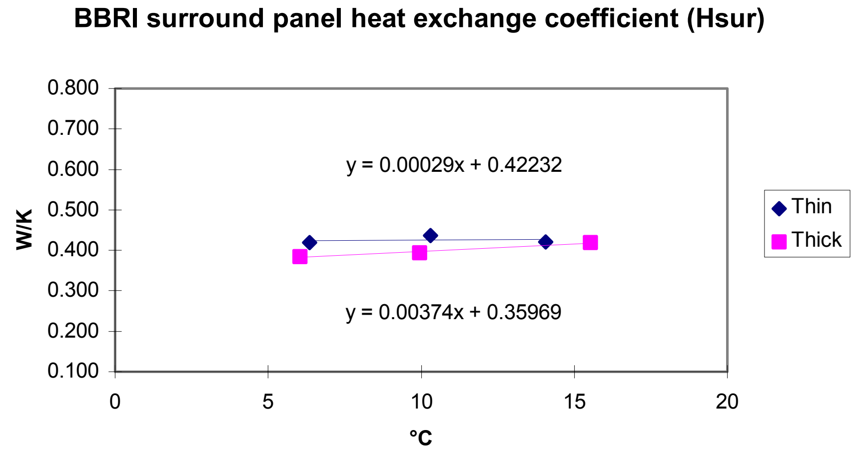
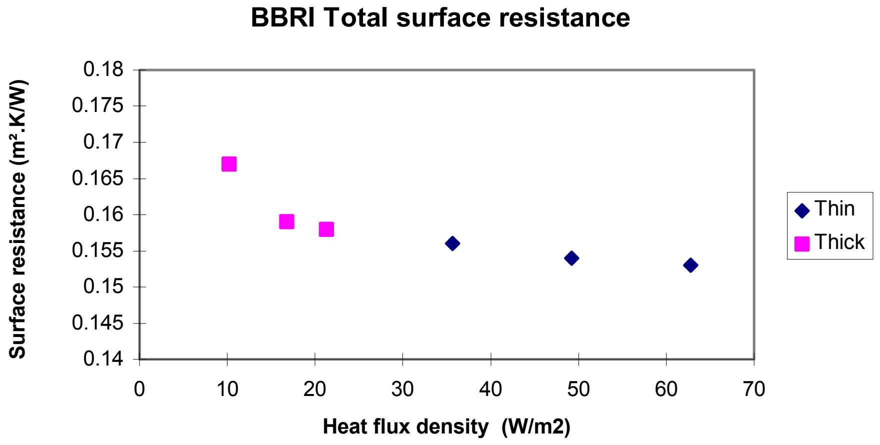
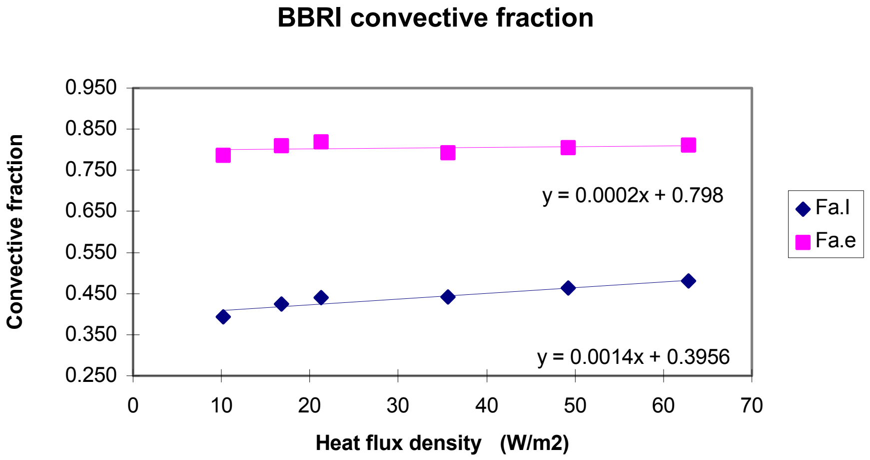

IFT convective fraction
Convective fraction
0.950
0.850
0.750
0.650
0.550
0.450
0.350
0.250
0.000
10.000
20.000
30.000
40.000
50.000
60.000
70.000
Heat flux density (W/m2)
y = -0.0002x + 0.856
y = 0.0027x + 0.2612
Fa.l
Fa.e

Figure 7 Three CEN graphs from the BBRI results


BBRI surround panel heat exchange coefficient (Hsur)

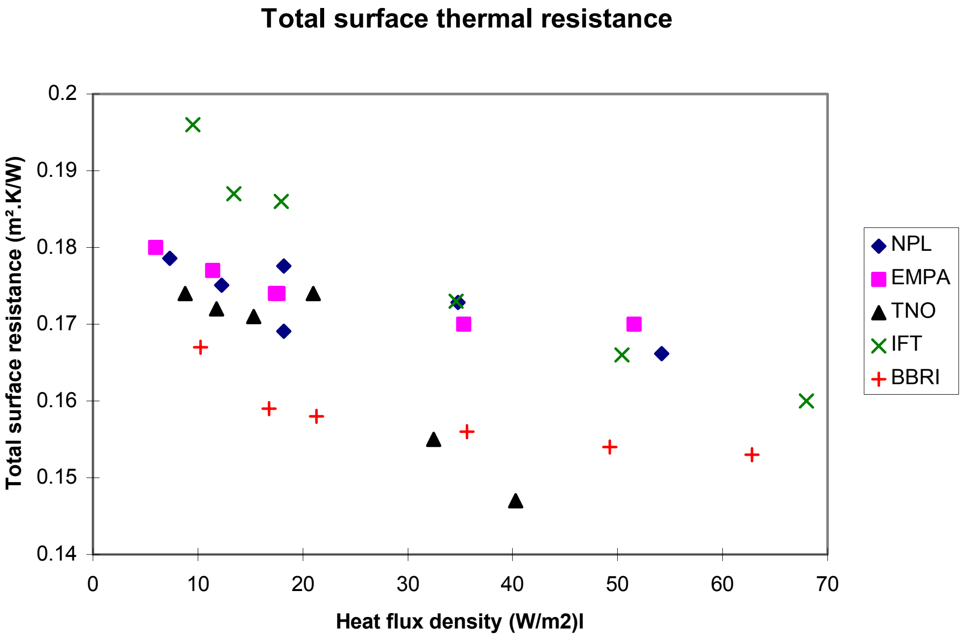

BBRI Total surface resistance


BBRI convective fraction

To help compare the results, the data for each graph type obtained by the different laboratories, has been plotted on one graph.

The data for Total surface resistance and Heat flux density for the different laboratories are compared in Figure 8.

Figure 8 Total surface resistance data for the five laboratories



The data for the Surround panel heat transfer coefficient and the Surround panel mean temperature for the different laboratories are compared in Figure 9 for the thin panels and in Figure 10 for the thick panels.

