DEPARTMENT OF THE ENVIRONMENT
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Validation of thermal performance design tools for window frame construction: an independent verification by agreed measurement procedures.

DOE Research contract 39/3/279 - Comparison between the measured, simulated and calculated U-values of eight window systems.

Ray Williams **(National Physical Laboratory)**
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ABSTRACT

This report summarises the results of DOE Research Contract 39/3/279. The U-values and surface temperatures of eight window systems measured in the NPL wall guarded hot box using the procedures specified in prEN 12412-1 are compared with those calculated and simulated by CWCT using the procedures specified in prEN 10077 parts 1 and 2 respectively. Additional simulations were carried out of selected frame sections using the THERM Software. The agreement between the measured and simulated U-values are shown to be good but the agreement between the U-values calculated using the simplified procedures and those measured varied widely and were mainly, though not always, very conservative (significantly higher than measured). A number of recommendations are made to improve both parts 1 and 2 of prEN 10077 and guidelines for good measurement and simulation practice are given.

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1 OBJECTIVES

To independently validate the procedures for measuring, simulating and calculating window system U-values that are currently being developed. These procedures are urgently required by the industry as a means of demonstrating that their products comply with the requirements of Part L of the UK Building Regulations.

This was achieved by doing the following:

- Defining standard measurement and calibration procedures that incorporate the needs of the industry, best practice in other countries and the requirement to produce realistic and reproducible U-values for window systems.

- Verifying the validity of the measurement and calculation procedures chosen, by comparing measured and calculated U-values for the Aluminium, UPVC and Wood framed windows.

- Comparing the simulated U-values produced by a high specification FEA programme with those produced by a low-cost window frame thermal property software package.
- Preparing guidance notes summarising the recommended measurement and calculation/simulation procedures to be disseminated through the measurement and calculation community, the window industry and CEN.

The project team comprised the following organisations:

NPL, Centre for Window and Cladding Technology (CWCT), Caradon Everest, Anglian Windows, Zenith Windows, BAC Ltd, Pilkington Glass Consultants, British Woodworking Federation, Council for Aluminium in Buildings, British Plastics Federation, and the Glass and Glazing Federation. The measurements were carried out by the NPL and the simulations by CWCT.

An early decision of the project team was that the measurement, calculation and simulation methods selected should be from the suite of draft CEN standards that had already reached an advanced stage. An overview of these standards is shown in Figure 1. It should be noted that in both prEN 10077 parts 1 and 2, the "centre of glazing" U-values are calculated using the procedures specified in BS 6993 Part 1 (prEN 673). In the Part 1 Simplified Calculation standard, the U-value of the frame sections is estimated from graphs and tables, whereas in the Part 2 Numerical Method Standard, the U-values of the frame sections are simulated using Finite Element or Finite Difference Software.

In the first phase of the project, the U-value measurements and calculations were made on window systems that are typical of the three main frame material types. When the results from this phase were shown to be acceptable the details of Phase II were decided. This approach gave the opportunity to resolve problems encountered when dealing with straightforward window designs, before advancing to more complex ones.

WINDOW U-VALUES - AN OVERVIEW OF THE DRAFT CEN STANDARDS

CEN prEN 12412-2

Hot box measurement procedures to measure the U-value of frame sections without the effects of the edge of glazing.

The frame sections are mounted in the hot box holder panel vertically (about 3 pieces). The infill between the sections is EPS. OR a window frame is constructed and EPS used as the IGU.

This method uses the same calibration procedures as **prEN 12412-1** only with plain EPS panels.

prEN 10077 Part 1
Been for public comment - target date for vote July 97
Simplified Procedures for calculating the U-values of either:

- a whole window system
- the frame section only

This standard adopts the convention that a window comprises 3 components.

Centre of Glazing U-value

The calc. method in **prEN 673** is used to calc the U-value of the centre of glazing area.

U-values of the centre of glass of an IGU can be measured using the procedurein **prEN1098**

Frame U-value

Simple procedures are given for calculating the U-values of the three main types of frame.

The values produced are intended to be on the safe side.

