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1. BACKGROUND

In recent years there has been an increasing demand for precise U-value measurements of building components and structures. That demand has been driven by the rigorous energy conservation legislation being implemented by developed countries around the world. This has been in response to concern over the long term damaging effects on the environment of emissions from fossil fuels as well as the traditional interest in reducing national expenditures on energy.

The measurement of window and door U-values, however, had for a long time posed the measurement community with special difficulties. Therefore, in response to the demand for precise U-value measurements of these types of products, CEN and ISO decided to draft a hot-box measurement standard incorporating a measurement procedure that had evolved from the experience gained from previous international intercomparisons of hot box measurements[1].

The CEN and ISO draft standards that specify the hot-box measurement procedures for determining the U-values of window and door systems are:

prEN 12412-1	- Drafted by CEN TC89/WG7
ISO/DIS 12567	- Drafted by ISO TC163 TC1/WG14.

The two groups worked together to draft these standards which are the same except for an annex in the ISO standard which specifies an additional procedure for deriving the heat flux through the calibration panels.

By May 1996, these two standards were nearly complete and the members of the ISO working group decided to carry out a measurement intercomparison using a U-PVC framed, double glazed window that had been used by the NPL in another project. The drawings and material specifications for that window were therefore available and the U-value of the window had been simulated by the Centre for Window and Cladding Technology (CWCT) using the procedures specified in prEN 10077-2 and prEN 673.

2. DESCRIPTION OF THE WINDOW

Size	1.48 m x 1.23 m
Frame type	U-PVC frame , 3 chamber with steel reinforcement in the mullion.
Design	One fixed light, one side-hung light and one top-hung light
Glazing	Air-filled, 4 mm/ 16 mm air gap/ 4 mm glazing unit (IGU). One pane was of float glass and the other of Pilkington K glass. The IGU was fixed in the frame so that the low-E surface was on the warm side. The normal hemispherical emittance of the Pilkington K had been measured at the NPL [10] to be 0.145.
Spacer bar	Desiccant-filled aluminium type.

Drawings showing the main dimensions of the different frame sections are given in Figure 2.

Detailed drawings and material properties can be seen in Annex A.

3. SUMMARY OF THE MEASUREMENT METHOD

The measurement procedure specified in ISO/CD 12567 and CEN prEN 12412-1 (May 1996) was used. This is an air-to-air method, requiring no surface temperature measurements of the window being tested.

The procedure requires a schedule of hot-box measurements on two different thicknesses of glazed, calibration panels, each at three different temperature conditions. The calibration panels comprise a core of expanded polystyrene sandwiched between sheets of 4 mm thick float glass. The thermal conductance of the calibration panels were determined by measuring the thermal conductivity of the expanded polystyrene material in standard guarded hot-plate apparatus and measuring the average thickness of the calibration panels after they were made.. The design, construction and application of these calibration panels were investigated by five organisations as part of a recent EU SMT Project 3032 [2].

From the data obtained from the measurements on the calibration panels, three graphs are produced from which the following parameters are derived:-

The heat flux density through the holder panel, including any boundary loss around the reveal.

- The environmental temperatures in both the hot and cold chambers.

A correction that is applied to compensate the measured U-value for the change in surface resistance that resulted from changing the heat flux density, from the value used to establish the air flow conditions that produced a total surface resistance of 0.17 m^2.K/W with the thin calibration panel, to the heat flux density used when measuring the window.

The test is carried out at a mean temperature of approximately 10 °C with an environmental temperature difference of 20 K ± 1 K.

The air flow must be such as to produce a total surface resistance (hot side + cold side) of 0.17 ± 0.01 m^2.K/W for the 20 mm thick calibration panel at the standard temperature conditions described above.

4. THE PARTICIPANTS

The following laboratories took part in this intercomparison.

NPL	UK	Ray Williams
EMPA	Switzerland	Thomas Nussbaumer
IFT	Germany	Hans Hartmann
FIW	Germany	Johannes Cammerer
TNO	Netherlands	Dick van Dijk
Tech Univ.	Denmark	Svend Svendson
Swedish Testing Institute	Sweden	Bertil Jonsonn
NRC	Canada	Hakim Elmahdy - not yet measured.
University of Mass.	USA	Bill Goss - not yet measured.

The phone, fax numbers and addresses are given in Annex D.

The North American Laboratories had not completed the hot-box measurements before this report was published. Their results will be added later.

5. EXPERIMENTAL DETAILS AND RESULTS

5.1 Transportation of the Window

A strong wooden box was made to house the window as it was transported around Europe and North America. The window was dispatched from the NPL to EMPA on the 27th May 1997.

5.2 Description of the hot-box apparatus used

A description of the hot-box apparatus used to carry out the measurements is given in Table 1.

Table 1 Description of hot-box apparatus used by the measurement laboratories

Laboratory	Hot-box type	Metering box dimensions (m)	Holder panel thickness (mm)
NPL	Wall Guarded Hot-Box [9]	1.95 x 1.95	150
EMPA	Calibrated hot-box	2.0 x 1.5	100
IFT	Guarded hot-box	1.25 x 1.48	200
FIW	Guarded hot-box	1.5 x 1.5	100
TNO	PASSYS Cell + cold-box	1.95 x 1.95	224
SP	Guarded hot-box	1.65 x 1.90	150
DTU	Guarded hot-box	1.6 x 1.35	170

5.3 Calibration measurements

Each laboratory had to make two glazed calibration panels and carry out the six calibration measurements as specified in ISO/DIS 12567. TNO did not make the calibration panels but extrapolated the results of the measurements they made on two 1.2 m x 1.2 m calibration panels, made for the SM&T Project 3032[2]. The three calibration curves derived from the hot-box measurements on the glazed calibration measurements are given for each laboratory in Annex B, Figures 11 to 15. The graphs produced are as follows:
Surround panel heat trannsfer coefficient (Hsur / W/m^2) vs Heat flux density (q_c)

A detailed description of the NPL calibration measurements is given in NPL Report QM115 [3].

5.4 Measured U-values

A summary of the measured U-values is given in Table 3. The detailed measurement data for each laboratory are given in Annex C, Tables 6 to 12.

5.5 Measurement uncertainty

The analysis of the measurement uncertainty associated with hot-box measurements using this procedure is complex and is currently being discussed by ISO TC 163 WG14 who are preparing an addendum to ISO 8990 concerning error analysis.

An error analysis of the NPL Wall Guarded Hot Box was undertaken using the procedures specified in the UKAS document M3003 - "The expression of uncertainty and confidence in measurement". This document complies with the requirements of the "ISO Guide to the expression of uncertainty in measurement". The U-value measured by the NPL is therefor correctly expressed as:-

"1.9 ± 0.14 W/m^2.K The reported expanded uncertainty is based on a standard uncertainty, multiplied by a coverage factor k = 2, providing a level of confidence of approximately 95%."

The CEN/ISO hot-box procedures based on the measurement of glazed calibration panels, is insensitive to errors in the calculated conductance of the calibration panels. The sensitivity of the three parameters to the calculated thermal conductance of the glazed calibration panels can be seen in Table 2. This table is taken from NPL Report CBTM 2 [2].

Table 2 The sensitivity of R_{tot}, H_{sur} and F to the calculated thermal conductance of the glazed calibration panels.

	Effect of increasing the calculated conductance of the panels by 5%			
	Rtot	Hsur	Hot convective fraction	Cold convective fraction
Thin panel	-4.8%	-14%	+5.5%	+0.6%
Thick panel	-4.8%	-5%	+5.5%	+0.6%

Because the effects of the calculated thermal conductance of the calibration panels on the surround panel heat transfer coefficient (H_{sur}) and on the convective fractions (F_i and F_e) are opposed to each other, the measured U-value only changes by 1% for a 5% change in the calculated thermal conductance of the glazed calibration panels (for the NPL situation). This insensitivity contributes to the low overall uncertainty of the method (for the NPL situation) of about ±7.5%.

Table 3 **Summary of measured U-values**

Laboratory	Heat flux through window (W/m^2)	Hot environmental temperature (°C)	Cold environmental temperature (°C)	U-value - prEN 12412-1 uncorrected for surface resistance $W/m^2 \cdot K$	U-value - prEN 12412-1 corrected for surface resistance $W/m^2 \cdot K$	U-value - ISO 12567 Annex D corrected for surface resistance $W/m^2 \cdot K$
FIW Munich	37.297	20.21	0.89	1.93	1.94 ± 0.16	n/a
IFT Rosenheim	39.456	23.85	2.96	1.89	1.94 ± 0.10	n/a
SP Sweden	36.835	19.87	0.20	1.87	1.90 ± 0.10	n/a
DTU Denmark	37.498	19.66	0.12	1.92	1.89 ± 0.10	n/a
EMPA Switz.	39.524	21.12	0.56	1.92	1.93 ± 0.17	1.93
TNO Netherlands	34.519	19.68	0.58	1.81	1.80 ± 0.10	n/a
NPL UK	37.47	22.04	2.30	1.90	1.90 ± 0.14	n/a
Univ Mass. USA	NOT	YET	MEASURED			
NRC Canada	NOT	YET	MEASURED			

5.6 Simulated U-values

The U-value of the window system has been simulated by the Centre for Window and Cladding Technology (CWCT) and the University of Massachusetts, using the drawings and material data supplied. The calculated and simulated U-values are shown in Table 4 as well as details of the software and procedures used. The centre of glazing U-value was obtained using the calculation procedure specified in prEN 673 or ISO 10292.