Figure 9 All the surround panel heat exchange coefficient (thin panel) data

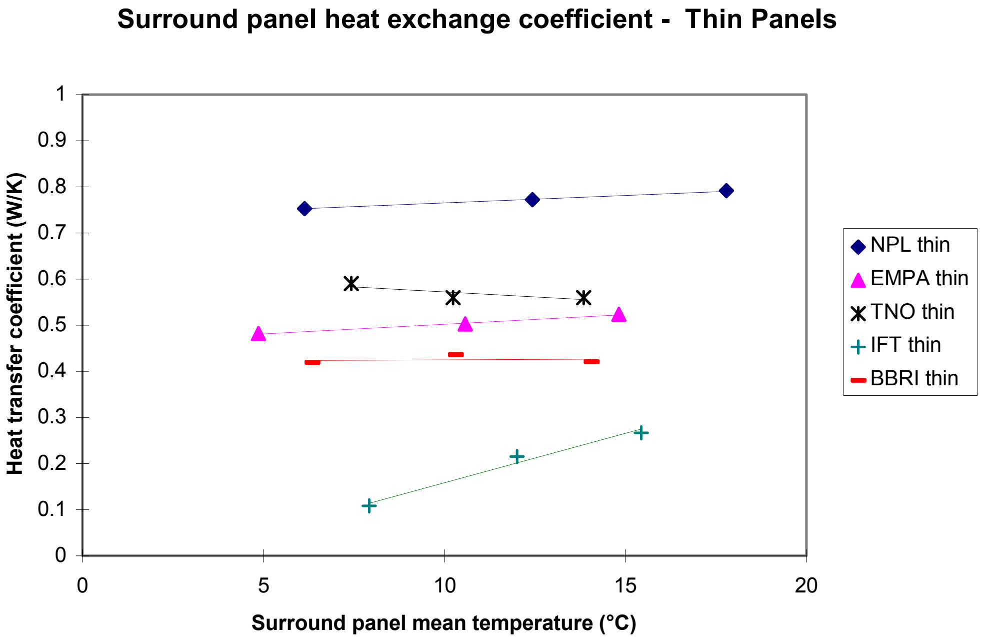
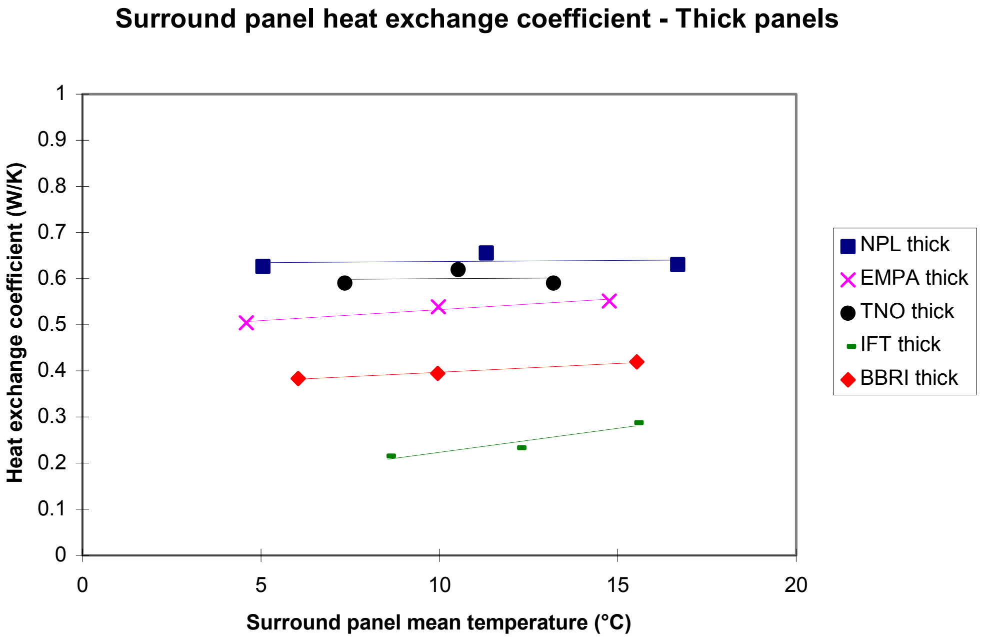
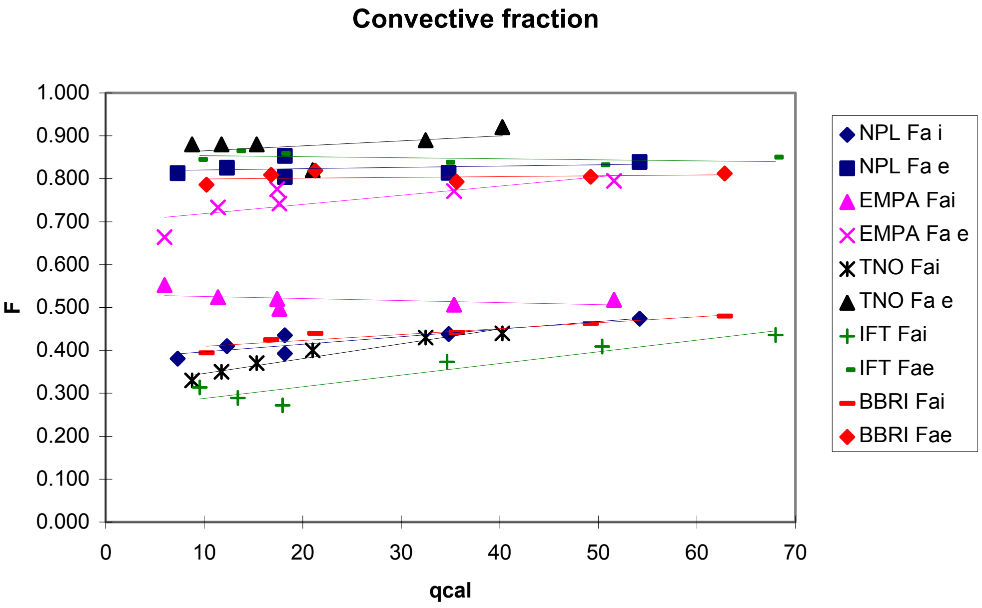


Figure 10 All the surround panel heat exchange coefficient (thick panel) data



The data for the convective fractions for the hot ($F_{a.i}$) and cold ($F_{a.e}$) boxes with heat flux density ($q_{cal}$), for the different laboratories, are compared in Figure 11, where the subscripts (i) and (e) refer to internal and external respectively.

Figure 11 Convective fraction data for all five laboratories



## 6.2 Hot-box measurement of other laboratories panels

Each laboratory carried out one hot-box measurement on a thin panel from another laboratory and a thick panel from a different laboratory. Three of the laboratories also carried out an additional hot box measurement of the EMPA thin panel. This panel has therefor been measured by all the participants. The U-value for the panels from the other laboratories were derived from the measurement data using the procedures given in prEN12412-1 Annex A and Annex B and the three graphs produced from measurements made on each of the laboratory's own calibration panels.

The hot-box measurement data for each laboratory, obtained for the calibration panels of the other laboratories, is given in Tables 11, 12, 13, 14 and 15.

Table 11 NPL Measurement data of the EMPA and IFT panels

| **Measured by** | **NPL** | Surround panel thickness (mms) | | | 150 | | |
|---|---|---|---|---|---|---|---|
| **Panel ID** | | | | **EMPA** | | **IFT** | |
| Panel thickness mm | (1.20 m x 1.20 m nominal size) | | | 20.20 | | 58.06 | |
| **MEASURED VALUES** | | | | | | | |
| **Hot side values** | | | | | | | |
| Air temp | (°C) | | | 23.20 | | 23.77 | |
| Baffle temp | (°C) | | | 22.35 | | 23.24 | |
| Reveal temp | (°C) | | | 20.52 | | 20.37 | |
| Element surface temp | (°C) | | | 18.25 | | 21.84 | |
| **Cold side values** | | | | | | | |
| Air temp | (°C) | | | 2.11 | | 2.8 | |
| Baffle temp | (°C) | | | 2.17 | | 2.84 | |
| Element surface temp | (°C) | | | 3.80 | | 3.34 | |
| **Surround panel values** | | | | | | | |
| Hot side temp | (°C) | | | 22.70 | | 23.11 | |
| Cold side temp | (°C) | | | 2.54 | | 3.32 | |
| Difference temp | (°C) | | | 20.16 | | 19.79 | |
| Mean temp surround | (°C) | | | 12.62 | | 13.215 | |
| Mean temp of test element | (°C) | | | 11.03 | | 12.59 | |
| Area | (m$^2$) | | | 1.219 | | 1.222 | |
| Power to hot box | (W) | | | 58.52 | | 27.623 | |
| **CALCULATIONS** | | | | | | | |
| Hsur - panel thickness | 68.3 | (0.63631+(0.00016*MeanT)) | | 12.62 | 0.6383 | 13.22 | 0.6384 |
| Hsur - panel thickness | 20.3 | (0.73256+(0.00327*MeanT)) | | 12.62 | 0.7738 | 13.22 | 0.7758 |
| Hsur - test element | | mean temp/Hsur = | | 12.62 | 0.7741 | 13.22 | 0.6677 |
| Power density through the test element | | W/m$^2$ | | 35.204 | | 11.791 | |
| **Environmental Temperatures** | | | | | | | |
| Cold side convective fraction | | (0.81761+(0.0003*Hfd)) | | | 0.8282 | | 0.8211 |
| Hot side convective fraction | | (0.3793+(0.00176*Hfd)) | | | 0.4413 | | 0.4001 |
| Mean hot radient temp | | Calculated elsewhere | °C | 22.05 | | 22.89 | |
| Mean cold radient temp (Assumed to be the same as baffle temp) | | | °C | 2.17 | | 2.84 | |
| Hot environmental temp | | | °C | 22.56 | | 23.242 | |
| Cold environmental temp | | | °C | 2.12 | | 2.81 | |
| Environmental temperature difference | | | °C | 20.437 | | 20.435 | |
| U-value CEN & measured directly | | | W/m$^2$.K | 1.7226 | [*] | 0.577 | [*] |
| Tot surface res. from | Thin | (0.18354-(0.00032*Hfd)) | m$^2$.K/W | 0.1723 | *0.163* | | |
| Tot surface res. from | Thick | (0.18532-(0.00088*Hfd)) | | | | 0.1749 | *0.179* |
| Standardised U-value (Total surface resistance = 0.17 m$^2$.K/W) | | | W/m$^2$.K | **1.73** | ***1.70*** | **0.58** | ***0.58*** |
| Standardised Conductance | | | W/m$^2$.K | **2.45** | ***2.40*** | **0.64** | ***0.64*** |