Wood	Plastic	Aluminium
Graph of U_f vs frame thickness for hard & soft wood	Table of U_f for 1 chamber 2 chamber 3 chamber	Graph of R_s vs smallest distance between Al sections. An equation is given

Edge of glazing & frame effect. (ψ)
Tables of values for 2 types of glazing & 3 types of frame.

OR

This can be simulated using PrEN 10077 Part 2

prEN 10077 Part 2
Going for comment soon - vote June 98
Numerical Simulation Procedures

For use with any FEA or FED software package that complies with ISO 10211- & ISO 10211-2

Defines material properties, interior and exterior surface coefficients, convective correlations, radiant exchange equations, how to treat small cavities etc.

- Can be used to simulate the following:

Linear thermal transmittance(ψ)	U-value of frame section only.	U-value of whole window.
Simulate whole	Frame simulated	Frame simulated

prEN 12412 - 1
& ISO/CD 12567
Been for comment - vote Dec 97
Hot Box Measurement Standard

- U-value for whole window

The complete window system is mounted in a hot box that meets the requirements of **ISO/CEN 8990**

The method relies on hot box measurements on 2 glazed calibration panels.

The temperature conditions are specified.

Figure 1 Draft CEN Standards dealing with the thermal properties of window systems.

2 SPECIFICATIONS OF THE WINDOW SYSTEMS USED

The window size chosen was that recommended in the draft CEN measurement standard prEN 12412-1:- 1230 mm (wide) x 1480 mm (high).

Each window comprises one opening casement, one top opening light and one fixed light. A drawing of this window design is shown in Figure 2 and the main details of the windows are given in Table 1. Detailed drawings and material lists are given in the CWCT Report CWCT/NPL_QM/3 (January 1997).

3 MEASUREMENT AND CALCULATION DETAILS

3.1 U-value measurement

3.1.1 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 prEN 12412-1. The procedure is described in some detail in NPL Reports QMS101 and QM132. 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 the draft 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 described above.

Additional (to those required by the standard) surface temperature measurements were made to enable comparisons with the surface temperatures predicted by the simulations. The positions of the thermocouples are shown in Figure 2. The surface temperature measurements were also used to produce area weighted hot and cold window surface temperatures. These were then used to derive environmental temperatures and hot and cold surface resistances. These values in turn were used to produce a standardized U-value directly from the measured power, environmental temperature difference and total measured surface resistance. The U-values derived in this manner are referred to as the "direct" U-value.

Table 1 Details of the window systems measured and simulated.

NPL ID No.	Frame details				Glazing details			
	Frame material	Thermal break type	Number of cavities	Reinfor -cement	Size (mm)	Gas type	Coating	Space bar 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
TT100	Wood (Hard)	n/a	n/a	n/a	4/16/4 Plus 4 mm secondary glazing unit (Inside)	Air	Pilkington K 3rd surface [1]	Al
TT101	Al (alloy)	4 mm urethane resin	n/a	n/a	6/12/6	Air	Both panes plain glass	Al
TT102	Wood (Hard)	n/a	n/a	n/a	4/12/4 [2]	Air	Pilkington K 3rd Surface [1]	High Perf. [3]
TT103	Al (alloy)	4 mm urethane resin	n/a	n/a	4/16/4	Air	Pilkington K 2nd & 3rd Surfaces [1]	Al
TT104	Al (alloy) [4]	26 mm Poly -amide	n/a	n/a	8/12/4 Plus 6 mm secondary window (Outside) [5]	Air	Pilkington K 4th & 5th Surfaces [1]	High perf. [3]

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

[2] The use of a 12 mm air gap was not intentional.

[3] Thermally broken aluminium spacer bar supplied by Azon Ltd.

[4] None of the surfaces were coated, all surfaces were bright aluminium. An attempt was made to increase the emissivity of all the surfaces visible by spraying them with deodorant containing Aluminium Chlorohydrate. This has been shown using thermal imaging to be effective in increasing the emissivity of metallic surfaces. It is unlikely that the overall emissivity value of all surfaces was as high as 0.9.

[5] The 4/12/4 IGU unit was specified in the drawing but a frame requiring a 4/16/4 unit was made. An additional piece of 4 mm thick glass was used to bring the IGU up to the required overall thickness of 24 mm. The additional glass was placed on the room side of the IGU. There will be a small contact resistance associated with the interface between the two surfaces.

