NPL Report QM119

DEPARTMENT OF THE ENVIRONMENT
PARTNERS IN TECHNOLOGY
- Technical Infrastructure Programme -

Validation of thermal performance design tools for window frame construction:- an independent verification by agreed measurement procedures.

Report on Phase I - Comparison between the measured and simulated U-values of three window systems comprising a thermally broken Aluminium frame, a PVC-U frame and a Hardwood frame.

Ray Williams	**(National Physical Laboratory)**
Richard Harris	**(Centre for Window and Cladding Technology)**

March 1996

DEPARTMENT OF THE ENVIRONMENT
PARTNERS IN TECHNOLOGY
- Technical Infrastructure Programme -

Validation of thermal performance design tools for window frame construction:- an independent verification by agreed measurement procedures.

Report on Phase I - Comparison between the measured and simulated U-values of three window systems comprising a thermally broken Aluminium frame, a PVC-U frame and a Hardwood frame.

Ray Williams (National Physical Laboratory)
Richard Harris (Centre for Window and Cladding Technology)

ABSTRACT

This report summarises the results of phase 1 of the above project. The U-values and surface temperatures of three window systems measured in the NPL wall guarded hot box using the procedures specified in CEN/TC 89 N 216E rev. are compared with those calculated and simulated by CWCT using the procedures specified in prEN 30077 parts 1 and 2 respectively. The agreement between the measured and simulated U-values are shown to be good and the agreement between the U-values calculated using the simplified procedures and those measured were adequate. A number of recommendations are made to improve both parts 1 and 2 of prEN 30077.

ISSN 1361-4045

National Physical Laboratory
Teddington, Middlesex, UK, TW11 0LW

Approved on behalf of Managing Director, NPL,
by Dr J R Gott, Director, Centre for Quantum Metrology.

CONTENTS

1 BACKGROUND

1.1 OBJECTIVES OF PHASE I

At the first project meeting (9/5/95) it was decided to carry out the hot-box measurements and calculations in two phases. In the first phase, measurements and calculations would be made on window systems that are "typical" of the three main frame material types. Only when the results from this phase were acceptable would the decisions be made on the details of Phase II. This approach would allow us to resolve problems on straightforward window designs first, before advancing to more complex ones.

1.2 WINDOW DESIGNS CHOSEN FOR PHASE I

The window size chosen was that recommended in the draft CEN measurement standard CEN/TC 89 N 216E rev. 02.1995. That is:- 1230 mm (wide) x 1480 mm (high).

Each window comprises one opening casement, one top opening light and one fixed light (Figure 1). The main details of the windows are shown in Table 1.

Table 1 Frame types used for the first phase.

Window ID number NPL	Frame details				Glazing details			
	Frame material	Thermal break type	Number of cavities	Reinforcement	Size (mm)	Gas type	Coating	Spacebar type
TT090	PVC-U	n/a	3	mullion only	4/16/4	Air	Pilkington K 3rd surface [1]	Al
TT089	Al (alloy)	4 mm urethane resin	n/a	n/a	4/16/4	Air	Pilkington K 3rd surface [1]	Al
TT091	Wood (Hard)	n/a	n/a	n/a	4/16/4	Air	Pilkington K 3rd surface [1]	Al

[1] Surfaces are numbered from the outside to inside.

Detailed drawings for the different frame sections used in the Aluminium window are given in the NPL Report QMS101: APPENDIX in Figures A1, A2, A3 and A4, for the PVC-U window in Figures A5, A6, A7 and A8, and for the wood window in Figures A9 and A10. Further details about the materials used in these frames can be found in the Report CWCT/NPL_QM/1.