Table 4 Simulated U-values

Laboratory	Software/ procedure	Simulated /calculated U-value $W/m^2.K$
CWCT [4] & [8]	Simulation - ANSYS / prEN 10077-2	1.98
CWCT [5] & [8]	Simple calculation - prEN 10077-1	2.02
University of Massachusetts	Simulation FIDAP	1.91

6. DISCUSSION

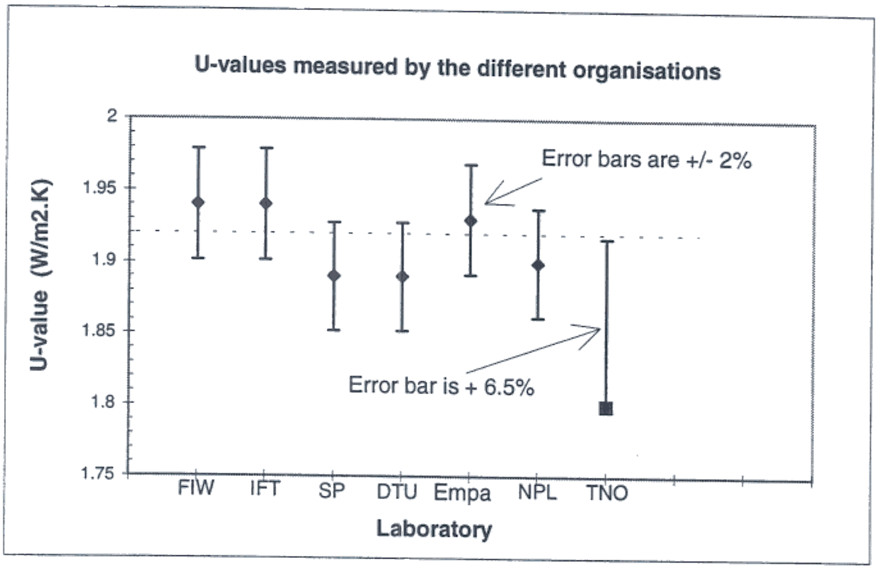
6.1 Measured values

A summary of the measured values can be seen in Table 3 and the graph shown in Figure 1. The values measured by the laboratories with hot box apparatus can be seen to be within about ± 2% of a value of 1.92 $W/m^2.K$. The exception was the TNO value which was measured using a PASSYS Cell plus a cold box. But despite the added complexity and intrinsic uncertainties that are associated with this apparatus their value was within 6.5% of the mean measured value. The total spread between U-values measured in the hot-boxes was 2.6 % and if the TNO PASSYS Cell value is included the maximum spread of measured U-values is 7.8%.

This agreement is significantly better than would be expected from the individual measurement uncertainties assigned to these measurements by the different laboratories (see section 5.5).

In a previous round-robin exercise, organised by the EU-BCR, to intercompare hot-box measurements of window U-values[1] the spread in the standardised U-values measured was 26% (or 14% if the highest and lowest values were disregarded). The values obtained in this exercise represent a substantial improvement.

Figure 1 Graph summarising the measured U-values



6.2 Simulated and calculated U-values

The simulated U-values are given in Table 4. The simulated U-values produced by both organisations are very close to the mean measured value of 1.92 $W/m^2.K$. The value produced by the CWCT was 3.1% higher than the mean measured value and the value produced by the University of Massachusetts was 0.5% lower than the measured value. However, CWCT followed the requirements of prEN 10077-2 when carrying out the simulation and some of the assumptions made are to ensure that simulated values are always slightly higher than the measured value.

The simple calculation using the procedures specified in prEN/ISO 10077-1 that was carried out by CWCT, produced a U-value that was only 5.2 % higher than the mean measured value.

The simulations carried out by CWCT were part of a larger project, summarised in NPL Report CBTM 2. As part of that project, CWCT simulated the U-value of a variety of frame sections (including the frames used in this window) using the software package THERM, produced by the Lawrence Berkley Laboratories. The results of those simulations are given in reports CWCT/NPL_QM/5[6] and NPL Report QM 131[6]. The U-values simulated for the U-PVC frame sections using THERM were almost identical to those obtained using ANSYS.

6.3 Changes made to the draft standard since this intercomparison

Since this Round-robin was carried out there have been two fairly significant changes made to the draft standards. The first was in response to the request by many countries to adapt the method to allow hot-box measurements to be carried out on a range of window sizes using the measurement data obtained from hot-box measurements of just one set of calibration panels. This was achieved by including in the standard, tables of the linear thermal transmittance values ψ_{edge} (W/m.K), simulated for different thickness of window and different thicknesses and thermal conductivity values for the surround panel. The measurements made with the calibration panels give a base figure for the heat flux density through the surround panel. That figure is then modified with the appropriate ψedge value.

The other change is that instead of the calibration panels being mounted 25 mm from the cold face of the surround panel they are mounted 40 mm from the hot face of the surround panel. Neither of these changes is considered likely to have a significant effect on the accuracy of the measurement procedure.

7. CONCLUSIONS

The excellent agreement between the U-values measured by the seven European laboratories is a clear validation of the measurement procedures specified in ISO/DIS 12567 and prEN 12412-1 standards. The agreement achieved was in all cases within the estimated measurement uncertainties quoted by the different laboratories and the agreement between all but one of the laboratories was significantly better than the stated measurement uncertainties would have allowed.

It has been shown that the measurement procedure is not critically dependent on the precision of the calculated thermal conductance of the glazed calibration panels. The measurement procedure has the added advantage of eliminating some systematic errors (perhaps previously unidentified) by including those errors into the heat transfer coefficient (Hsur) of the surround panel.

The results of the two U-value calculation and simulation exercises were also very encouraging. The simulated values were particularly good, showing very good agreement with the measured U-values. The U-value produced by the simple calculation method specified in prEN 10077-1 was actually rather too close to the measured value, being only 6.3% higher than the measured values and so is in danger of not ensuring that the simple calculation produces a pessimistic U-value.

8. REFERENCES

[1] Intercomparison of thermal measurements on double-glazed windows: Synthesis report N König (April 1992)
BCR Programme on applied metrology and chemical analysis. Project MTR - 105

[2] NPL Report CBTM 2 (September 1997).
Final report SM&T Framework III project 3032 - Calibration Panels for Thermal Transmittance of Glazed Assemblies. Ray Williams and David Hall.

[3] NPL Report QM115 (December 1995)
Report on hot box measurements using the procedures specified in ISO/CD 12567 and CEN/TC 89 WI26 part 2.03.1995 on two glazed, calibrated reference panels (1.48 m x 1.23 m). Ray Williams and David Hall

[4] CWCT/NPL_QM/3 (January 1997)
Simulated U-values of the frames and whole window systems. Simulations made using the procedures specified in prEN 10077-2. Dr Richard Harris CWCT

[5] CWCT/NPL_QM/4 (January 1997)
Calculated whole window U-values, using the procedures specified in prEN 10077-1
Dr Richard Harris CWCT

[6] CWCT/NPL_QM/5 (January 1997)
Frame U-values simulated using the Lawrence Berkeley Laboratory's THERM software. Dr Richard Harris CWCT

[7] NPL Report QM132 (February 1997)
Final measurements report - Report of the hot box measurements made of all eight window systems. Ray Williams and David Hall

[8] NPL Report QM131 (February 1997)
Final summary report comparing the various measured, simulated and calculated values obtained in this project. Ray Williams and Dr Richard Harris

[9] NPL Report QU 91 (August 1992)
A new approach to the measurement of thermal transmittance; the NPL Wall Guarded Hot Box. Ray Williams

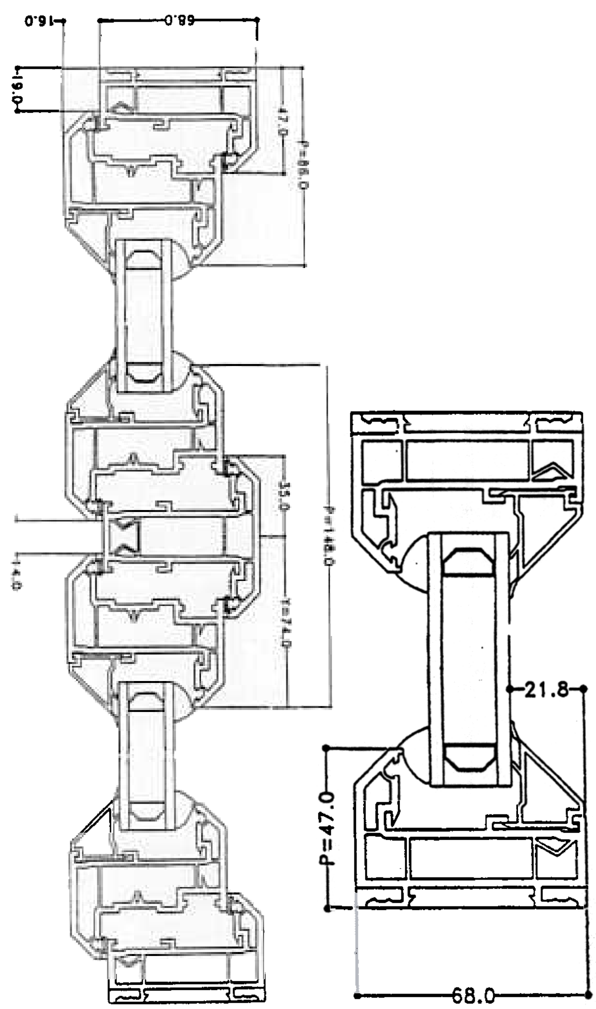
[10] NPL Certificate of Calibration CETM/27/96/023 (Dr F J J Clarke)