[*] Uses the equation of the corrected Rtot graph shown in Figure 14

Table 12 EMPA Measurement data of the IFT and BBRI panels

| **Measured by EMPA** | | Surround panel thickness (mms) | | 100 | | | |
|---|---|---|---|---|---|---|---|
| **Panel ID** | | | | **IFT** | | **BBRI** | |
| Thickness (mm) | 1.20 m x 1.20 m nominal size | | | 17.77 | | 56.90 | |
| **MEASURED VALUES** | | | | | | | |
| **Hot side values** | | | | | | | |
| Air temp | (°C) | | | 19.05 | | 20.07 | |
| Baffle temp | (°C) | | | 18.18 | | 19.62 | |
| Reveal temp | (°C) | | | 16.61 | | 18.6 | |
| Element surface temp | (°C) | | | 14.50 | | 18.45 | |
| **Cold side values** | | | | | | | |
| Air temp | (°C) | | | 0.45 | | 0.51 | |
| Baffle temp | (°C) | | | 0.51 | | 0.44 | |
| Element surface temp | (°C) | | | 2.89 | | 1.16 | |
| **Surround panel values** | | | | | | | |
| Hot side temp | (°C) | | | 18.30 | | 19.16 | |
| Cold side temp | (°C) | | | 0.84 | | 0.82 | |
| Difference temp | (°C) | | | 17.46 | | 18.34 | |
| Mean temp surround | (°C) | | | 9.57 | | 9.99 | |
| Mean temp of test element | (°C) | | | 8.70 | | 9.81 | |
| Area | ($m^2$) | | | 1.44 | | 1.44 | |
| Power to hot box | (W) | | | 59.87 | | 26.49 | |
| **CALCULATIONS** | | | | | | | |
| Hsur - panel thickness | 59 | (0.4846+(0.0048*sur mean temp)) | | 9.57 | 0.5305 | 9.99 | 0.5326 |
| Hsur - panel thickness | 20 | (0.4607+(0.0042*Sur mean temp)) | | 9.57 | 0.5009 | 9.99 | 0.5027 |
| Hsur - test element | | mean temp/Hsur = | | 9.57 | 0.4992 | 9.99 | 0.5309 |
| Power density through the test element | | W/$m^2$ | | 35.524 | | 11.634 | |
| **Environmental Temperatures** | | | | | | | |
| Cold side convective fraction | | (0.6972+(0.0021*heat flux density)) | | | 0.7718 | | 0.7216 |
| Hot side convective fraction | | (0.5306+(0.0005*heat flux density)) | | | 0.5484 | | 0.5364 |
| Mean hot radient temp | | Calculated elsewhere | °C | 18.00 | | 19.55 | |
| Mean cold radient temp (Assumed to be the same as baffle temp) | | | °C | 0.51 | | 0.44 | |
| Hot environmental temp | | | °C | 18.58 | | 19.83 | |
| Cold environmental temp | | | °C | 0.46 | | 0.49 | |
| Environmental temperature difference | | | °C | 18.11 | | 19.34 | |

| | | | | |
|---|---|---|---|---|
| U-value CEN & measured directly | | W/$m^2$.K | 1.961 | 0.602 |
| Tot surface res. from | 0.1892*(heat flux density^-0.0286) | $m^2$.K/W | 0.171 | 0.176 |
| Standardised U-value (Total surface resistance = 0.17 $m^2$.K/W) | | W/$m^2$.K | **1.96** | **0.60** |
| Standardised Conductance | | W/$m^2$.K | **2.95** | **0.67** |

Table 13 BBRI Measurement data of the TNO, NPL and EMPA panels

| **Measured by BBRI** | Surround panel thickness (mms) | 100 ASSUMED!!! | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Panel ID** | | | **TNO** | | **NPL** | | **EMPA** | |
| Thickness (mm) | 1.20 m x 1.20 m nominal size | | 22.40 | | 68.30 | | 20.20 | |
| **MEASURED VALUES** | | | | | | | | |
| **Hot side values** | | | | | | | | |
| Air temp | (°C) | | 24.35 | | 24.16 | | 24.38 | |
| Baffle temp | (°C) | | 23.17 | | 23.68 | | 23.11 | |
| Reveal temp | (°C) | | 20.14 | | 21.99 | | 19.85 | |
| Specimen surface temp | (°C) | | 18.18 | | 22.04 | | 17.72 | |
| **Cold side values** | | | | | | | | |
| Air temp | (°C) | | -4.36 | | -4.24 | | -4.22 | |
| Baffle temp | (°C) | | -4.04 | | -4.04 | | -3.86 | |
| Specimen surface temp | (°C) | | -2.29 | | -3.55 | | -2.00 | |
| **Surround panel values** | | | | | | | | |
| Hot side temp | (°C) | | 24.43 | | 23.73 | | 24.49 | |
| Cold side temp | (°C) | | -4.04 | | -3.95 | | -3.88 | |
| Difference temp | (°C) | | 28.47 | | 27.68 | | 28.37 | |
| Mean temp surround | (°C) | | 10.195 | | 9.89 | | 10.31 | |
| Mean temp of test element | (°C) | | 7.95 | | 9.25 | | 7.86 | |
| Area | ($m^2$) | | 1.219 | | 1.216 | | 1.216 | |
| Power to hot box | (W) | | 68.85 | | 28.11 | | 73.80 | |
| **CALCULATIONS** | | | | | | | | |
| Hsur - panel thickness | 56.9 | (0.3723+(0.0022*sur mean temp)) | 10.20 | 0.3974 | 9.89 | 0.3963 | 10.31 | 0.3978 |
| Hsur - panel thickness | 20.3 | (0.4296+(0.0004*Sur mean temp)) | 10.20 | 0.4253 | 9.89 | 0.4252 | 10.31 | 0.4253 |
| Hsur - test element | 22.40 | mean temp/Hsur = | 10.20 | 0.4237 | 9.89 | 0.3873 | 10.31 | 0.4254 |
| Power density through the test element | W/$m^2$ | | 46.574 | | 14.301 | | 50.766 | |
| **Environmental Temperatures** | | | | | | | | |
| Cold side convective fraction | | (0.798+(0.0002*heat flux density)) | | 0.8073 | | 0.8009 | | 0.8082 |
| Hot side convective fraction | | (0.3956+(0.0014*heat flux density)) | | 0.4608 | | 0.4156 | | 0.4667 |
| Mean hot radient temp | °C | Calculated elsewhere | 22.94 | | 23.65 | | 22.86 | |
| Mean cold radient temp (Assumed to be the same as baffle temp) | °C | | -4.04 | | -4.04 | | -3.86 | |
| Hot environmental temp | °C | | 23.59 | | 23.86 | | 23.57 | |
| Cold environmental temp | °C | | -4.30 | | -4.20 | | -4.15 | |
| Environmental temperature difference | °C | | 27.89 | | 28.06 | | 27.72 | |

| | | | | | |
|---|---|---|---|---|---|
| U-value CEN & measured directly | | W/$m^2$.K | 1.670 | 0.510 | 1.831 |
| Tot surface res. from | 0.18203*(hfd^-0.04331) | $m^2$.K/W | 0.154 | 0.162 | 0.154 |
| Standardised U-value (Total surface resistance = 0.17 $m^2$.K/W) | | W/$m^2$.K | **1.63** | **0.51** | **1.78** |
| Standardised Conductance | | W/$m^2$.K | **2.25** | **0.56** | **2.55** |