Figure 2 Positions of the surface mounted thermocouples

3.1.2 Measurement uncertainty

The error analysis for measurements made with a variety of test elements, in the NPL WGHB, are described in NPL Procedure Document QPDQM/B/417.

The uncertainty in the absolute U-value of a homogeneous test element mounted directly into the hot box and therefore not requiring a boundary loss correction, is estimated to be ± 4.0% at the 95% confidence level.

For a homogeneous test element mounted in a holder panel - where the U-value is corrected to the standard surface resistance value by deducting the measured total surface resistance and adding the standard value - the uncertainty in the U-value is estimated as ± 6.6% at the 95% confidence level.

These uncertainty figures are confirmed by measurements made on various homogeneous reference panels, of different constructions, with thermal conductances ranging from 0.6 to 6.8 W/m^2K. The thermal conductances measured in the NPL WGHB, of all of those panels, were within ± 5% of the values calculated from thermal conductivity data measured in the NPL guarded hot-plate apparatus. The uncertainty of the guarded hot-plate measurements was ± 3% or better.

The uncertainty of the measurement procedure specified in prEN 12412-1 for very non-homogeneous test elements is still the subject of international research. An estimate has been made using a method developed by TNO (Netherlands) which produces a figure of ± 8.5% at the 95% confidence level when the thermal conductance of the calibration panels are known to an uncertainty of ± 6.5%.

3.2 U-value simulation and calculation details

3.2.1 Simulations

Simulation is a process in which a mathematical model of the structure is created by dividing the structure into a large number of small zones and then defining all the equations for the heat transfer across each of those zones. The overall heat transfer through the structure is then obtained by solving the equations for all of the zones. This can be carried out by hand but it is an extremely time consuming task. This type of numerical analysis is now almost always carried out using a computer with commercially available software.

The majority of 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. The equations, the thermal property data, and the conventions used are those defined in draft CEN Standard prEN 1077-2 - "Window and Door components - Thermal transmittance. Numerical calculation method." This standard was prepared by CEN TC 89/WG7.

Additionally, the U-value of some of the frame sections have been simulated using a software

package called THERM, produced by Lawrence Berkeley Laboratory California USA. It is designed to evaluate the heat transfer through windows and building structures and is presently free but may eventually be sold for a small fee. The boundary conditions and material thermal properties were the same for both sets of simulations.

3.2.2 Simple calculations

The term "calculation" here refers to a process that can be carried out using pen and paper and a calculator. For situations where only an estimate of the thermal properties are required there is another CEN/ISO draft standard: prEN 10077 Part 1 - Windows, doors and shutters - Thermal transmittance - Simplified Calculation Method. This again has been prepared by CEN TC 89/WG 7.

The U-values of the window systems used in this project have also been evaluated using the procedures specified in the above CEN/ISO standard.

3.3 Emissivity measurements

The total hemispherical emissivity of the two batches of low-E coated glass used in the IGUs measured in this project were determined by measuring the emissivity of five glass samples cut from each batch of low emissivity coated glass, used to make the units. The measurements were made at the NPL (NPL Certificates CETM/27/96/023 and CETM/27/96/036).

4 RESULTS

4.1 Summary of reports

The different values that have been measured, simulated or calculated are described in greater detail in the following reports:

NPL Report QM115
December 95

- Calibration Panels - Results of the Hot Box measurements made on two, glazed calibration panels carried out in the NPL Wall Guarded Hot Box (WGHB) using the procedures specified in prEN 12412-1.

NPL Reports QMS101
January 96

- Phase I measurements - Whole window U-values measured in the NPL Hot box using the method specified in prEN 12412-1 and the a direct method that relies on calculated boundary loss values.
- Measured surface temperatures.