9. ANNEX A Drawings of the window sections and details of the materials

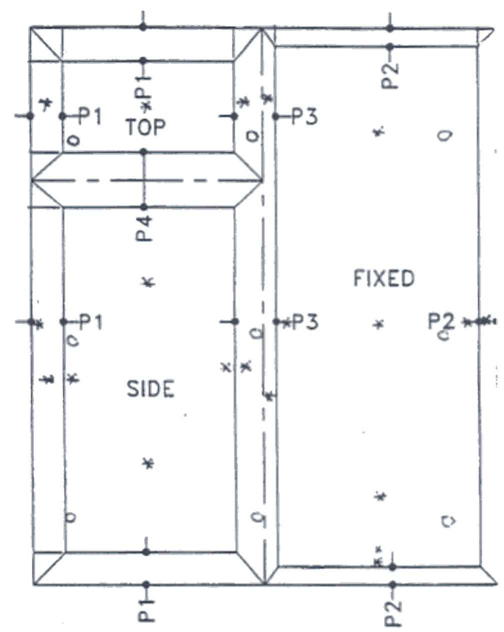
EMPA, Section Applied Physics in Building 12 / 13

Client: ISO TC 163 / SC1 / WG14 Test Report Nr. 4218

Annex 3



Detail sections vertical

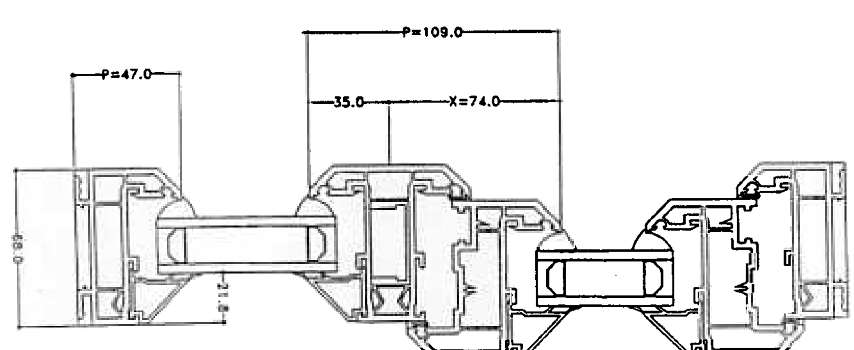


View of the window (warm side)

(order of measuring)

o Air temperature measuring points

* Surface temperature measuring p.



Detail section horizontal

Figure 2 **Overall section drawing of the window system.**

Table 5 Thermal conductivity of the materials used in the U-PVC Window Frames

Material code	Material description	Thermal conductivity W/m·K
P1	PVC-U	0.16
P2	EPDM	0.25
P3	Vinyl (flexible)	0.12
G4	Float glass	1.0
P5	Cavity	0.21
G6	Cavity - 16 mm air + 1 low E	0.0375
G7	Silicone sealant	0.35
P8	Cavity	0.127
G9	Hot melt butyl	0.24
G10	Silica gel	0.13
P11	Cavity	0.065
G12	Aluminium alloy	200
P13	Mild steel	50
P14	Cavity	0.132
P16	Cavity	0.035
P19	Cavity	0.03
P22	Cavity	0.06
P27	Cavity	0.11(v)
P30	Cavity	0.14
P33	Cavity	0.07
P38	Cavity	0.055
P41	Cavity	0.045
P44	Cavity	0.155