2 MEASUREMENT AND CALCULATION DETAILS

2.1 MEASUREMENT PROCEDURES AND CONDITIONS

The U-values were measured in the NPL Wall Guarded Hot Box (NPL Report QM91) using the measurement procedures specified in the draft CEN measurement standard CEN/TC 89 N 216E rev. 02.1995. This procedure is described in some detail in NPL Report QMS101. The method relies on a schedule of hot box measurements on two glazed calibration panels. These measurements are described in NPL Report QM115. The temperature conditions specified by that CEN Standard are as follows:-

- 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^2K/W for the 20 mm thick calibration panel at the standard temperature conditions

An additional measurement was made of each frame using an increased temperature difference to assess how sensitive the U-value measurements are to temperature differences.

Additional (to those required by the standard) surface temperature measurements were made to enable comparisons with the surface temperatures predicted by the simulations.

2.2 SIMULATION AND CALCULATION DETAILS

The simulations of the window system thermal performance were carried out by CWCT using a finite element analysis software package called ANSYS - a commercially available FEA software package.

There are two CEN standards concerned with calculation and simulation of window U values. These are:-

- CEN TC 89/WG 7 prEN 30077 N16 E Feb 1995 (ISO/DIS 11077) Part 1 - Windows, doors and shutters - Thermal transmittance - Simplified Calculation Method.
- TC 89/WG7/N114 rev. 3 (22/2/95) - This will become prEN 30077 Part 2 - Window and Door components - Thermal transmittance. Numerical calculation method.

The methods and procedures described in both standards have been used to determine the U-values of the window systems discussed in this report. The data have been used to produce the U-values in a variety of ways and to produce linear thermal transmittance coefficient (ψ) values for the respective frames. The ψ value is used in prEN 30077 Part 1 to account for the heat flow between the frame and edge of glazing.

The values that have been either measured, simulated or calculated in Phase 1 are:

A)	Whole window U-value	Measured in the Hot box using the CEN method Report QMS101
B)	Whole window U-value	Measured in the Hot box using the directly measured surface temperatures and calculated boundary losses. Report QMS101
C)	Whole window U-value	Simulated using prEN 30077 (part 2) with glazing in the frame. Report CWCT/NPL_QM/1
D)	Whole window U-value	Simulated using prEN 30077 (part 2) with EPS in place of glazing & ψ from Part 1 Report CWCT/NPL_QM/2
E)	Whole window U-value	Calculated using prEN 30077 Part 1 using ψ values given in prEN 30077 Part 1 Report CWCT/NPL_QM/2
F)	Whole window U-value	Calculated using prEN 30077 Part 1 using ψ values obtained by simulation using prEN 30077 Part 2 Report QMS102
G)	Frame U-values	Simulated using prEN 30077 (part 2) with EPS in place of glazing. Report CWCT/NPL_QM/1
H)	Frame U-values	Simulated using prEN 30077 (part 2) with glazing in the frame. Report CWCT/NPL_QM/1
J)	ψ values	From G) and H) Report CWCT/NPL_QM/2

A summary of some of these values (A, C, D, E, J, F) is presented in Table 2.

Table 2 Summary of measured, simulated or calculated U-values and ψ values.

ID	U-value Measured Hot box CEN method W/m².K	U-value Simulated prEN30077 (part 2) with glazing in the frame W/m².K	U-value Simulated prEN30077 (part 2) with EPS in place of glazing & ψ value from Part 1 W/m².K	ψ value given in prEN 30077 Part 1 W/m.K	ψ value simulated using prEN30077 Part 2 Note [1] W/m.K	U-value Calculated prEN30077 Part 1 using ψ value given in prEN30077 Part 1 W/m².K	U-value Calculated prEN30077 Part 1 using ψ value obtained by simulation using prEN30077 Part 2 W/m².K
89 Al	2.53	2.57	2.53	0.08	0.100 0.080 0.075 0.075 M-0.0862 Note[2]	2.86	2.89
90 PVC	1.89	1.96	1.86	0.06	0.08 0.075 0.075 0.075 M-0.0769 Note[2]	1.98	2.05
91 Wood	2.15	2.11	1.96	0.06	0.085 0.085 0.085 0.085 M-0.085 Note[2]	2.08	2.18

Notes

[1] There are four ψ values, one for each of the different frame/glazing configurations identified in Reports CWCT/NPL_QM/1 & 2 as frames A, B, C & D, respectively.