CWCT Report
CWCT/NPL_QM/3

- Simulated U-values of the frames and whole window systems. Simulations made using the

January 97	procedures specified in prEN 10077-2 with a) glazing in the frame and simulated ψ values. • Evaluation of the sensitivity of the simulated values to the material property data used. • Surface temperatures. • Detailed drawings of the frame sections and material properties.
CWCT Report CWCT/NPL_QM/4 January 97	• Calculated whole window U-values, using the procedures specified in prEN 10077-1. • U-values simulated with EPS in place of the glazing & ψ values from prEN 10077-1 • Detailed drawings of the frame sections and material properties.
CWCT Report CWCT/NPL_QM/5 January 97	• Frame U-values simulated using the Lawrence Berkeley Laboratory's THERM software.
NPL Report QM119 March 96	• Phase I - Comparison of measured, simulated and calculated values obtained in Phase I of the project.
NPL Report QM131 February 97	• Final summary report comparing the various measured, simulated and calculated values obtained in this project.
NPL Report QM132 February 97	• Final measurements report - Report of the hot box measurements made of all eight window systems.

4.2 Comparison of measured, calculated and simulated U-values - CEN procedures.

A summary of these values is presented in Table 2.

4.3 Comparison of U-values measured using the CEN and the "direct" procedures.

The measured U-values, produced by the two different procedures are presented in Table 3.

4.4 Comparison of simulated frame U-values obtained with ANSYS and THERM

A summary of these values is presented in Table 4.

4.5 ψ values simulated using CEN procedures

A summary of these values is presented in Table 5.

Table 2 Summary of Measured, Simulated and Calculated U-values

Window frame ID	Measured U prEN 12412-1 standardised (0.17m².K/W) U_{Meas} (W/m².K)	Simulated U prEN 10077-2 using ANSYS standardised (0.17m².K/W) U_{Sim} (W/m².K)	Difference U-value $\frac{U_{Sim}-U_{Meas}}{U_{Meas}}$ (%)	Calculated U-value prEN 10077-1 U_{calc} (W/m².K)	Difference U-value $\frac{U_{Calc}-U_{Meas}}{U_{Meas}}$ (%)
TT089 - Al(1) 4/16/4 1K	2.53	2.59	2.4	2.96	17.0
TT090 - UPVC 4/16/4 1K	1.90	1.98	4.2	2.02	6.9
TT091 - HWood 4/16/4 1K	2.15	2.12	-1.4	2.11	-1.9
TT100 - HWood 4/16/4 1K & Sec. glazing	1.58	1.57	-0.6	1.48	-6.3
TT101 - Al(1) 6/12/6 0K	3.17	3.31	4.4	3.68	16.1
TT102 - HWood 4/12/4 1K + low λ S/Bar	2.16	2.20	1.9	2.25	4.2
TT103 - Al(1) 4/16/4 2K	2.41	2.48	2.9	2.83	17.4
TT104 - Al(2) 8/12/4 2K + 6mm Sec/unit	1.75[1]	2.03[1] 1.58[1]	16	2.25	28.6

Note[1] The emissivities of the surfaces of this frame are uncertain. To assess the effect of the emissivity on the overall U-value, the simulated U-values were carried out using emissivity values of 0.9 (giving a U-value of 2.03 W/m².K) and 0.1 (giving a U-value of 1.58 W/m².K). The measured U-value of 1.75 W/m².K is approximately the mean of

these two simulated values.

Table 3 Summary of U-values measured using the CEN and "direct" procedures

Window frame ID	Measured U prEN 12412-1 standardised ($0.17 m^2.K/W$) U_{CEN} ($W/m^2.K$)	Measured U "direct method" standardised ($0.17 m^2.K/W$) U_{Dir} ($W/m^2.K$)	Difference U-value $U_{Dir}-U_{CEN}$ $U_{\circ CEN}$ (%)
TT089 - Al(1) 4/16/4 1K	2.53	2.41	-4.7
TT090 - UPVC 4/16/4 1K	1.90	1.82	-4.2
TT091 - HWood 4/16/4 1K	2.15	2.02	-6.0
TT100 - HWood 4/16/4 1K & Sec. glazing	1.58	1.55	-1.9
TT101 - Al(1) 6/12/6 0K	3.17	3.18	0.3
TT102 - HWood 4/12/4 1K + low λ S/Bar	2.16	2.08	-3.7
TT103 - Al(1) 4/16/4 2K	2.41	2.35	-2.5
TT104 - Al(2) 8/12/4 2K + 6mm Sec/unit	1.75[1]	1.80[1]	2.9

Note[1] The emissivities of the surfaces of this frame are uncertain.