Table 14 TNO Measurement data of the NPL and two EMPA panels

| **Measured by TNO** | Surround panel thickness (mms) | | 224 | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Panel ID** | | | **NPL** | | **EMPA** | | EMPA | |
| Thickness | 1.20 m x 1.20 m nominal size | | 20.30 | | 58.90 | | 20.20 | |
| **MEASURED VALUES** | | | | | | | | |
| **Hot side values** | | | | | | | | |
| Air temp | | (°C) | 21.12 | | 20.13 | | 21.26 | |
| Baffle temp | | (°C) | 19.37 | | 18.94 | | 19.69 | |
| Reveal temp | | (°C) | 17.31 | | 18.28 | | 18.11 | |
| Specimen surface temp | | (°C) | 15.00 | | 17.70 | | 16.32 | |
| **Cold side values** | | | | | | | | |
| Air temp | | (°C) | 0.49 | | 4.45 | | 5.38 | |
| Baffle temp | | (°C) | 0.63 | | 4.54 | | 5.49 | |
| Specimen surface temp | | (°C) | 1.77 | | 4.79 | | 6.33 | |
| **Surround panel values** | | | | | | | | |
| Hot side temp | | (°C) | 19.62 | | 18.85 | | 19.89 | |
| Cold side temp | | (°C) | 0.67 | | 4.57 | | 5.52 | |
| Difference temp | | (°C) | 18.95 | | 14.28 | | 14.37 | |
| Mean temp surround | | (°C) | 10.145 | | 11.71 | | 12.71 | |
| Mean temp of test element | | (°C) | 8.39 | | 11.25 | | 11.33 | |
| Area | | ($m^2$) | 1.21 | | 1.21 | | 1.21 | |
| Power to hot box | | (W) | 52.25 | | 20.34 | | 40.43 | |
| **CALCULATIONS** | | | | | | | | |
| Hsur - panel thickness | 58 (0.597+(0.0003*sur mean temp)) | | 10.15 | 0.6274 | 11.71 | 0.6321 | 12.71 | 0.6351 |
| Hsur - panel thickness | 22.4 (0.6167+(0.0044*Sur mean temp)) | | 10.15 | 0.6613 | 11.71 | 0.6682 | 12.71 | 0.6726 |
| Hsur - test element | mean temp/Hsur = | | 10.15 | 0.6633 | 11.71 | 0.6312 | 12.71 | 0.6749 |
| Power density through the test element | W/$m^2$ | | 32.793 | | 9.361 | | 25.398 | |
| **Environmental Temperatures** | | | | | | | | |
| Cold side convective fraction | (0.8533+(0.0012*heat flux density)) | | | 0.8927 | | 0.8645 | | 0.8838 |
| Hot side convective fraction | (0.3121+(0.0035*heat flux density)) | | | 0.4269 | | 0.3449 | | 0.4010 |
| Mean hot radient temp | Calculated elsewhere | °C | 18.88 | | 18.21 | | 19.31 | |
| Mean cold radient temp (Assumed to be the same as baffle temp) | | °C | 0.63 | | 4.54 | | 5.49 | |
| Hot environmental temp | | °C | 19.836 | | 18.872 | | 20.09 | |
| Cold environmental temp | | °C | 0.505 | | 4.4622 | | 5.39 | |
| Environmental temperature difference | | °C | 19.331 | | 14.41 | | 14.70 | |

| | | | | | |
|---|---|---|---|---|---|
| U-value CEN & measured directly | | W/$m^2$.K | 1.696 | 0.650 | 1.728 |
| Tot surface res. from | 0.182649+(heat flux density*0.000868) | $m^2$.K/W | 0.211 | 0.177 | 0.172 |
| Standardised U-value (Total surface resistance = 0.17 $m^2$.K/W) | | W/$m^2$.K | **1.82** | **0.65** | **1.74** |
| Standardised Conductance | | W/$m^2$.K | **2.64** | **0.73** | **2.46** |

Table 15 IFT Measurement data of the BBRI, TNO and EMPA panels

| **Measured by IFT** | | Surround panel thickness (mms) | 200 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Panel ID** | | | | **BBRI** | | **TNO** | | EMPA | |
| Thickness (mms) | 1.20 m x 1.20 m nominal size | | | 20.30 | | 56.96 | | 20.20 | |
| **MEASURED VALUES** | | | | | | | | | |
| **Hot side values** | | | | | | | | | |
| Air temp | (°C) | | | 23.21 | | 23.42 | | 22.67 | |
| Baffle temp | (°C) | | | 24.30 | | 23.88 | | 23.73 | |
| Reveal temp | (°C) | | | 23.09 | | 23.32 | | 22.60 | |
| Specimen surface temp | (°C) | | | 18.71 | | 21.62 | | 18.13 | |
| **Cold side values** | | | | | | | | | |
| Air temp | (°C) | | | 2.83 | | 2.85 | | 2.84 | |
| Baffle temp | (°C) | | | 2.91 | | 2.74 | | 2.89 | |
| Specimen surface temp | (°C) | | | 4.45 | | 3.28 | | 4.35 | |
| **Surround panel values** | | | | | | | | | |
| Hot side temp | (°C) | | | 23.09 | | 23.32 | | 22.60 | |
| Cold side temp | (°C) | | | 3.26 | | 3.02 | | 3.24 | |
| Difference temp | (°C) | | | 19.83 | | 20.30 | | 19.36 | |
| Mean temp surround | (°C) | | | 13.175 | | 13.17 | | 12.92 | |
| Mean temp of test element | (°C) | | | 11.58 | | 12.45 | | 11.24 | |
| Area | ($m^2$) | | | 1.21 | | 1.21 | | 1.21 | |
| Power to hot box | (W) | | | 50.59 | | 20.74 | | 49.22 | |
| **CALCULATIONS** | | | | | | | | | |
| Hsur - panel thickness | 57.8 | (0.1336+(0.0099*sur mean temp)) | | 13.18 | 0.2640 | 13.17 | 0.2640 | 12.92 | 0.2615 |
| Hsur - panel thickness | 17.3 | (0.0038+(0.0099*Sur mean temp)) | | 13.18 | 0.2594 | 13.17 | 0.2593 | 12.92 | 0.2544 |
| Hsur - test element | | mean temp/Hsur = | | 13.18 | 0.2597 | 13.17 | 0.2639 | 12.92 | 0.2550 |
| Power density through the test element | | W/$m^2$ | | 37.553 | | 12.713 | | 36.598 | |
| **Environmental Temperatures** | | | | | | | | | |
| Cold side convective fraction | | (0.856+(0.0002*heat flux density)) | | | 0.8635 | | 0.8585 | | 0.8633 |
| Hot side convective fraction | | (0.2612+(0.0027*heat flux density)) | | | 0.3626 | | 0.2955 | | 0.3600 |
| Mean hot radient temp | | Calculated elsewhere | °C | 24.04 | | 23.78 | | 23.51 | |
| Mean cold radient temp (Assumed to be the same as baffle temp) | | | °C | 2.91 | | 2.74 | | 2.89 | |
| Hot environmental temp | | | °C | 23.739 | | 23.674 | | 23.21 | |
| Cold environmental temp | | | °C | 2.8409 | | 2.8344 | | 2.85 | |
| Environmental temperature difference | | | °C | 20.898 | | 20.839 | | 20.36 | |

| | | | | | |
|---|---|---|---|---|---|
| U-value CEN & measured directly | | W/$m^2$.K | 1.797 | 0.6101 | 1.797 |
| Tot surface res. from | 0.203-(0.001147*Hfd)+(0.0000075*Hfd^2) | $m^2$.K/W | 0.1705 | 0.1896 | 0.171 |
| Standardised U-value (Total surface resistance = 0.17 $m^2$.K/W) | | W/$m^2$.K | **1.80** | **0.62** | **1.80** |
| Standardised Conductance | | W/$m^2$.K | **2.59** | **0.69** | **2.60** |