[2] This mean ψ value was calculated as follows:
The fraction of the total frame length of each frame type was calculated. This fraction was then multiplied by the simulated ψ value for that frame, taken from report CWCT/NPL_QM/2. The four fractions were then added up.

3 COMPARISON BETWEEN MEASURED, SIMULATED AND CALCULATED U-VALUES AND TEMPERATURES

3.1 WINDOW U-VALUES

3.1.1 Comparison between measured and simulated U-values

The measured U-values from the NPL Report QMS101 and the simulated U-values from the CWCT Report CWCT/NPL_QM/1 (using prEN 30077 part 2) are summarised in Table 3.

Table 3 Comparison between measured U-values and those simulated using prEN 30077 part 2)

Window frame ID	Directly measured standardised (0.17m².K/W) U_{dir} (W/m².K)	CEN method measured standardised (0.17m².K/W) U_{CEN} (W/m².K)	Simulated (ANSYS) standardised (0.17m².K/W) U_{sim} (W/m².K)	Difference $\frac{U_{Sim}-U_{dir}}{U_{(dir)}}$ (%)	Difference $\frac{U_{sim}-U_{CEN}}{U_{CEN}}$ (%)
Aluminium TT089	2.38	2.53	2.57	8.0	1.6
U-PVC TT090	1.83	1.89	1.96	7.1	3.7
Hardwood TT091	2.04	2.15	2.11	3.4	-1.9

It should be noted that in the U-value simulations the near normal total emissivity (ε) of the Pilkington K glass was taken as 0.145, a value previously measured at the NPL and Pilkingtons for another project. The emissivity of the spare Insulated Glazing Unit (IGU) has not yet been measured. If the emissivity of the K glass should prove to be significantly different from that assumed above, the values will be recalculated.

The hardwood frame was made from West/Central African sapele. A value of 0.15 W/m.K for the thermal conductivity of this wood was obtained from Timber Research and Development Association (TRADA). Unfortunately, the origin of that value is not known.

3.1.2 Comparison between measured and calculated U-values

The measured U-values from the NPL Report QMS101 and the calculated U-values, (using prEN 30077 part 1), from the CWCT Report CWCT/NPL_QM/2 are summarised in Table 4.

Table 4 Comparison between measured U-values and those calculated using prEN 30077 part 2.

Window frame ID	CEN method measured standardised (0.17m².K/W) U_{CEN} (W/m².K)	Calculated prEN30077 I standardised (0.17m².K/W) U_{calc} (W/m².K)	Difference $\frac{U_{calc}-U_{CEN}}{U_{CEN}}$ (%)	Calculated prEN30077 I standardised (0.17m².K/W) + simulated ψ values U_{calc1} (W/m².K)	Difference $\frac{U_{calc1}-U_{CEN}}{U_{CEN}}$ (%)
Aluminium TT089	2.53	2.86 Note[1]	13	2.89 Note[1]	14.2
U-PVC TT090	1.89	1.98 Note[2]	5	2.05 Note[2]	8.5
Hardwood TT091	2.15	2.08	-3	2.18	1.4

Note [1]
prEN 30077 part 1 graph D4 is only valid if the ratio of the width of the thermal break material to the width of the frame complies with given criteria. For the aluminium window considered here the mullion and transom do not comply so a U-value cannot be calculated to this standard.

Note [2]
prEN 30077 part 1 table D1 only gives U-values for plastic frame with metal reinforcement. Despite the fact that use of non-reinforced frames would make the calculated values even "safer", the standard requires the values from this table to be applied only to metal reinforced frames. For the PVC-U window considered here, the fixed frame and transom does not have metal reinforcement and therefore a U-value calculated to this standard could not be quoted for this window.

The Spreadsheets showing these calculations are given in Figures 2, 3 and 4.