Table 4 Summary of simulated U-values of some specific frame sections using ANSYS and the LBL THERM software with the prEN 10077-2 procedures.

Window frame section details	Simulated U-value prEN 10077-2 (using ANSYS) standardised ($0.17 m^2.K/W$) U_{CEN} ($W/m^2.K$)	Simulated U-value prEN 10077-2 (using THERM) standardised ($0.17 m^2.K/W$) U_{THERM} ($W/m^2.K$)	Difference U-value $\frac{U_{CEN}-U_{THERM}}{U_{CEN}}$ (%)
• UPVC fixed frame **(Frame A)** • 4/16/4 with 1 low E coating • Standard Aluminium spacer bar	2.85	2.85	0
• Hardwood transom frame **(Frame A)** • 4/16/4 with 1 low E coating • Standard Aluminium spacer bar • Single glazed secondary window	1.96	1.95	0.5
• Aluminium vent frame **(Frame A)** • 4/16/4 with 1 low E coating • Standard Aluminium spacer bar	4.59	4.71	-2.6
• Aluminium vent frame **(Frame A)** • 4/16/4 with 2 low E coatings • Standard Aluminium spacer bar	4.63	4.75	-2.6

NB - The above U-values are for specific frame sections only - not the whole window.

4.6 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/3.

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, there are vertical temperature gradients in the air, especially on the hot side. To enable the measured and simulated surface temperatures to be compared properly the simulated temperatures were adjusted to match more closely the temperature gradients that were measured during the 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 summary of the comparison between the measured and corrected simulated hot surface temperatures are given in Tables 6, 7, 8, 9, 10, 11 and 12 for all the window systems except the high performance aluminium double window.

Table 5 ψ values simulated using CEN procedures

Specimen Number	ψ value given in prEN 10077 Part 1 W/m.K	ψ value simulated using prEN 10077 Part 2 Note [1] W/m.K
Aluminium frame TT089	0.08	0.100 0.080 0.075 0.075 Mean 0.0862 Note[2]
UPVC frame TT090	0.06	0.080 0.075 0.075 0.075 Mean 0.0769 Note[2]
Wood frame TT091	0.06	0.085 0.085 0.085 0.085 Mean 0.085 Note[2]

Notes

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

[2] The 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.

Table 6
Surface temperatures on the Aluminium window TT089 with 4/16/4 1 low-E IGU.

Position	Hot Surface Temperature			Cold Surface Temperature
	Measured WGHB (°C)	Simulated (°C)	Difference WGHB-Sim. (°C)	Measured 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 7
Surface temperatures on the PVC-U window TT090 with 4/16/4 1 low-E IGU

Position	Hot Surface Temperature			Cold Surface Temperature
	Measured WGHB (°C)	Simulated (°C)	Difference WGHB-Sim. (°C)	Measured 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 8
Surface temperatures on the Hardwood window TT091 with 4/16/4 1 low-E IGU

Position	Hot Temperature			Cold Surface Temperature
	Measured WGHB (°C)	Simulated (°C)	Difference WGHB-Sim (°C)	Measured 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

Table 9
Surface temperatures on the Hardwood window TT100
with 4/16/4 1 low E IGU + secondary glazing unit

Position	Hot Temperature		
	Measured WGHB (°C)	Simulated (°C)	Difference WGHB-Sim. (°C)
Mean Environmental temperature	23.07	23.07	
centre transom Base window	16.4	17.7	-1.3
Secondary unit	18.9	19.8	-0.9
centre mullion Base window	14.1	16.6	-2.5
Secondary unit	19.4	19.3	0.1
centre large IGU Base window	14.1	14.6	-0.5
Secondary unit	19.7	19.7	0
centre med IGU Base window	13.7	14.3	-0.6
Secondary unit	19.0	19.1	-0.1
centre small IGU Base window	15.7	15.4	0.3
Secondary unit	20.7	21.0	-0.3

Table 10
Surface temperatures on the Aluminium frame TT101
IGU 6/12/6 - clear glass