Figure 3 **Dimensions of Frame A**

All dimensions in mm

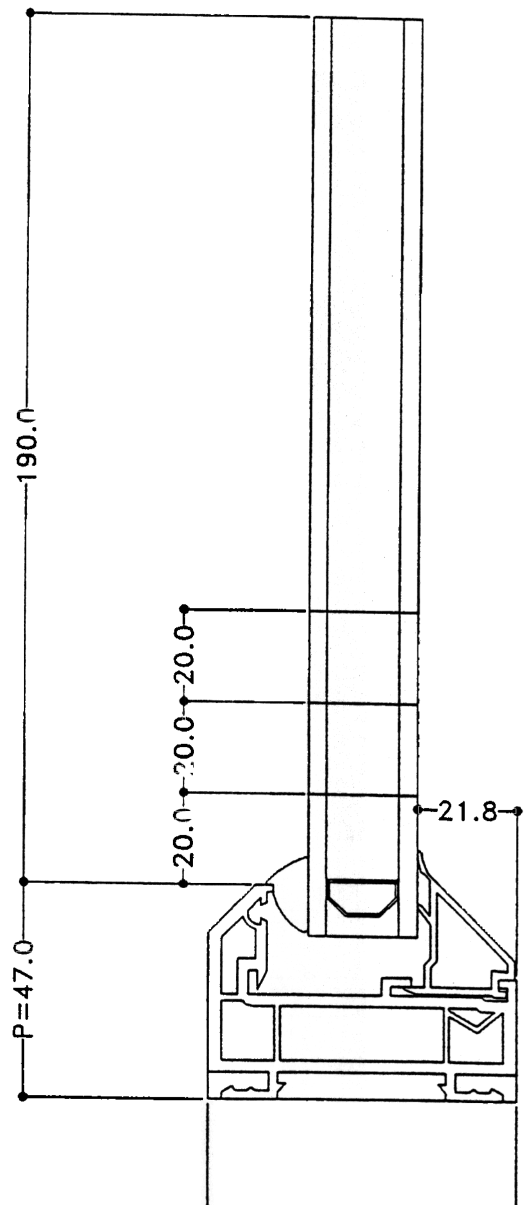


Figure **Materials used in Frame A**

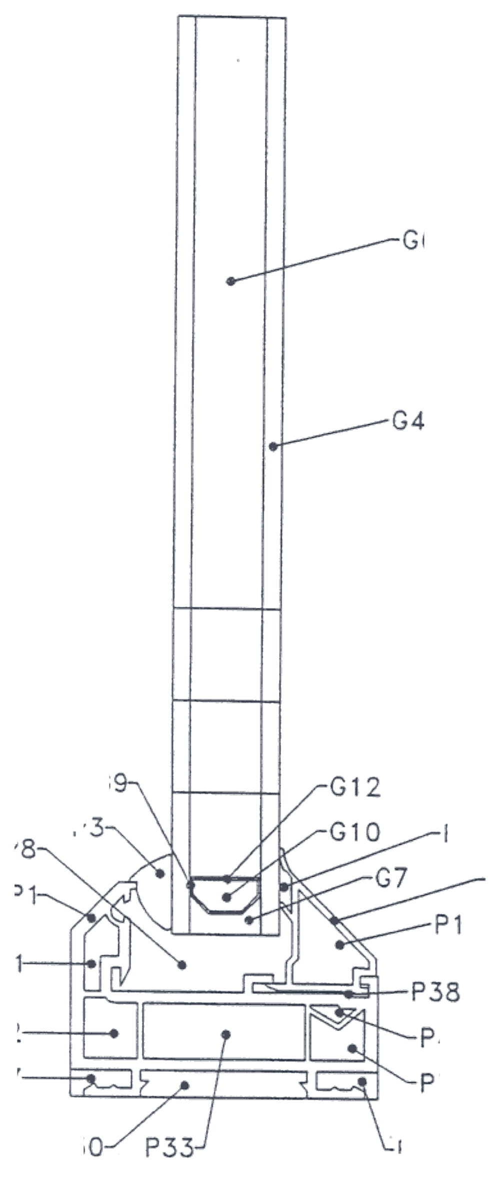


Figure 5 **Dimensions of Frame B**

All dimensions in mm

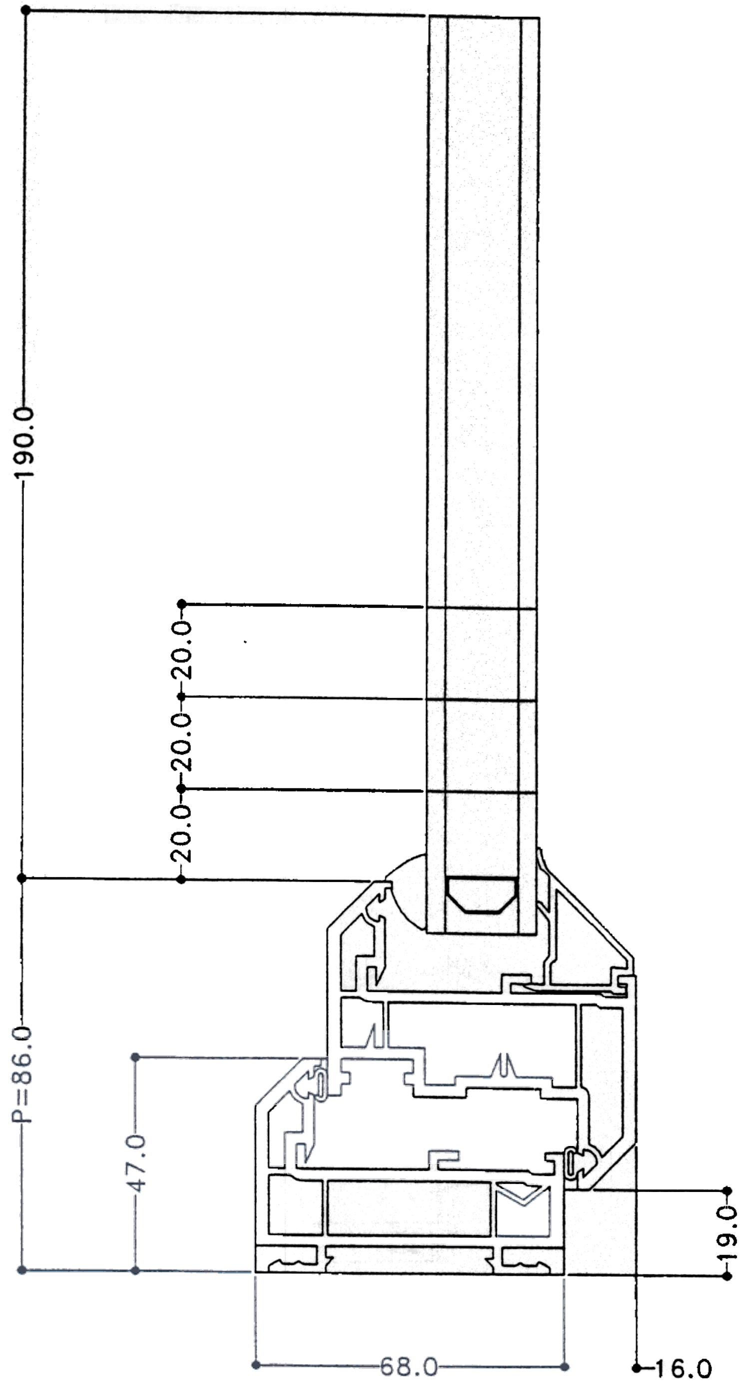


Figure **Materials in Frame B**

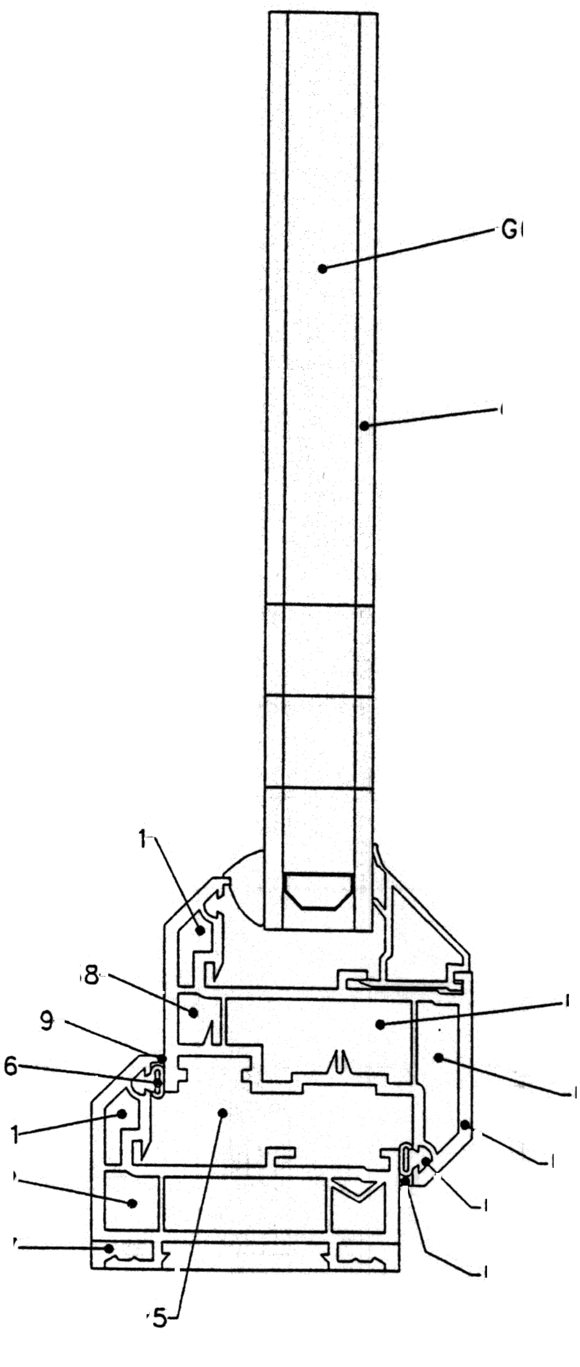


Figure 7 **Dimensions of Frame C**

All dimensions in mm

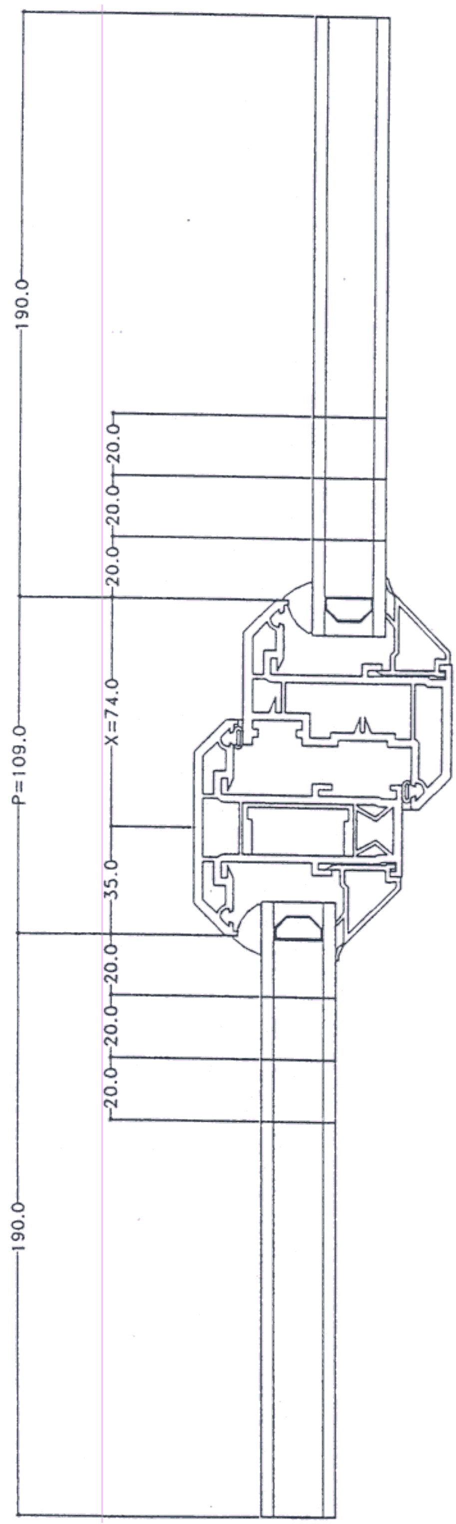