3.2 SURFACE TEMPERATURES

The temperatures of the various frame sections and glazed units were measured when carrying out the hot box U-value measurements. These are presented in NPL Report QMS101. Surface temperatures were also derived when the window thermal properties were simulated. These values are given in the Report CWCT/NPL_QM/1.

Comparison between the two sets of figures was not straightforward. Uniform hot and cold air temperatures are assumed when carrying out the simulations but in the hot box apparatus, vertical temperature gradients exist in the air, especially on the hot side. To enable the measured and simulated surface temperatures to be compared the simulated temperatures were adjusted to accommodate the temperature gradients that were established during U-value measurements.

This was achieved by first calculating the hot box environmental temperature at each of the positions where the surface temperatures were to be compared. The cold box environmental temperature was assumed to be uniform. The simulated surface temperatures were then adjusted to the appropriate hot environmental temperature by using equation (1) below.

$$\frac{THsur_{sim} - TCenv_{sim}}{THenv_{sim} - TCenv_{sim}} = \frac{THsur_{cor} - TCenv_{meas}}{THenv_{meas1} - TCenv_{meas}} \quad \text{......................(1)}$$

THenv = Hot environmental temperature °C
TCenv = Cold environmental temperature °C
THsur = Hot surface temperature °C

sim = simulated values
meas = mean measured values
cor = corrected simulated values
meas1 = measured values at the specific vertical level

A further complication is that the surface temperatures are simulated by assuming a uniform surface resistance over the whole hot surface and a uniform surface resistance over the whole cold surface. In the hot box this is not the case.

A summary of the comparison between the measured and corrected simulated hot surface temperatures are given in Tables 5, 6 and 7 for the Aluminium, U-PVC and Hardwood windows respectively.

Table 5 Surface temperatures on the Aluminium window TT089

Position	Hot Surface Temperature			Cold Surface Temperature
	WGHB (°C)	Simulated (°C)	Difference (°C)	WGHB (°C)
Mean Environmental temperature	{21.34}	{21.34}		{1.76}
centre header	17.8	17.4	0.4	6.7
corner header	18.0	-		6.0
mid vertical frame	15.7	15.3	0.4	4.9
corner cill	13.2	-		4.1
centre cill	12.7	13.1	0.4	4.6
centre mullion	13.5	12.8	0.7	6.9
centre transom	15.4	13.9	1.5	8.1
corner large IGU pos	11.3	-		2.9
3 large IGU	11.2	12.6	-1.4	2.8
pos 2 large IGU	13.3	14.2	-0.9	2.4
pos 1 large IGU	14.2	14.8	-0.6	2.3
centre large IGU	17.3	17.4	-0.1	3.8
centre med. IGU	16.5	16.6	-0.1	3.6
corner small IGU	13.7	-		5.0
pos 2 small IGU	14.6	15.0	-0.4	4.3
pos 1 small IGU	16.5	17.1	-0.6	3.8
centre small IGU	18.6	19.0	-0.4	4.2

Table 6 Surface temperatures on the PVC-U window TT090

Position	Hot Surface Temperature			Cold Surface Temperature
	WGHB (°C)	Simulated (°C)	Difference (°C)	WGHB (°C)
Mean Environmental temperature	{22.01}	{22.01}		{2.29}
centre header	21.5	20.8	0.7	5.3
corner header	21.8	-	-	4.8
mid vertical frame	19.0	18.7	0.3	3.8
corner cill	15.9	-	-	3.4
centre cill	16.1	16.4	0.3	3.5
centre mullion	18.8	18.0	0.7	4.6
centre transom	20.0	20.0	0	3.6
corner large IGU pos	13.5	-	-	3.4
3 large IGU	13.7	13.7	0	3.3
pos 2 large IGU	14.9	15.1	-0.2	3.3
pos 1 large IGU	15.5	15.6	-0.1	3.2
centre large IGU	17.7	17.9	-0.2	4.3
centre med. IGU	17.3	17.2	0.1	3.9
corner small IGU	15.7	-	-	5.0
pos 2 small IGU	16.1	16.0	0.1	4.3
pos 1 small IGU	17.6	17.7	-0.1	3.8
centre small IGU	19.1	18.5	0.6	4.5