Position	Hot Temperature		
	Measured WGHB (°C)	Simulated (°C)	Difference WGHB-Sim. (°C)
Mean Environmental temperature	21.35	21.35	0
centre header	18.5	17.4	1.1
corner header			
mid vertical frame	13.1	15.0	-1.8
corner cill			
centre cill	12.5	12.6	-0.1
centre mullion	13.5	12.5	1.0
centre transom	15.2	13.7	1.5
corner large IGU pos			
3 large IGU	11.1	10.5	0.6
pos 2 large IGU	12.4	11.4	1.0
pos 1 large IGU	n/a		
centre large IGU	14.9	14.2	0.7
centre med. IGU	14.5	13.4	1.1
corner small IGU			
pos 2 small IGU	15.0	12.6	2.4
pos 1 small IGU	16.3	14.1	2.2
centre small IGU	16.7	15.7	1.0

Table 11 Surface temperatures on the Hardwood window TT102 IGU 4/12/4 - 1 low E- thermally broken spacer bar system.

Position	Hot Temperature		
	Measured WGHB (°C)	Simulated (°C)	Difference WGHB-Sim. (°C)
Mean Environmental temperature	23.21	23.21	
centre header	22.2	21.6	0.5
corner header			
mid vertical frame	19.0	19.9	-0.9
corner cill			
centre cill	16.1	17.8	-1.7
centre mullion	19.3	20.5	-1.2
centre transom	21.6	21.1	0.5
corner large IGU pos			
3 large IGU	14.5	15.2	-0.7
pos 2 large IGU	16.2	16.3	-0.1
pos 1 large IGU	17.9	16.5	1.3
centre large IGU	18.4	18.3	0.1
centre med. IGU	17.9	17.8	0.1
corner small IGU			
pos 2 small IGU	17.0	17.0	0
pos 1 small IGU	18.6	18.2	0.4
centre small IGU	19.7	19.3	0.4

Table 12 Surface temperatures on the Aluminium frame TT103
IGU 4/12/4 - 2 low E coatings.

Position	Hot Temperature		
	Measured WGHB (°C)	Simulated (°C)	Difference WGHB-Sim. (°C)
Mean Environmental temperature	21.72	21.72	
centre header	18.5	18.0	0.5
corner header			
mid vertical frame	13.5	15.3	-1.8
corner cill			
centre cill	13.0	13.3	-0.2
centre mullion	13.7	12.8	0.9
centre transom	15.3	14.0	1.3
corner large IGU pos			
3 large IGU	12.8	12.9	-0.1
pos 2 large IGU	14.5	14.6	-0.1
pos 1 large IGU	15.9	15.2	0.7
centre large IGU	17.8	17.9	-0.1
centre med. IGU	17.1	17.1	0.0
corner small IGU			
pos 2 small IGU	14.5	15.2	-0.7
pos 1 small IGU	17.3	17.5	-0.2
centre small IGU	19.3	19.5	-0.2

5 SENSITIVITY OF THE CALCULATED U-VALUES TO VARIATIONS IN KEY VARIABLES

5.1 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.

5.2 Simulated values

The sensitivity of the simulated U-values 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 calculations are described in detail in the report CWCT/NPL_QM/3. A summary is presented in Table 13.

Table 13 Sensitivity of simulations to material properties.

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	200.00 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	-
Emissivity		
• IGU coating	0.2 to 0.156	4.0
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

6 CONCLUSIONS

6.1 General conclusions

(i) The measured U-values obtained using the CEN prEN 12412-1 procedures were within 5% of the directly measured values in seven out of the eight measurements (Table 3). For the wood frame, 4/16/4 one low-E coated IGU, the difference was 6%.

ii) The agreement between the measured (using the CEN procedures) window U-values and those simulated using the procedures in prEN 10077 Part 2 with the glazing unit in the frame, were excellent (Table 2). All but one of the values were within ± 5% of each other. The exception was the high performance window which was supplied uncoated. The attempt to increase the emissivity of all the surfaces was not successful (metallic surfaces were visible after the measurements were made) and so the actual emissivity of those surfaces is not well enough defined.

iii) The evaluation of the window U-values using simplified calculation procedures given in prEN 10077 Part 1, highlighted a number of issues to be resolved by TC89 WG7, who drafted the standard (See 5.2). For example, the acceptance criteria for the total width of thermal break material, given in section D of the standard, were not met by the mullion.