Figure 8 Materials used in Frame C

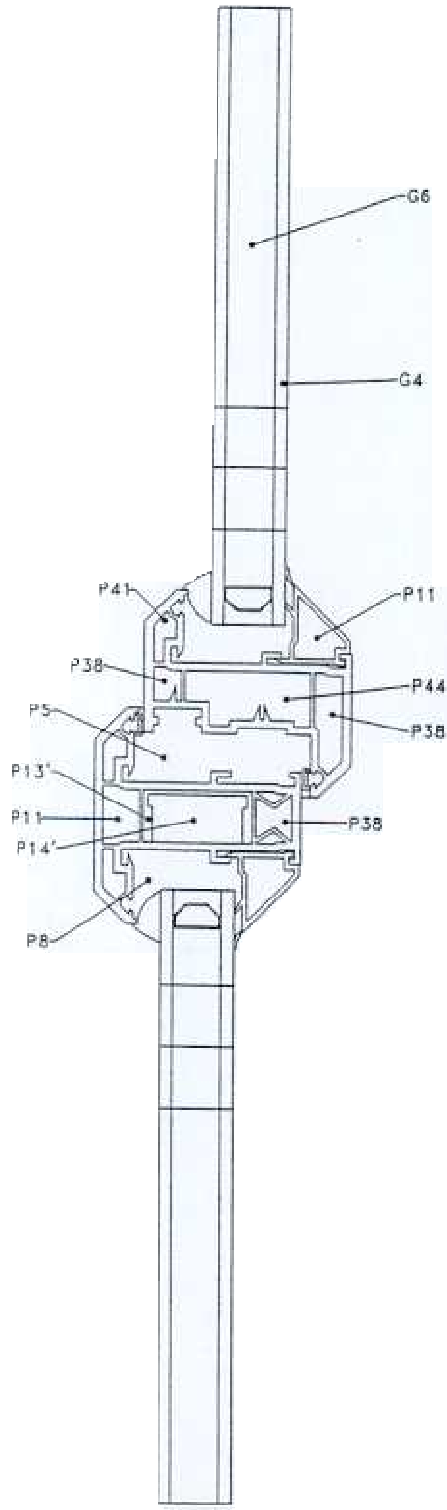


Figure 9 Dimensions of Frame D

All dimensions in mm

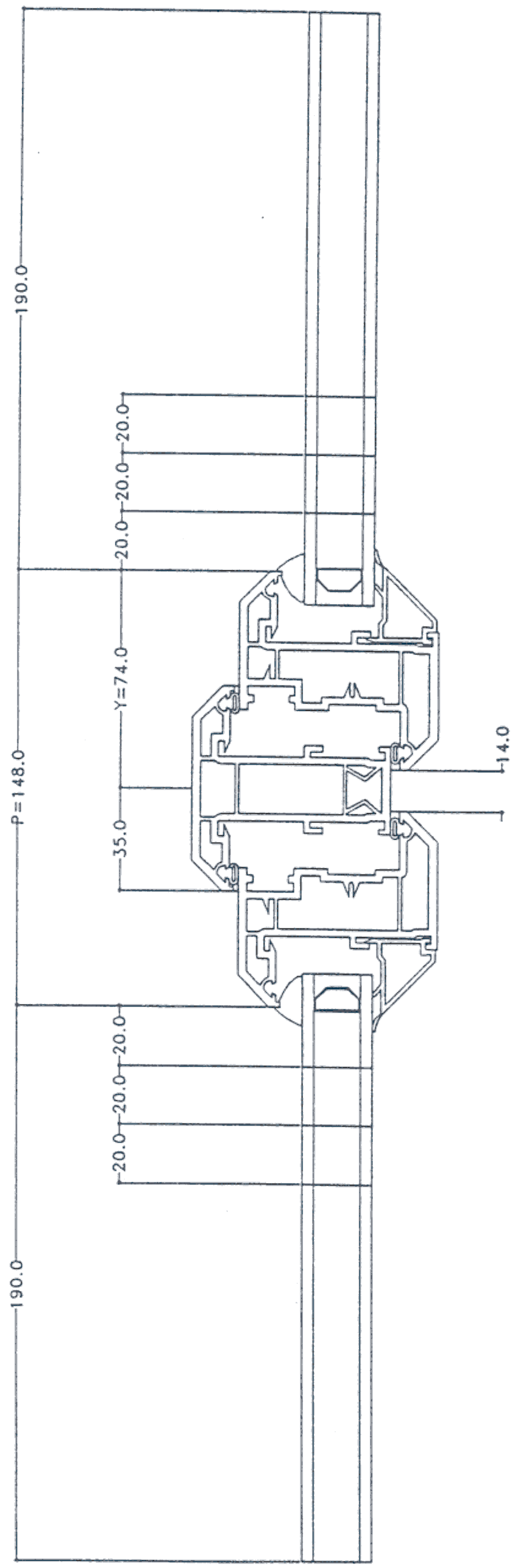
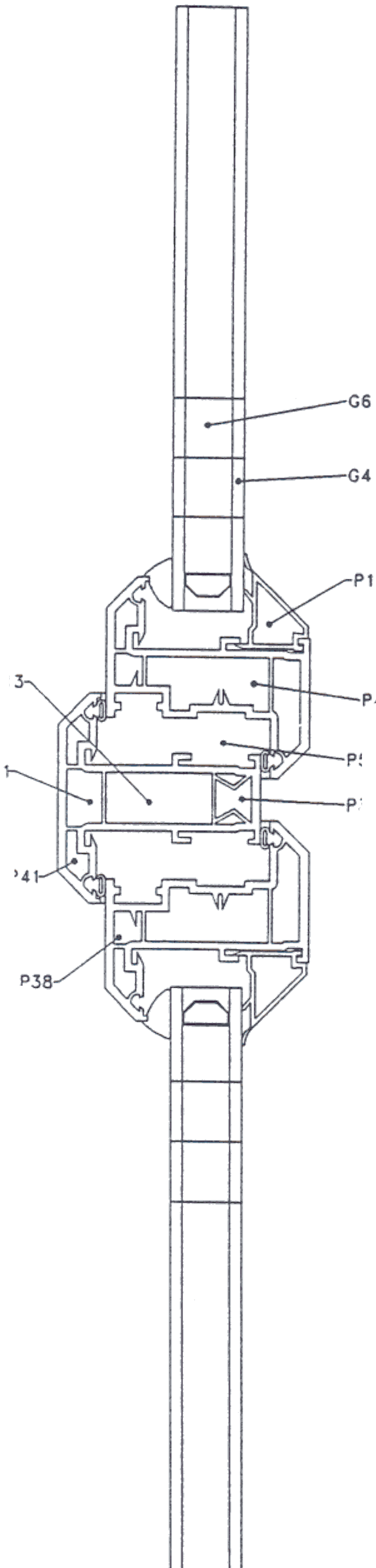
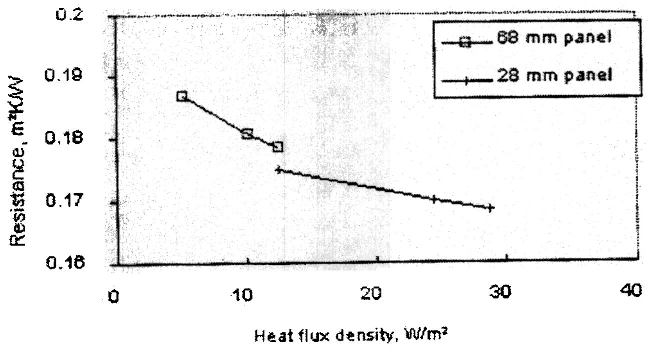


Figure 10 Materials used in Frame D



10. ANNEX B The graphs from the calibration panel measurements



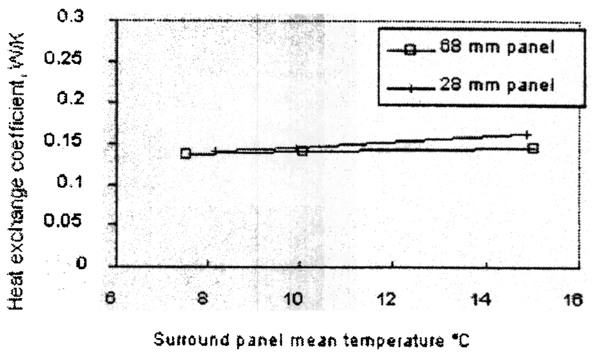
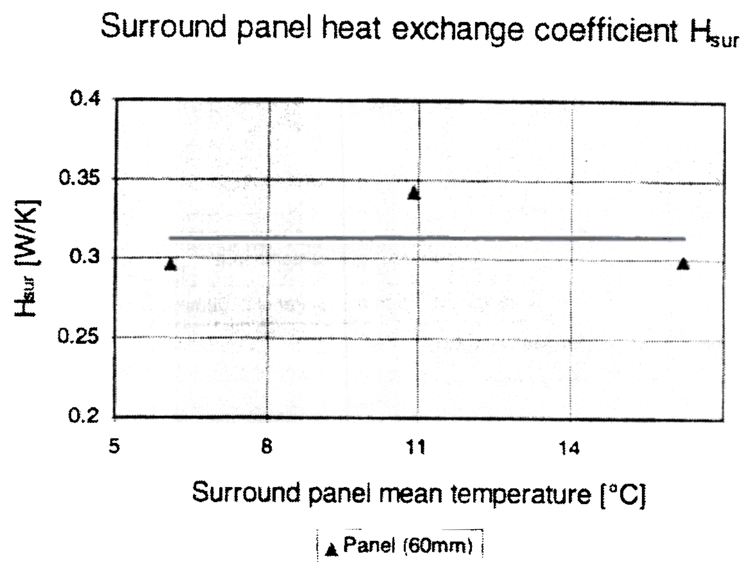
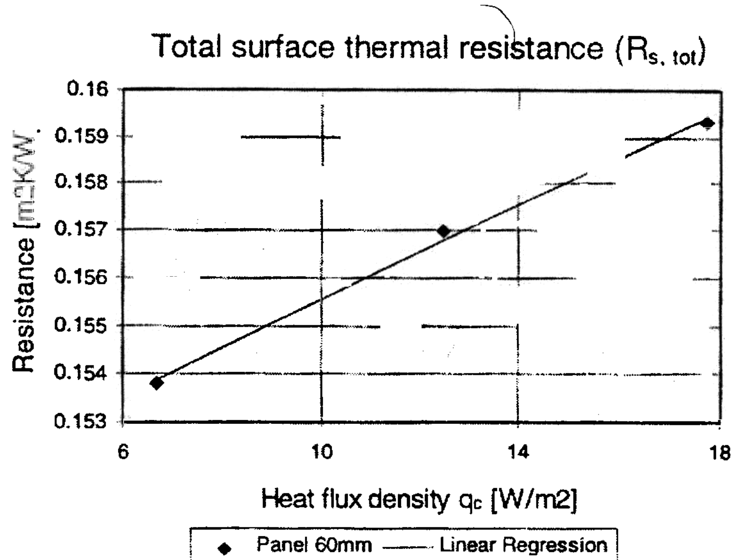