The standardised U-value of the glazed calibration panels measured by the different laboratories using the CEN procedures, are compared to the calculated U-values in Table 16. The calculated U-values were derived by adding 0.17 m$^{2\cdot}$.K/W to the thermal resistance of the calibration panel (at the mean temperature of the U-value measurement) and taking the reciprocal.

Table 16 Comparison between the measured and calculated U-values of the glazed calibration panels.

| | **NPL panel** | | **EMPA panel** | | **BBRI panel** | | **TNO panel** | | **IFT panel** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Thin** | **Thick** | **Thin** | **Thick** | **Thin** | **Thick** | **Thin** | **Thick** | **Thin** | **Thick** |
| | (W/$m^2$.K) | (W/$m^2$.K) | (W/$m^2$.K) | (W/$m^2$.K) | (W/$m^2$.K) | (W/$m^2$.K) | (W/$m^2$.K) | (W/$m^2$.K) | (W/$m^2$.K) | (W/$m^2$.K) |
| **NPL** U--value (W/$m^2$.K) | | | 1.729 | | | | | | | 0.579 |
| Mean temperature °C[$] | | | 11.03 | | | | | | | 12.59 |
| Calc. conductance (W/$m^2$.K) | | | 2.637 | | | | | | | 0.653 |
| Calc. U-value (W/$m^2$.K) | | | 1.821 | | | | | | | 0.588 |
| Difference in U-value % | | | 5.0% | | | | | | | 1.5% |
| **EMPA** U--value (W/$m^2$.K) | | | - | | | 0.604 | | | 1.965 | |
| Mean temperature °C[$] | | | - | | | 9.81 | | | 8.70 | |
| Calc. conductance (W/$m^2$.K) | | | - | | | 0.669 | | | 3.423 | |
| Calc. U-value (W/$m^2$.K) | | | - | | | 0.601 | | | 2.164 | |
| Difference in U-value % | | | - | | | -0.5% | | | 9.2% | |
| **TNO** U--value (W/$m^2$.K) | 1.824 | | 1.735 | 0.653 | | | | | | |
| Mean temperature °C[$] | 8.39 | | 11.33 | 11.25 | | | | | | |
| Calc. conductance (W/$m^2$.K) | 2.381 | | 2.640 | 0.675 | | | | | | |
| Calc. U-value (W/$m^2$.K) | 1.695 | | 1.822 | 0.605 | | | | | | |
| Difference in U-value % | -7.6% | | 4.8% | -7.9% | | | | | | |
| **IFT** U--value (W/$m^2$.K) | | | 1.801 | | 1.799 | | | 0.617 | | |
| Mean temperature °C[$] | | | 11.240 | | 11.58 | | | 12.45 | | |
| Calc. conductance (W/$m^2$.K) | | | 2.640 | | 2.493 | | | 0.670 | | |
| Calc. U-value (W/$m^2$.K) | | | 1.822 | | 1.751 | | | 0.601 | | |
| Difference in U-value % | | | 1.2% | | -2.7% | | | -2.7% | | |
| **BBRI** U--value (W/$m^2$.K) | | 0.508 | 1.778 | | | | 1.627 | | | |
| Mean temperature °C[$] | | 7.95 | 7.86 | | | | 7.95 | | | |
| Calc. conductance (W/$m^2$.K) | | 0.558 | 2.61 | | | | 2.197 | | | |
| Calc. U-value (W/$m^2$.K) | | 0.510 | 1.806 | | | | 1.599 | | | |
| Difference in U-value % | | 0.5% | 1.6% | | | | -1.7% | | | |

# 7 DISCUSSION

## 7.1 Thermal conductivity measurements

The details of the thermal conductivity measurements are described in NPL Report QM 122[9]. The conclusion of which was that the agreement between the laboratories was poorer than would be expected from their claimed measurement uncertainties, but that except for one inter-compared value, the differences between the measured values were compatible with a measurement uncertainty of ± 3.6% for each of the laboratories.

The outlying result was the TNO value for the IFT thin EPS material. No satisfactory reason for that difference was identified. However, IFT used different EPS material to make their calibration panels, to that measured in the inter-comparison.

## 7.2 Thickness measurements

A number of methods were adopted by the different laboratories for measuring the overall thickness of the glazed calibration panels (see Table 14). Despite this, the agreement between different laboratories is mainly very good, as can be seen in Table 4. The biggest discrepancy between laboratories was 1.8% for the thin panel, but in ten out of the twelve comparison measurements, the differences were about 0.5%.

## 7.3 Variations in the calculated conductance values

Each laboratory was asked to calculate the conductance of their two calibration panels by assuming that the gap between the glass was completely full of EPS. The effect of the glue and the air gap was to be ignored. The values they derived are shown in Figures 1 and 2, plotted against mean temperature. These show that the IFT thin panel has a much higher conductance than those of the other laboratories. This is caused by the IFT EPS being thinner than that used by the other laboratories for their thin panels. The calculated conductance of the NPL thick panel was lower than that of the other panels because the NPL used 60 mm thick EPS instead of the 50 mm thick EPS used by the other laboratories.

The graphs in Figures 1 and 2 show that the calculated conductance of the two panels made by IFT appear to be constant over the temperature range. However, it would be expected that the thermal conductance would increase slightly with temperature because the thermal conductivity of EPS increases slightly with temperature. The IFT thermal conductivity data do not show the same relationship to temperature as that of the other laboratories.

### 7.4 The set of three calibration graphs

The set of three CEN calibration graphs for each laboratory can be seen in Figures 3, 4, 5, 6 and 7. The data for each graph type are compared in Figures 8, 9 and 10.

The values plotted in these graphs are sensitive to the calculated conductance of the calibration panels. The actual sensitivity will vary with surround panel details but as a guide, the sensitivity of the NPL data to the calculated conductance is shown in Table 17.