iv) The U-value for the Aluminium window, calculated using the procedures in prEN 10077 Part 1, is 17% higher than the measured value (Table 2). This is a very high (conservative) value and results from the need to make the values that are produced by graph D4, correspond to the very poorest type of thermally broken aluminium frame.

v) The U-value for the PVC-U frame, calculated using the procedures in prEN 10077 Part 1, is only 6.9% higher than the measured values despite the fact that the fixed frame and transom did not contain metal reinforcement. It therefore should have produced a rather higher than expected U-value.

vi) Both the simulated and calculated U-values for the Hardwood window were slightly lower than the measured U-values, by -1.4% and -1.9% respectively. These simulated and calculated values are directly affected 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.

vii) The derived ψ values for the hardwood frame appear slightly too high compared to the values derived for the PVC-U frame. If a thermal conductivity of 0.18 W/m.K is taken for the wood then the ψ value would also be nearer to that expected.

viii) The comparisons between the measured and simulated surface temperatures required the simulated surface temperatures to be corrected to accommodate the vertical temperature gradient present in the hot box apparatus. In general there was fair agreement between the measured and simulated surface temperatures for all the window systems. Agreement was poorest with the Aluminium frame with the 6 mm thick glass.

6.2 Conclusions concerning the draft standards

6.2.1 prEN 10077 Part 1 calculation standard

i) Annex D of the above standard 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 found in frame 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 10077 Part 2 were significantly higher than those given in Table E in prEN 10077 Part 1. (See Table 4 of this report.) The U-values calculated using the procedures given in prEN 10077 Part 1 and the separately calculated ψ values, were all higher than the measured U-values. This was not the case for the U-values calculated using the prEN 10077 Part 1 values of ψ.

iii) The wording associated with Table D1 originally stated that if a plastic frame is not reinforced the frame U-value(U_f) must be measured or calculated. It should allow the values in Table D1 to be used as they would be even higher(ie safer) when the frame has no metal reinforcement. This statement has since been changed.

6.2.2 prEN 10077 Part 2 Simulation Standard

i) The examples given in Annex C of the above standard all have rectangular sections. We recommend that there should be an example with curved and angled surfaces.

ii) Guidance should be given to finite-difference analysts on how to model 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 discussion of the above and other points see Appendix A in report CWCT/NPL_QM/3.

6.2.3 Measurement standard prEN 12412-1

i) To keep the total uncertainty of the prEN 12412-1 method to about ± 8%, the uncertainty in the predicted thermal conductance of the glazed calibration panels must be about ± 6%. The design and fabrication of these panels is the subject of a current European Community Framework 3 project (SMT Project 3032).

ii) The hot box measurements of the two calibration panels must be carried out very carefully. Special attention must be given to the surface temperature measurement procedures and care must be taken to ensure that the best possible balance of the critical hot box parameters are achieved.

iii) At present, this draft measurement procedure requires that two calibration panels are fabricated and measured for every size of test element. Recommendations have been made to CEN TC 89 WG7 that this method is developed to enable measurements made on one size of calibration panel to be used for a range of test element sizes.

7 GUIDELINES FOR THE DETERMINATION OF WINDOW U-VALUES

7.1 General

The procedures specified in the four draft European Standards below have been evaluated:

i) prEN 12412-1 Windows, Doors and Shutters - Determination of thermal transmittance by Hot Box Method - Part 1: Windows and Doors.

ii) prEN 10077-1 Windows, Doors and Shutters - Thermal transmittance - Part 1 Complete elements - Simplified Calculation Method.

iii) prEN 10077-2 Windows, Doors and Shutters - Calculation of thermal transmittance - Part 2: Numerical method for frames.

iv) BS 6993 Pt 1 (prEN 673) (ISO 10292) Thermal and radiometric properties of glazing: Part 1. Method for calculation of the steady state U-value (thermal transmittance).

Precise and consistent U-values for a wide range of window systems can be both measured and simulated using the procedures specified in prEN 12412-1 and prEN 10077-2, respectively.

The U-values determined using the Simplified Calculation procedures specified in prEN 10077-1 were in many cases very high (conservative) compared to the measured values.