Figure 11 DTU - Calibration graphs





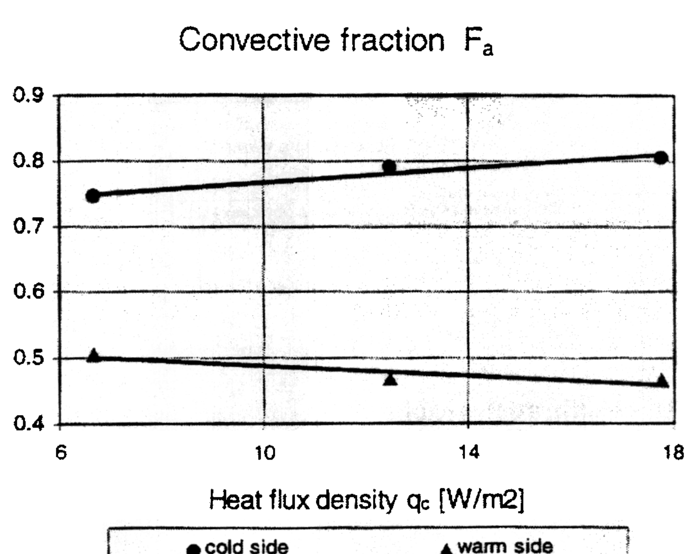


Figure 12 EMPA - Calibration graphs

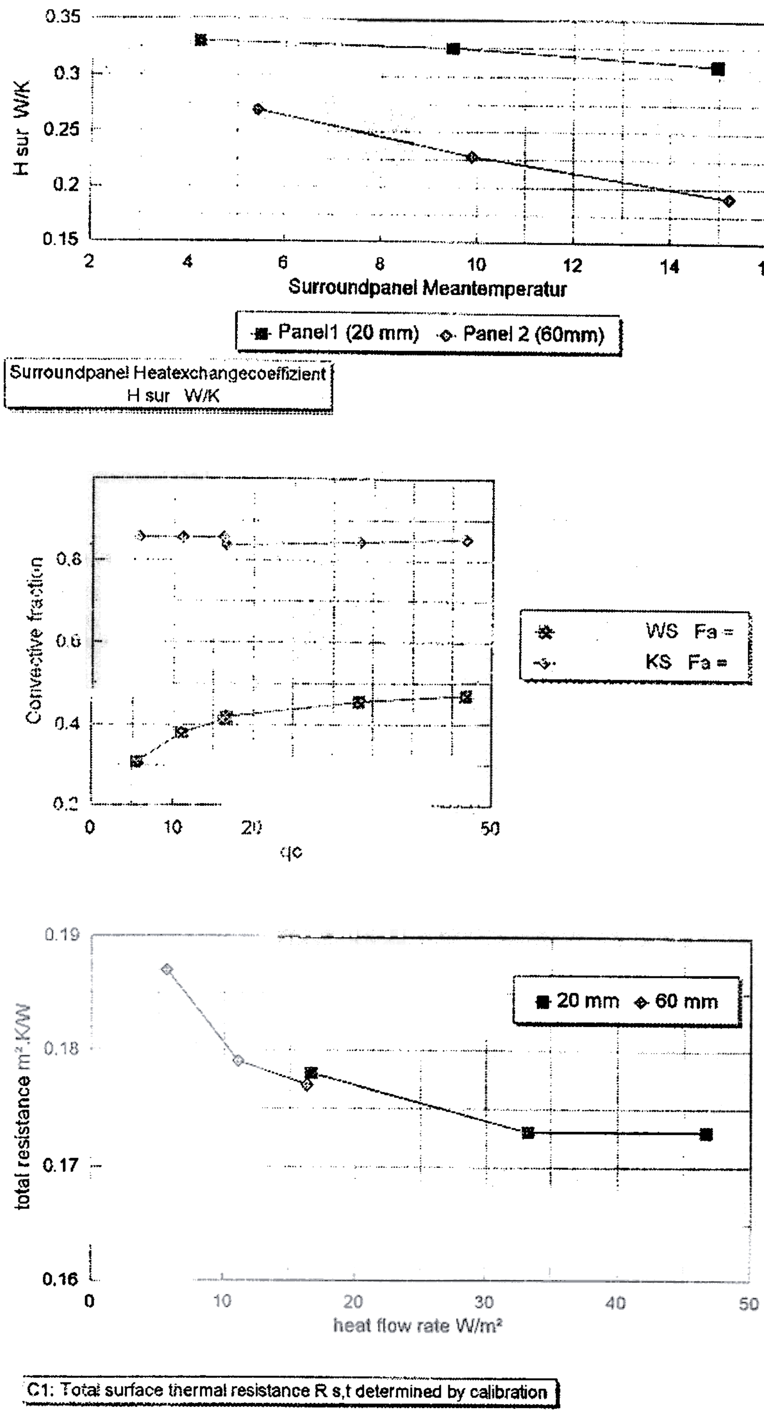
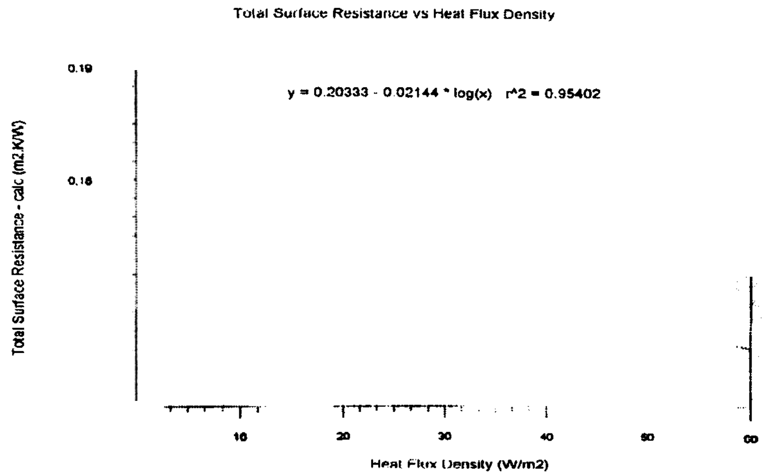
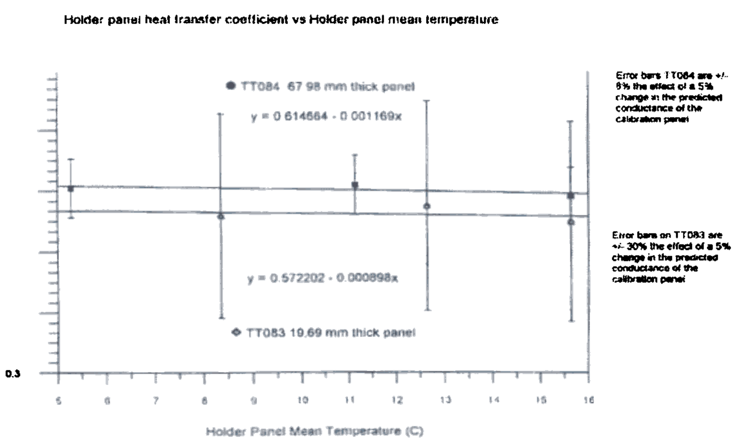


Figure 13 **FIW - Calibration graphs**





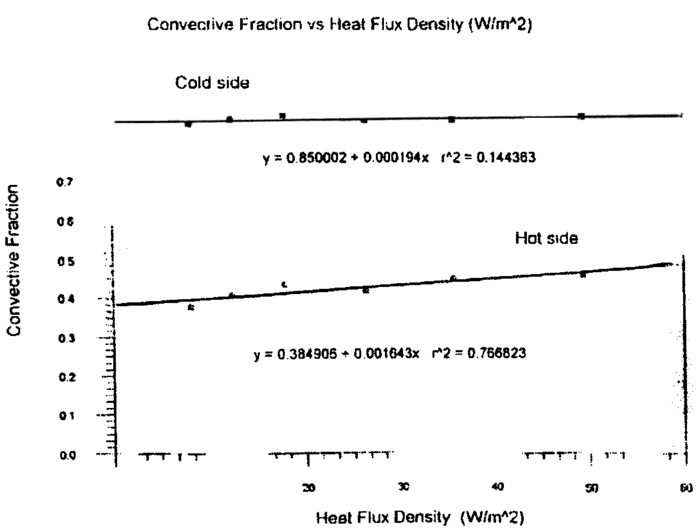
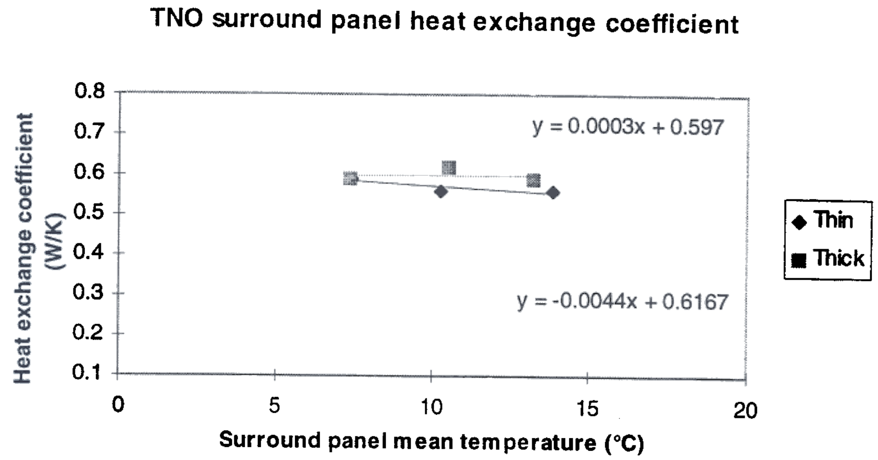
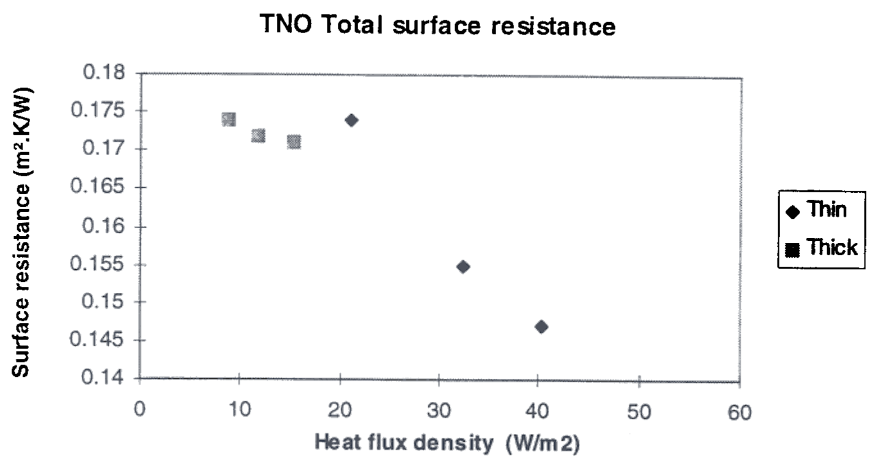