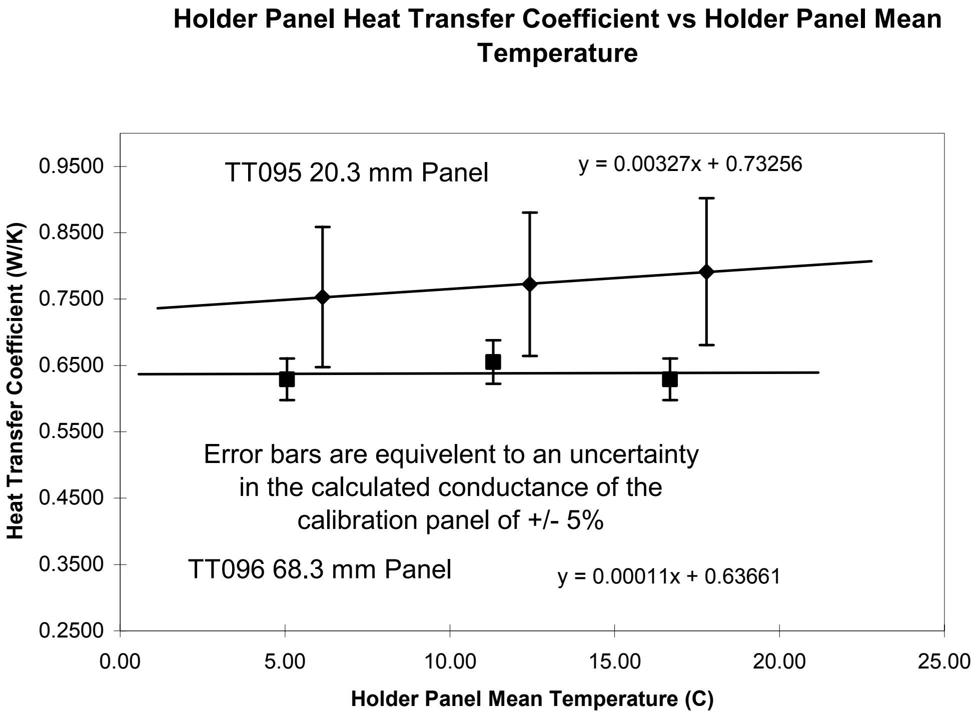
Table 17 Sensitivity of the critical parameters to calculated conductance (NPL data)

| | Effect of changing the calculated conductance of the panels by 5% | | | |
|---|---|---|---|---|
| | $R_{tot}$ | $H_{sur}$ | Hot convective fraction | Cold convective fraction |
| Thin panel | 4.8% | 14% | 5.5% | 0.6% |
| Thick panel | 4.8% | 5% | 5.5% | 0.6% |

i) **Surround Panel Heat Exchange Coefficient (Hsur)**

The sensitivity of the Surround Panel heat transfer coefficient to the calculated conductance (for the NPL results) can be seen in Figure 12.

Figure 12 Surround panel heat transfer coefficient sensitivity to calculated conductance for the NPL data

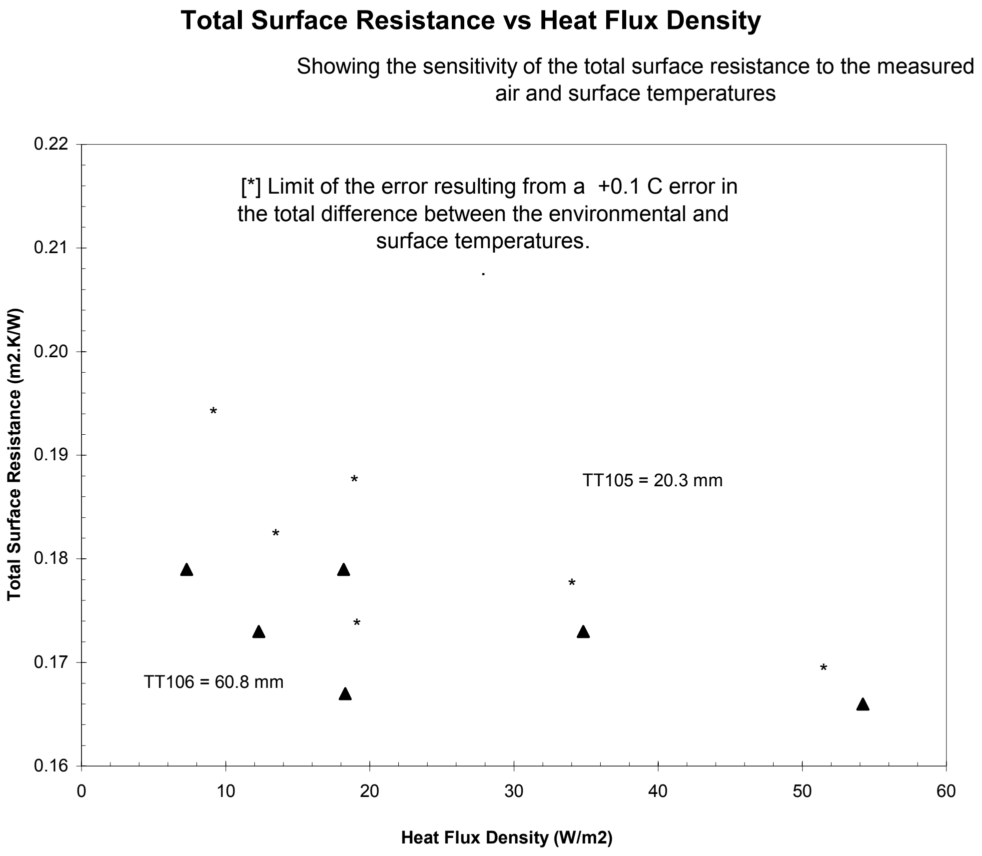


The sensitivity of the Surround panel heat transfer coefficient ($H_{sur}$)to the calculated conductance value will depend on the conductance of the surround panel and its area. It is possible for the Hsur value for the thick panel to be higher than for the thin. This effect can be seen in Figures 4, 5 and 6 for EMPA, TNO and IFT. However, if the extrapolation / interpolation to the specimen thickness is not great, this reversal does not have a very significant effect on the U-value derived using it. This is why the U-values of the other laboratories that were measured using these values show good agreement with the calculated values even when the order of the Hsur graphs were reversed. In that case, however, it will be very important that calibration measurements are carried out using calibration panels of approximately the same thickness as the test element.

### ii) **Total Surface Resistance (Rtot)**

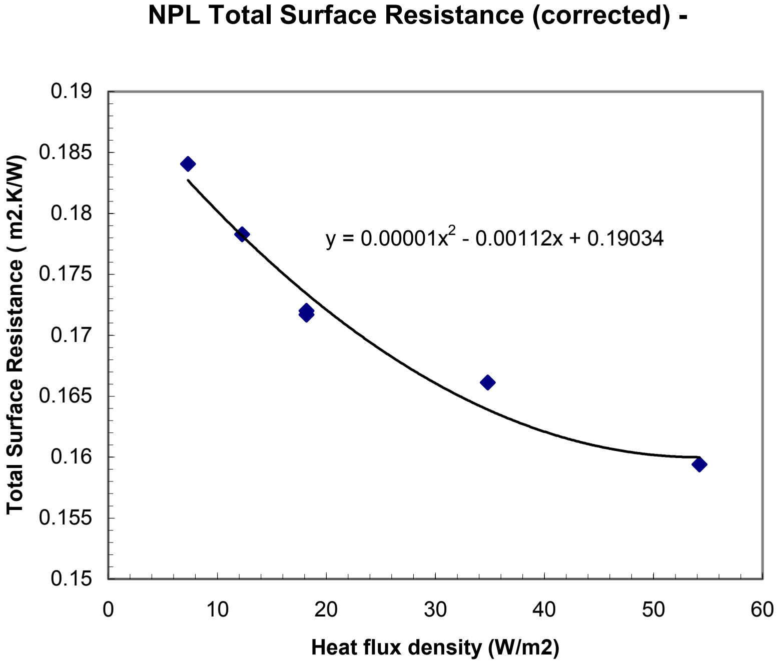
The total surface resistance value is very sensitive to temperature measurement errors. The most probable error would be for the measured hot surface temperature to be too warm (tending towards the air temperature) and the cold surface temperature to be too cold (tending towards the cold air temperature). The effect of a 0.1 °C error in the difference between the surface and environmental temperatures on the total surface resistance is shown in Figure 13.

Figure 13 Sensitivity of the total resistance to surface temperature difference (NPL data)



The figures in Table 18 also show that the total surface resistance is also affected by the calculated conductance value. The graph of total surface resistance against heat flux density for the NPL results (Figure 3) show two distinct sets of data that do not fall on one smooth curve as expected. However, if the calculated total surface resistance was reduced by 3.75% for thin panel and increased 3% for the thick panel, a continuous smooth curve of total surface resistance against heat flux density is produced (see Figure 14).