Table 7 Surface temperatures on the Hardwood window TT091

Position	Hot Temperature			Cold Surface Temperature
	WGHB (°C)	Simulated (°C)	Difference (°C)	WGHB (°C)
Mean Environmental temperature	{21.81}	{21.81}		{2.19}
centre header	20.7	21.0	0.3	5.9
corner header	22.0	-	-	6.6
mid vertical frame	17.3	18.5	-1.2	3.6
corner cill	14.6	-	-	3.5
centre cill	14.8	16.1	-1.3	4.3
centre mullion	18.2	19.1	-0.9	4.1
centre transom	20.4	19.9	0.5	8.0
corner large IGU pos	12.1	-	-	3.2
3 large IGU	12.6	13.3	-0.7	3.5
pos 2 large IGU	14.5	14.7	-0.2	3.1
pos 1 large IGU	15.2	15.3	-0.1	3.0
centre large IGU	17.6	17.6	0	3.8
centre med. IGU	17.0	16.9	0.1	3.9
corner small IGU	14.1	-	-	5.7
pos 2 small IGU	15.7	16.0	-0.3	5.1
pos 1 small IGU	17.0	17.6	-0.6	4.1
centre small IGU	18.9	19.2	-0.3	4.3

4 SENSITIVITY OF THE MEASURED AND CALCULATED U-VALUES TO VARIATIONS IN KEY VARIABLES

4.1 MEASURED VALUES

The sensitivity of the measured U-values to parameters that are specific to the new CEN method are discussed in NPL Report QMS101 Section 7.

4.2 SIMULATED VALUES

The sensitivity of the simulated U-value to key material properties was determined by recalculating the U-value of each window with the value of each of those properties increased by 10%. The results of the recalculations are described in detail in the report CWCT/NPL_QM/1. A summary is given below in Table 8.

Table 8 Summary of the results of the sensitivity study

Material, physical property and original value	Effect on the simulated U-value of an increase of 10% in the value of this property. (% change)
Aluminium Window	
Thermal conductivity	
Aluminium = 200 W/m.K	+0.4
Weatherstripping = 0.14 W/m.K	+0.4
Glazing gaskets = 0.12 W/m.K	+0.4
Thermal break = 0.106 W/m.K	+0.8
Foam packing = 0.032 W/m.K	+0.4
PVC-U Window	
Thermal conductivity;	
PVC-U material = 0.16 W/m.K	+0.5
Weatherstripping = 0.25 W/m.K	-
Glazing gaskets = 0.12 W/m.K	-
Reinforcements = 50 W/m.K	-
Hardwood Window	
Thermal conductivity;	
Wood = 0.15 W/m.K	+1.9
Weatherstripping = 0.06 W/m.K	-

Glazing tapes = 0.06 W/m.K	+0.5

The effect of changing the effective emissivity value of Pilkington K glass coating from 0.2 to 0.156 for the PVC-U window is to change the overall U-value of the window by 4%.

5 CONCLUSIONS

5.1 GENERAL CONCLUSIONS

(i) The U-values for the Aluminium and Hardwood windows that were produced using the CEN measurement procedures were about 6% higher than when using the measured surface temperatures and were 3% higher for the PVC-U window.

ii) The agreement between the measured (using the CEN procedures) window U-values and those simulated using the procedures in prEN 30077 Part 2 with the glazing unit in the frame, were excellent. All values were within ±4% of each other.

iii) The evaluation of the window U-values using simplified calculation procedures given in prEN 30077 Part 1 highlighted a number of issues to be resolved by TC89 WG7 who drafted the standard (See 5.2). The acceptance criteria given in the standard were not met by the Aluminium and PVC-U windows so the U-values determined for these windows, using this standard, are invalid.