Figure 14 NPL - Calibration graphs





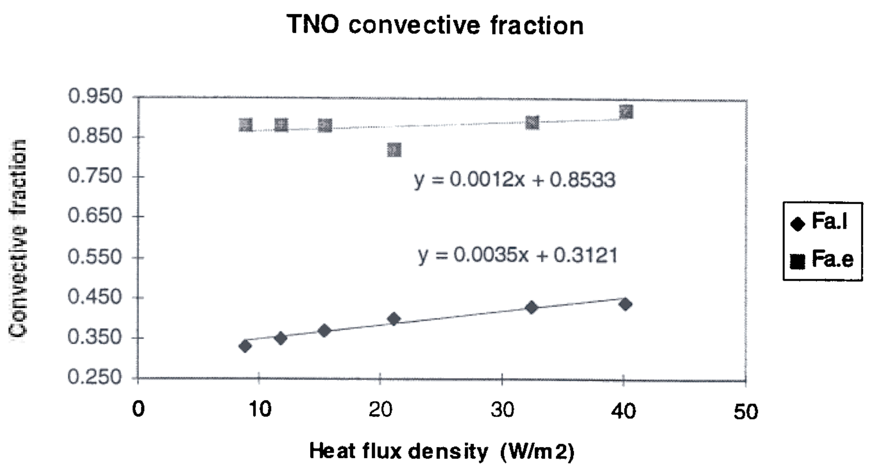


Figure 15 TNO - Calibration graphs

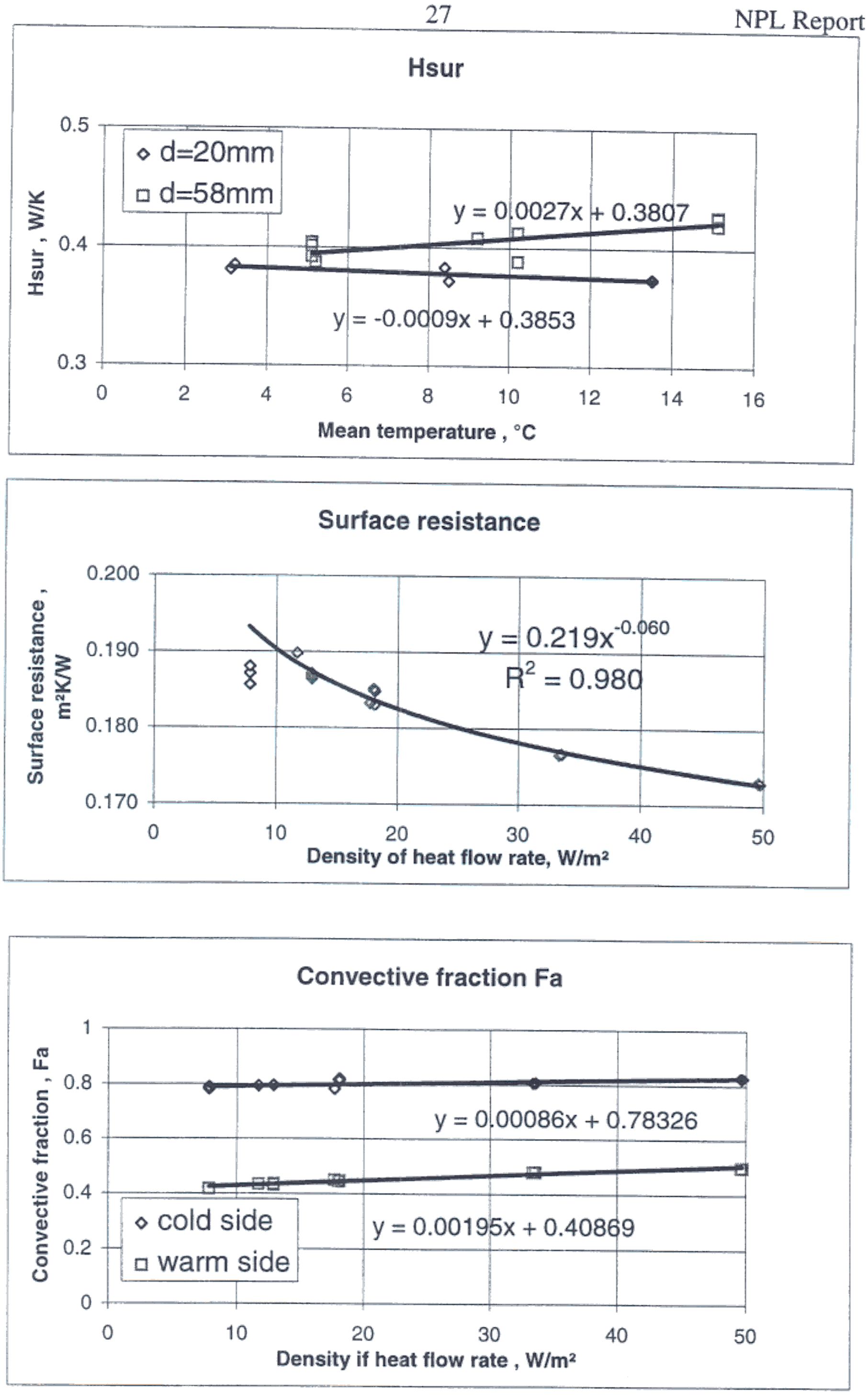


Figure 16 SP - Calibration graphs

11. ANNEX C Measurement data for each laboratory

NPL MEASUREMENT AND CALCULATION DATA FOR UPVC ROUND ROBIN WINDOW

Measured by	NPL		Window size (1.48 m x 1.23 m nominal size)			
Panel ID					TT090	
Surround panel thickness mm					150.0	
MEASURED VALUES						
Hot side values						
Air temp	(°C)				22.96	
Baffle temp	(°C)				21.34	
Reveal temp	(°C)				20.87	
Element surface temp	(°C)				21.00	
Cold side values						
Air temp	(°C)				2.29	
Baffle temp	(°C)				2.36	
Element surface temp	(°C)				2.36	
Surround panel values						
Hot side temp	(°C)				22.28	
Cold side temp	(°C)				2.67	
Difference temp	(°C)				19.61	
Mean temp surround	(°C)				12.48	
Mean temp of test element	(°C)				11.68	
Area	(m^2)				1.845	
Power to hot box	(W)				80.90	
CALCULATIONS			Equation from calibration data			
Hsur - with cal panel thickness		67.98 mm	(0.614664-(0.001169*MeanT))		12.48	0.6001
Hsur - with cal panel thickness		19.69 mm	(0.572202-(0.000898*MeanT))		12.48	0.5610
Hsur - with test element		68.00 mm	mean temp/Hsur =		12.48	0.6001
Power density through the test element				W/m²	37.470	
Environmental Temperatures			Equation from calibration data			
Cold side convective fraction			(0.850002+(0.000194*Hfd))			0.8573
Hot side convective fraction			(0.384906+(0.001643*Hfd))			0.4465
Mean hot radient temp			Calculated elsewhere	°C	21.29	
Mean cold radient temp (Assumed to be the same as baffle temp)				°C	2.36	
Hot environmental temp				°C	22.04	
Cold environmental temp				°C	2.30	
Environmental temperature difference				°C	19.74	
U-value CEN & measured directly			Equation from calibration data	W/m².K	1.899	
Tot surface res. from			(0.20333-(0.02144*LOG(Hfd)))	m².K/W	0.170	
Standardised U-value (Total surface resistance = 0.17 m².K/W)				W/m².K	**1.90**	

Table 6 NPL Hot box measurement data

SP MEASUREMENT AND CALCULATION DATA FOR UPVC ROUND ROBIN WINDOW

Measured by	SP	Window size	(1.48 m x 1.23 m nominal size)		
				TT090	
				150.0	
MEASURED VALUES					
Hot side values					
Air temp	(°C)			20.46	
Baffle temp	(°C)			19.45	
Reveal temp	(°C)			18.22	
Element surface temp	(°C)				
Cold side values					
Air temp	(°C)			0.17	
Baffle temp	(°C)			0.32	
Element surface temp	(°C)				
Surround panel values					
Hot side temp	(°C)			19.67	
Cold side temp	(°C)			0.39	
Difference temp	(°C)			19.28	
Mean temp surround	(°C)			10.03	
Mean temp of test element	(°C)			0.00	
Area	(m²)			1.8204	
Power to hot box	(W)			74.92	
CALCULATIONS		Equation from calibration data			
Hsur - with cal panel thickness	57.9 mm	(0.3807+(0.0027*MeanT))		10.03	0.4078
Hsur - with cal panel thickness	20.5 mm	(0.3853-(0.0009*MeanT))		10.03	0.3763
Hsur - with test element	68.00 mm	mean temp/Hsur =		10.03	0.4080
Power density through the test element			W/m²	36.835	
Environmental Temperatures		Equation from calibration data			
Cold side convective fraction		(0.7833+(0.00086*Hfd))			0.8150
Hot side convective fraction		(0.40869+(0.00195*Hfd))			0.4805
Mean hot radient temp		Calculated elsewhere	°C	19.32	
Mean cold radient temp (Assumed to be the same as baffle temp)			°C	0.32	
Hot environmental temp			°C	19.87	
Cold environmental temp			°C	0.20	
Environmental temperature difference			°C	19.67	
U-value CEN & measured directly		Equation from calibration data	W/m².K	1.873	
Tot surface res. from		(0.219*(Hfd^-0.06))	m².K/W	0.1764	
Standardised U-value (Total surface resistance = 0.17 m².K/W)			W/m².K	**1.90**	