Figure 14 Corrected total surface resistance for the NPL results



The figures in Table 18 show how the total calculated surface resistance changed with changing heat flux density, for the thick and thin panels for the different laboratories. The slope of the graph for the thin panels was about 2.3 x $10^{-4}$ $m^4$.K/$W^2$ , although the TNO value was much higher at 14 x $10^{-4}$ $m^4$.K/$W^2$. For the thick panels however there were two laboratories with slopes of about 10 x $10^{-4}$ $m^4$.K/$W^2$ and three with values of about 5 x $10^{-4}$ $m^4$.K/$W^2$.

Although at first sight these differences would appear significant, it must be remembered that the effect of this normalisation procedure is quite small. For example for a test element with a U-value of 3.5 W/$m^2$K, the effect of normalising to 0.17 $m^2$.K/W, is to change the measured U-value by 3% (assuming the slope of the graph to be 2.5 x $10^{-4}$ $m^4$.K/$W^2$). For a test element with U-value of 0.5 W/$m^2$K the effect of normalising to 0.17 $m^2$.K/W is 0.5% when the slope is 5 x $10^{-4}$ $m^4$.K/$W^2$ and 0.8% when the slope is 12 x $10^{-4}$ $m^4$.K/$W^2$ .

This normalisation procedure may therefore be unnecessary. The procedure could be simplified to just specifying that the U-value measurements must be carried out with the same air flow conditions that were established when the calibration measurements were carried out. Therefore each U-value measurement should be carried out under the same air flow conditions that produced a total surface resistance value of 0.17 ± 0.01 $m^2$.K/W with the thin calibration panel.

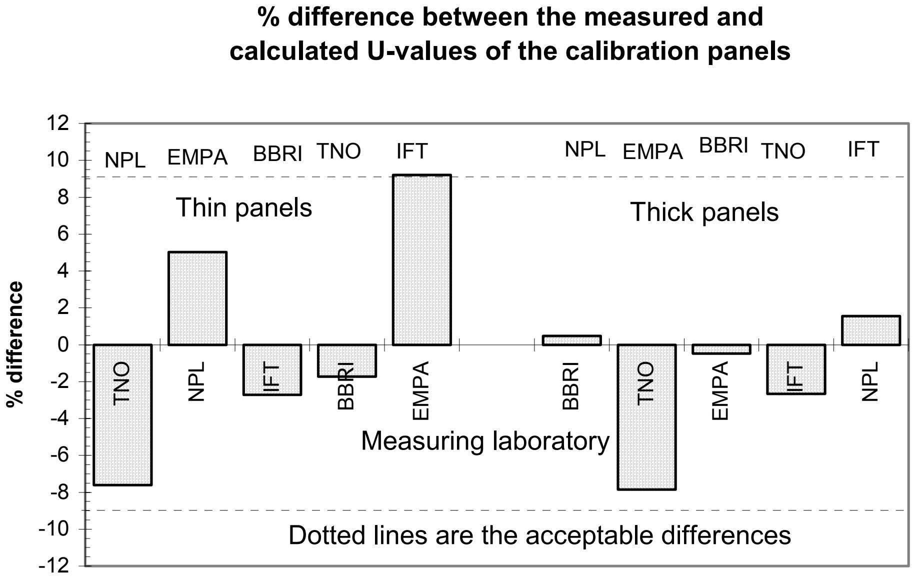
Table 18 Surface resistance dependence on heat flux density

| Laboratory | Total surface resistance | | Heat flux density | | Change in total surface resistance per unit heat flux density |
|---|---|---|---|---|---|
| | Minimum m$^{2\cdot}$.K/W | Maximum m$^{2\cdot}$.K/W | Maximum W/m$^{2}$ | Minimum W/m$^{2}$ | m$^{4}$.K/W$^{2}$ $\times 10^{-4}$ |
| NPL Thin | 0.1662 | 0.1776 | 54.201 | 18.194 | 3.2 |
| Thick | 0.1691 | 0.1786 | 18.192 | 7.305 | 8.7 |
| EMPA Thin | 0.17 | 0.174 | 51.59 | 17.63 | 1.2 |
| Thick | 0.174 | 0.180 | 17.41 | 5.98 | 5.2 |
| TNO Thin | 0.147 | 0.174 | 40.26 | 21.01 | 14 |
| Thick | 0.171 | 0.174 | 15.33 | 8.76 | 4.6 |
| IFT Thin | 0.16 | 0.173 | 67.99 | 34.59 | 3.9 |
| Thick | 0.186 | 0.196 | 17.95 | 9.55 | 12 |
| BBRI Thin | 0.154 | 0.156 | 62.81 | 35.65 | 0.7 |
| Thick | 0.158 | 0.164 | 21.28 | 10.24 | 5.4 |

## 7.5 U-value measurements of the other laboratories calibration panels

Each laboratory measured at least two calibration panels that were fabricated by other laboratories. The U-values that were measured using the CEN procedure (using the hot-box measurement data obtained with their own calibration panels) are shown in Table 16. These measured and calculated U-values are compared in Figure 15.

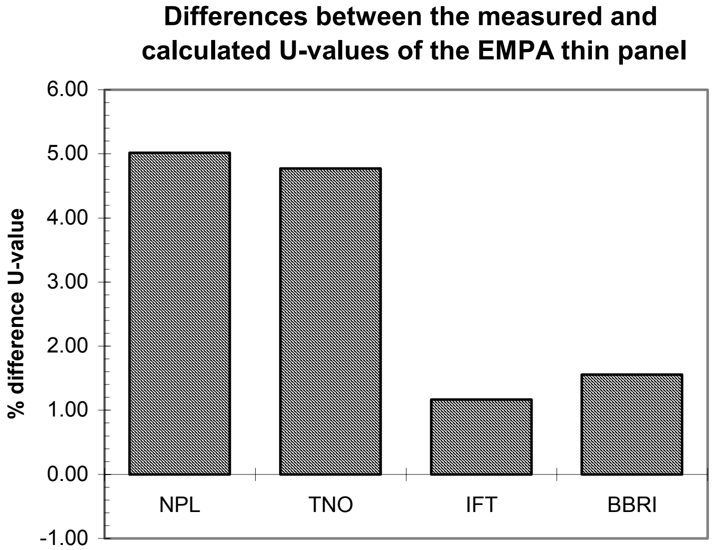
Figure 15 Comparison between measured and calculated U-values



If the uncertainty in the calculated conductance of the calibration panels is assumed to be + 5.8% to - 4.6% and the measurement uncertainty of measurements made using the CEN procedure is assume to be within ±7%, then the maximum difference between the measured and calculated U-values should be about ±9%. This has been achieved in all of the measurements.

The EMPA thin panel was measured by the other four laboratories using the CEN procedures. The difference between the measured and calculated U-values are compared in Figure 16.

Figure 16 Comparison between the measured and calculated U-values for the EMPA thin panel



The calibration panels and the measurement procedure would therefore appear to have fulfilled their purpose in facilitating hot box measurements of window and glazing panels U-values with an measurement uncertainty of (better than) ±7%.

### 7.6 Durability of the calibration panels

The design, the method of construction and the adhesive selected were all very successful. The finished panels were robust enough to survive their journeys around Europe. The comparison of the thickness measured by the different laboratories given in Table 4 shows that they remained stable even after many months and long journeys by road, rail and air.

One of the calibration panels was broken when it was transported back to its owner. The side panels had been removed from the box used to transport the panel, which allowed the container to be laid down flat. It appears that a heavy weight was dropped onto the box, which punctured the 6 mm thick plywood and EPS protective layer and shattered the toughened glass. However, it proved impossible to remove the glass that was actually glued to the EPS. The bond was very tenacious.

None of the panels showed any signs of de-laminating due to the very low temperatures that they were subjected to during the calibration measurements.