iv) The U-value for the Aluminium window, calculated using the procedures in prEN 30077 Part 1, is 13% higher than the measured value. This very conservative value is slightly at odds with the fact that the large area of thermal break in the mullion and transom should have resulted in the calculated value being too low.

v) The U-value for the PVC-U frame, calculated using the procedures in prEN 30077 Part 1, is only 5% too high despite the fact that the fixed frame and transom did not contain metal reinforcement and so should have produced a rather higher than expected U-value.

vi) The simulated and calculated U-values for the Hardwood window were slightly lower than the measured U-values and the derived ψ values for this frame appear slightly too high relative to the PVC-U frame. These calculated values are directly effected by the thermal conductivity value that has been used for the wood. If a value 0.18 W/m.K were used instead of 0.15 W/m.K then the calculated and simulated U-values would be slightly higher than the measured U-values and the ψ value would be more as expected. The value of thermal conductivity taken for this frame will be verified.

vii) The comparisons between the measured and simulated surface temperatures required the simulated surface temperatures to be corrected to accommodate the temperature gradient present in the hot box apparatus. In general there was fair agreement between the measured and simulated surface temperatures for all three window systems.

viii) The first phase of the project has shown that U-values simulated for the three window systems using the procedures given in the simulation standard prEN 30077 Part 2, agree to within an acceptable level with those measured using the procedures specified in CEN/TC N216 E rev 02.95.

The next phase of this project will seek to test these measurement and simulation tools over a wider range of window systems. Details such as glass thickness, multiple low emissivity coatings and secondary glazing will be investigated and the U-value of a very high performance window will be measured, simulated and calculated.

5.2 CONCLUSIONS CONCERNING THE DRAFT STANDARDS

5.2.1 prEN 30077 Part 1

i) Annex D does not deal with frames having glazing on both sides. For example:

- Figure D3 gives several examples for determining the mean thickness of a timber frame but they are all frames with a single sash.

- The acceptance criteria given in Figures D5 and D6 do not allow the proportions of thermal break material often found in frames with two sashes, a construction often used in UK windows.

ii) The ψ values calculated for the window frames using the procedures described in prEN 30077 Part 2 were significantly higher than given in Table E in prEN 30077 Part 1. (See Table 2 of this report). The U-values calculated using the procedures given in prEN 30077 Part 1 and these calculated ψ values were all higher than the measured U-values, which they were not for the U-values calculated using the prEN 30077 Part 1 values of ψ.

iii) The wording associated with Table D1 states that if a plastic frame is not reinforced the U_f value must be measured or calculated. It should allow the values in Table D1 to be used as they would be even safer when the frame has no metal reinforcement. Plastic frames in the UK often do not have metal reinforcement.

5.2.2 prEN 30077 Part 2

i) The examples given in Annex C all have rectangular sections. There should be an example with curved surfaces.

ii) Guidance should be given to finite difference analysts on how to represent curved and angled surfaces.

iii) A minimum width of cavity should be defined below which convection can be assumed not to occur. For example, in a cavity 25 mm deep and 2 mm wide the formula given would indicate that the heat transfer is dominated by convection!

iv) For a more complete description of the above and other problems see Appendix A in report CWCT/NPL_QM/1.

5.2.3 CEN/TC 89 N 216E rev. 02.1995.

i) The measurement uncertainty of thermal conductance of the glazed calibration panels must be about ± 5%. The design and fabrication of these panels is the subject of a current European Community Framework 3 project (SM&T Project 3032).

ii) Great care must be taken with the hot box measurements of the two calibration panels in order to produce the required calibration data.

Figure 1 The window design used in phase 1.

Figure 2 prEN 30077 Part 1 calculations for TT089

Figure 3 prEN 30077 Part 1 calculations for TT090

Figure 4 prEN 30077 Part 1 calculations for TT091