Table 7 SP Hot box measurement data

EMPA MEASUREMENT AND CALCULATION DATA FOR UPVC ROUND ROBIN WINDOW

Measured by	EMPA		Window size	(1.48 m x 1.23 m nominal size)		
Panel ID					**TT090**	
Surround panel thickness mm					100.0	
MEASURED VALUES						
Hot side values						
Air temp	(°C)				21.57	
Baffle temp	(°C)				20.75	
Reveal temp	(°C)				19.34	
Element surface temp	(°C)				17.16	
Cold side values						
Air temp	(°C)				0.53	
Baffle temp	(°C)				0.68	
Element surface temp	(°C)				2.59	
Surround panel values						
Hot side temp	(°C)				20.66	
Cold side temp	(°C)				0.82	
Difference temp	(°C)				19.84	
Mean temp surround	(°C)				10.74	
Mean temp of test element	(°C)				9.88	
Area	(m^2)				1.82	
Power to hot box	(W)				78.68	
CALCULATIONS			Equation from calibration data			
Hsur - with cal panel thickness		59.2 mm	0.310538715254224+ ts 0.0002015		10.74	0.3400
Hsur - with cal panel thickness		- mm	-		10.74	
Hsur - with test element		68.00 mm	mean temp/Hsur =		10.74	0.3400
Power density through the test element				W/m^2	39.524	
Environmental Temperatures			Equation from calibration data			
Cold side convective fraction			0.71255716063276+g: 0.0055121			0.7903
Hot side convective fraction			0.523977421568551+(-0.003637			0.4936
Mean hot radient temp			Calculated elsewhere	°C	20.69	
Mean cold radient temp (Assumed to be the same as baffle temp)				°C	0.68	
Hot environmental temp				°C	21.12	
Cold environmental temp				°C	0.56	
Environmental temperature difference				°C	20.56	
U-value CEN & measured directly			Equation from calibration data	W/m^2.K	1.922	
Tot surface res. from calibration data			0.150634602691884+g3 1.0032055	m^2.K/W	0.171	
Standardised U-value (Total surface resistance = 0.17 m^2.K/W)				W/m^2.K	1.93	

Table 8 EMPA Hot box measurement data

TNO MEASUREMENT AND CALCULATION DATA FOR UPVC ROUND ROBIN WINDOW

Measured by	TNO		Window size	(1.48 m x 1.23 m nominal size)		
Panel ID					**TT090**	
Surround panel thickness mm					220.0	
MEASURED VALUES						
Hot side values						
Air temp	(°C)				20.90	
Baffle temp	(°C)				18.86	
Reveal temp	(°C)				?	
Element surface temp	(°C)				?	
Cold side values						
Air temp	(°C)				0.52	
Baffle temp	(°C)				0.96	
Element surface temp	(°C)				?	
Surround panel values						
Hot side temp	(°C)				19.41	
Cold side temp	(°C)				0.91	
Difference temp	(°C)				18.50	
Mean temp surround	(°C)				10.15	
Mean temp of test element	(°C)				?	
Area	(m^2)				1.82	
Power to hot box	(W)				69.30	
CALCULATIONS						
Hsur - with cal panel thickness			Equation from calibration data		10.15	
Hsur - with cal panel thickness			Equation from calibration data		10.15	
Hsur - with test element		68.00 mm	mean temp/Hsur =		10.15	0.3500
Power density through the test element				W/m^2	34.519	
Environmental Temperatures						
Cold side convective fraction			Equation from calibration data			0.8700
Hot side convective fraction			Equation from calibration data			0.4000
Mean hot radient temp			Hot baffle temp	°C	18.86	
Mean cold radient temp (Assumed to be the same as baffle temp)				°C	0.96	
Hot environmental temp				°C	19.68	
Cold environmental temp				°C	0.58	
Environmental temperature difference				°C	19.10	
U-value CEN & measured directly				$W/m^2.K$	1.807	
Tot surface res. from			Equation from calibration data	$m^2.K/W$	0.169	
Standardised U-value (Total surface resistance = 0.17 $m^2.K/W$)				$W/m^2.K$	**1.80**	

Table 9 TNO Hot box measurement data

FIW MEASUREMENT AND CALCULATION DATA FOR UPVC ROUND ROBIN WINDOW

Measured by	FIW	Window size	(1.48 m x 1.23 m nominal size)		
Panel ID				TT090	
Surround panel thickness mm				100.0	
MEASURED VALUES					
Hot side values					
Air temp	(°C)			20.88	
Baffle temp	(°C)			19.65	
Reveal temp	(°C)			19.15	
Element surface temp	(°C)			19.76	
Cold side values					
Air temp	(°C)			0.85	
Baffle temp	(°C)			1.13	
Element surface temp	(°C)			1.22	
Surround panel values					
Hot side temp	(°C)			19.61	
Cold side temp	(°C)			1.07	
Difference temp	(°C)			18.54	
Mean temp surround	(°C)			10.34	
Mean temp of test element	(°C)			10.49	
Area	(m^2)			1.82	
Power to hot box	(W)			72.07	
CALCULATIONS		Equation from calibration data			
Hsur - with cal panel thickness	20 mm	Equation 0.3426 - 0.002(Tm)		10.34	0.3219
Hsur - with cal panel thickness	60 mm	Equation 0.31299 - 0.008(Tm)		10.34	0.2303
Hsur - with test element	68.00 mm	mean temp/Hsur =		10.34	0.2260
Power density through the test element			W/m^2	37.297	
Environmental Temperatures		Equation from calibration data			
Cold side convective fraction		Equation ?			0.8500
Hot side convective fraction		Equation ?			0.4600
Mean hot radient temp		Calculated elsewhere	°C	19.63	
Mean cold radient temp (Assumed to be the same as baffle temp)			°C	1.13	
Hot environmental temp			°C	20.21	
Cold environmental temp			°C	0.89	
Environmental temperature difference			°C	19.31	
U-value CEN & measured directly		Equation from calibration data	$W/m^2.K$	1.931	
Tot surface res. from		Equation ?	$m^2.K/W$	0.173	
Standardised U-value (Total surface resistance = 0.17 $m^2.K/W$)			$W/m^2.K$	**1.94**	

Table 10 **FIW Hot box measurement data**

DTU MEASUREMENT AND CALCULATION DATA FOR UPVC ROUND ROBIN WINDOW

Measured by	DTU		Window size	(1.48 m x 1.23 m nominal size)		
					TT090	
					170.0	
MEASURED VALUES						
Hot side values						
Air temp	(°C)				20.00	
Baffle temp	(°C)				19.57	
Reveal temp	(°C)				18.29	
Element surface temp	(°C)				15.50	
Cold side values						
Air temp	(°C)				0.08	
Baffle temp	(°C)				0.28	
Element surface temp	(°C)				1.97	
Surround panel values						
Hot side temp	(°C)				19.48	
Cold side temp	(°C)				0.63	
Difference temp	(°C)				18.85	
Mean temp surround	(°C)				10.06	
Mean temp of test element	(°C)				8.74	
Area	(m^2)				1.82	
Power to hot box	(W)				70.96	
CALCULATIONS			Equation from calibration data			
Hsur - with cal panel thickness		68.1 mm			10.06	?
Hsur - with cal panel thickness		28 mm			10.06	?
Hsur - with test element		68.00 mm	mean temp/Hsur =		10.06	0.1440
Power density through the test element				W/m^2	37.498	
Environmental Temperatures			Equation from calibration data			
Cold side convective fraction			?			0.8180
Hot side convective fraction			?			0.5170
Mean hot radient temp			Calculated elsewhere	°C	19.29	
Mean cold radient temp (Assumed to be the same as baffle temp)				°C	0.28	
Hot environmental temp				°C	19.66	19.69
Cold environmental temp				°C	0.12	0.12
Environmental temperature difference				°C	19.54	
U-value CEN & measured directly			Equation from calibration data	$W/m^2.K$	1.919	
Tot surface res. from			?	$m^2.K/W$	0.163	
Standardised U-value (Total surface resistance = 0.17 $m^2.K/W$)				$W/m^2.K$	**1.89**	

Table 11 **DTU Hot box measurement data**

IFT MEASUREMENT AND CALCULATION DATA FOR UPVC ROUND ROBIN WINDOW

Measured by	IFT	Window size	(1.48 m x 1.23 m nominal size)		
Panel ID				**TT090**	
Surround panel thickness mm				200.0	
MEASURED VALUES					
Hot side values					
Air temp	(°C)			22.86	
Baffle temp	(°C)			24.67	
Reveal temp	(°C)			22.60	
Element surface temp	(°C)			n/a	
Cold side values					
Air temp	(°C)			2.94	
Baffle temp	(°C)			3.06	
Element surface temp	(°C)			n/a	
Surround panel values					
Hot side temp	(°C)			22.00	
Cold side temp	(°C)			2.67	
Difference temp	(°C)			19.33	
Mean temp surround	(°C)			12.34	
Mean temp of test element	(°C)			n/a	
Area	(m^2)			1.82	
Power to hot box	(W)			76.16	
CALCULATIONS		Equation from calibration data			
Hsur - with cal panel thickness		Equation ?			?
Hsur - with cal panel thickness		Equation ?			?
Hsur - with test element	68.00 mm	mean temp/Hsur =		12.34	0.2250
Power density through the test element			W/m^2	39.456	
Environmental Temperatures		Equation from calibration data			
Cold side convective fraction		Equation ?			0.8480
Hot side convective fraction		Equation ?			0.3200
Mean hot radient temp		Calculated elsewhere	°C	-	
Mean cold radient temp (Assumed to be the same as baffle temp)			°C	-	
Hot environmental temp			°C	23.85	
Cold environmental temp			°C	2.96	
Environmental temperature difference			°C	20.89	
U-value CEN & measured directly		Equation from calibration data	$W/m^2.K$	1.889	
Tot surface res. from		Equation ?	$m^2.K/W$	0.183	
Standardised U-value (Total surface resistance = 0.17 $m^2.K/W$)			$W/m^2.K$	**1.94**	

Table 12 **IFT Hot box measurement data**

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