### 7.7 The measurement procedures required by the standards

A number of issues concerning the Hot Box measurement standards have been highlighted during this project and they are summarised below.

i. Is it necessary to plot the graph of total surface resistance against heat flux density and use it to normalise the measured U-value to a surface resistance of 0.17 $m^{2\cdot}$.K/W? See section 7.4.

ii. Can the method be adapted to enable the results from one size of glazed calibration panels be used to derive the U-value of test elements of a different size.

iii. The description of the calibration procedure should rewritten to make it clearer.

iv. The main point of the new measurement procedures is that the heat flow around the specimen edges, the calculation of environmental temperatures and the normalisation of the measured U-value to include a standardised total surface resistance value can all be carried out without the need to measure the surface temperature of the specimen. However, when calculating the Mean Radiant Temperature (Tr) there appears to be a need to have a specimen surface temperature. But, for all practical purposes (when the difference between the Baffle temperature and the Reveal temperature is less than 15 °C) the mean radiant temperature is independent of the specimen surface temperature. In fact, as long as the temperature difference between the baffle and reveal is less than 5°C, the simplified equation shown below (to determine Tr) can be used instead of equation 11 in Annex A prEN 12412-1.

$$Tr = \frac{\alpha cb\,.\,Tb + \alpha cp\,.\,Tp}{cb + \alpha cp}$$

v. An important requirement is for the hot-side reveal temperature to be measured but there are no instructions on how this is to be done. The method adopted at the NPL was to measure the temperature of each of the four reveals with two thermocouples, each placed on the mid point between the panel and the face of the surround panel. The two thermocouples were spaced such that each was measuring an equal length of reveal. An instruction of how this should be carried out should be included in the standard.

- The above issues will be brought to the attention of TC 89 WG 7.

## 8 CONCLUSIONS

### 8.1 Fabrication of the glazed calibration panels

i. The agreement between the five laboratories' measurements of thermal conductivity of the EPS material indicated that a measurement uncertainty of ±3.6% can be assumed for thermal conductivity measurements of the insulation material used.

ii. The agreement between the five laboratories' measurements of overall panel thickness indicated that a measurement uncertainty of ±2% can be assumed for the overall panel thickness measurements.

iii. The fabrication method specified in Annex A was shown to produce reliable and robust glazed calibration panels whose thermal conductance value can be calculated to within an uncertainty of ±5.8%.

iv. The U-value measurements made using the data from the calibration panels and the CEN procedures have shown that the data from these panels enabled U-nvalue measurement uncertainties of approximately ±7% to be attained.

v. The specification for the design and construction of the glazed calibration panels that have been verified by this project is given in Annex A.

### 8.2 The measurement standards

i. TC 89 WG7 should discuss whether it is necessary to plot the graph of total surface resistance against heat flux density and use it to normalise the measured U-value to a surface resistance of 0.17 $m^{2}$.K/W. Should this normalisation procedure be dropped?

ii. TC 89 WG7 should discuss whether the CEN measurement method should be adapted to enable the result from one set of glazed calibration panels be used to derive the U-value of test elements of different sizes.

iii. The method of evaluating the mean radiant temperature should be clarified.

## 9 EXPLOITATION

The work carried out by the five laboratories during this project has shown that the panel design and fabrication method specified in this document will meet the requirements of the CEN hot box standards prEN 12412-1, ISO/DIS 12567 and prEN 1098.

i. The prime method of exploiting this information will be to ask the two standards working groups TC 89 WG7 and ISO TC 163 WG14 to incorporate this design into their standards or to produce a technical annex. Four of the six people involved in this project are active members of the two working groups. One of the participants is the secretary of CEN TC 89 WG7.

ii. Every effort will be made to present a summary of this project, either at a conference or as paper in an appropriate scientific journal.

iii. Copies of the report will be available for the measurement community.

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# ANNEX A: DESIGN AND CONSTRUCTION OF THE CALIBRATION PANELS

## 1 DESIGN AND MATERIALS

| | |
|---|---|
| **Type of panel** | Non-instrumented |
| **Core material** | White expanded polystyrene (EPS) with a density of approximately 28 kg/m$^3$. The core of both panels to be made from the same sheets of EPS from which the thermal conductivity specimens were taken. |
| **Glazing material** | 4 mm thick float glass with arrissed (chamfered) edges. |
| **Adhesive** | Dow Corning 7091 |

## 2 CONSTRUCTION DETAILS

**Layout of adhesive spots.**

Glass to be glued to EPS using Dow Corning 7091 compound in a 4 x 4 array of glue points for 1.2 m x 1.2 m panels and a 4 x 6 array for 1.48 m x 1.23 m panels. Care should be taken that the glue spots do not coincide with the positions of the surface thermocouples that must be fixed during the hot box calibration measurements.

**Method of applying the adhesive**

i. Fix the toughened glass to the EPS core material using Dow Corning 7091 silicone compound in a 4 x 4 array of glue points about 35 mm diameter. The sixteen glue points should be distributed evenly and care should be taken to avoid where the surface thermocouples will be fixed during the calibration measurements.

ii. The following method has been shown to be successful in producing an even adhesive "spot" about 35 mm in diameter: Metal "washers" with a 28 mm diameter hole and 0.5 mm thick are placed in the required array on the EPS surface. The holes are filled flush to the top surface with Dow Corning 7091 compound and then the washers are removed.

iii. The glass is put in position, ensuring that the edges are square to the EPS material. The joint is put under pressure by placing a piece of 19 mm thick plywood on top of the glass and weighting with buckets filled with sand. ( A weight of 100 kg evenly distributed over the surface has been found to be adequate).

**iv. It is very important that the glass is thoroughly cleaned using a solvent such as acetone, prior to fixing the adhesive.**

v. Tape the edges of panel, to reduce moisture pick-up and always keep the panels in a dry environment.

## Panel thickness determination

The accurate determination of the EPS sheet thickness and the average overall panel thickness is one of the most critical stages in the fabrication of the calibration panels.

a) Determine the EPS sheet thickness and the average glazed panel thickness as precisely as practically possible. NB an uncertainty of ± 0.1 mm in 12 mm is ± 0.8% in conductance.

b) Each laboratory can use their own method to measure the panel thickness in at least twenty five places,
c) uniformly spread over the panel surface.

c) For the purpose of calculating the thermal conductance of the calibration panel the thickness of the core will be assumed to be the average gap between the inner surfaces of the two glass sheets. A correction can be made for the air gap if required.

**Note** The thickness of glass is very uniform and can be assumed to be the thickness as measured at the edges.

## Thermal Conductivity measurements of the EPS material.

This is a critical stage of the process. The thermal conductivity of the EPS should be measured with apparatus conforming to the procedures specified in ISO 8302. In any case the thermal conductivity must be measured to an uncertainty of better than ±3.6% at the 95% confidence level.

## Method of mounting surface thermocouples

- Thermocouples shall be made of wire with a maximum diameter of 0.25 mm
- The insulation shall be stripped back a minimum of 15 mm from the hot junction
- The thermocouple should be taped to the glass surface for a minimum of 100 mm.
- The tape should be of the paper "masking tape" type.

## REFERENCES

[1] prEN 1098 (June 1993)

Measuring method for the determination of the thermal transmittance of multiple glazing (U-value): calibrated and guarded hot-box method.
Prepared by CEN/TC129

[2] prEN 12412-1

Part 1
Windows and doors - Thermal transmittance - calibrated and guarded hot-box method.
Prepared by: CEN/TC89/WG7

[3] ISO/CD 12567

Thermal Insulation - Determination of thermal resistance of components. - Hot Box method for doors and Windows.

[4] NPL Report CBTM 1
SM&T Project 3032 - Contract MATI-CT 940063 - Report on hot box measurements using the procedures specified in prEN 12412-1 with 1.2 m x 1.2 m glazed, calibration panels .

[5] IFT Test report
320 16092/10

[6] TNO Test Report
5.26.5.3376

[7] EMPA Test reports
157’378/3 - Measurements on the EMPA panels
157’378/5a - Measurements on the BBRI and IFT panels

[8] BBRI Test Results
Report - No identification

[9] NPL Report QM122 - Interim report SM&T Framework III project 3032 - Calibration panels for thermal transmittance of glazed assemblies.