When the U-value is required for either:

- Commercial purposes to demonstrate how one system performs relative to another and to enable users to base their selection on fair and accurate data,

- Regulatory purposes; eg to show that a particular system conforms to Part L of the UK Building regulations,

then the window U-values should then only be obtained by method A or B below.

A) Measurement of the whole system in a hot box.

i) The Hot Box must be built and operated according to ISO 8990. In general if the equipment conforms to BS 874 Part 3: Sections 3.0 or 3.1 it can be assumed that it will comply with the requirements of ISO 8990. (It is possible that future supplements to ISO 8990 will mean that this assumption would not then always be true.)

ii) The measurement procedures specified in prEN 12412-1 "Windows, Doors and Shutters - Determination of thermal transmittance by Hot Box Method - Part 1: Windows and Doors" shall be followed exactly.

iii) The glazed calibration panels should be either fabricated according to the specification currently being defined and validated by EU Project SMT (3032) or purchased from an organisation that can fabricate them to those requirements (such as the NPL). This

specification will eventually be a supplement to prEN 12412-1

iv) The U-value measurements should only be carried out by a laboratory accredited to the criteria set out in EN 45001 and ISO/IEC Guide 25 or by an appropriate National Standards Laboratory. In the UK, laboratories are accredited to those criteria by UKAS (NAMAS), with traceability to the NPL - the UK National Standards Laboratory with the appropriate measurement facilities.

vi) The reproducibility of a hot box measurement is usually better than ± 2% and is readily verifiable but the absolute accuracy is much more difficult to determine. With this measurement procedure, using calibration panels with conductances values known to ± 6.5% an experimental uncertainty of ± 8.5% at the 95% confidence level is possible.

B) Simulation

i) Any two dimensional numerical method (Finite Element or Finite Difference) may be used as long as it complies with the requirements set out in ISO 10211-1 and ISO 10211-2.

ii) The measurement procedures specified in prEN 10077-2 "Windows, Doors and Shutters - Calculation of thermal transmittance - Part 2: Numerical method for frames" must be followed exactly.

iii) The U-value of the centre-of-glazing should be either:-
- calculated using the procedures specified in BS 6993 Part 1 (prEN 673)
- measured in a hot box using the procedures specified in BS 6993 Part 2 (prEN 1098)

iv) It is essential that the individual window component materials are correctly identified and that the thermal property data is measured using CEN standard procedures by NAMAS accredited laboratories. If substantiated manufacturers data for those component materials is not available then data from the CEN Draft prEN 12524 "Building Materials and Products - Energy Related Properties -Tabulated design values" should be used.

v) To ensure the credibility of simulated U-values, organisations carrying out simulations for the purposes C and D should prove their competence in some way. The UKAS (NAMAS) scheme would be one way of achieving this. One of the most important tasks facing the industry will be to draw up acceptability criteria for such organisations. Round robin exercises are another way of proving competence.

vi) The uncertainty associated with these simulations has not been determined. It will include:
- Uncertainties associated with the correlations used.
- Uncertainties associated with the simplifications made.
- Uncertainties associated with the deviation of the material properties used in the simulation from the actual values. The sensitivity study summarised in Table 2 will help to evaluate this.
- Uncertainties associated with any variation of the actual window dimensions from those given in the drawing.

GLOSSARY

CEN	European Committee for Standardisation
Centre of glazing	The central part of an IGU, the U-value of which is calculated using BS 6993 Part 1. It is defined in prEN 10077-2 as the IGU with an annulus of 190 mm removed.
Environmental temperature	The environmental temperature influencing a surface is a suitably weighted mean of the adjacent air temperature and the mean radiant temperature of the surroundings, in order to indicate correctly the change in heat flow rate to or from the surface for a small change in surface temperature.
EPS	Expanded polystyrene
FDA	Finite Difference Analysis
FEA	Finite Element Analysis
IGU	Insulated glazing unit
ISO	International Standards Organisation
Low-E coated glass	Float glass that has one or both surfaces coated with a substance that transmits most visible light but has a low emissivity to electromagnetic radiation with longer wavelengths.
prEN	A draft CEN standard that has reached acceptance by the drafting group and is now ready for public comment.
U-value	The heat flux density through a given structure divided by the difference in environmental temperature on either side of the structure under steady state conditions.
WGHB	Wall Guarded Hot Box