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U-VALUE MEASUREMENTS ON ROOF WINDOW

KARSTEN DUER

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1 INTRODUCTION

This report describes the results of the U-value measurements performed on a roof window.
The measurements have been performed using the procedures given in CEN prEN 12412:1996 with a few modifications especially concerning the calibration procedure.
The measurements were carried out at the Technical University of Denmark, Department of Buildings and Energy.

2 DESCRIPTION OF THE WINDOW

Sections of top, side and bottom frame of the roof window are shown in figure 1. The window is a wooden roof window and measures 1400 mm high x 1140 mm wide. The glazings are 4-16-4 mm with one hardened glass pane outermost and one soft-coated glass pane innermost (low e-coating in position 3). The gap between the glass panes is Argon filled and the spacer material is aluminium.

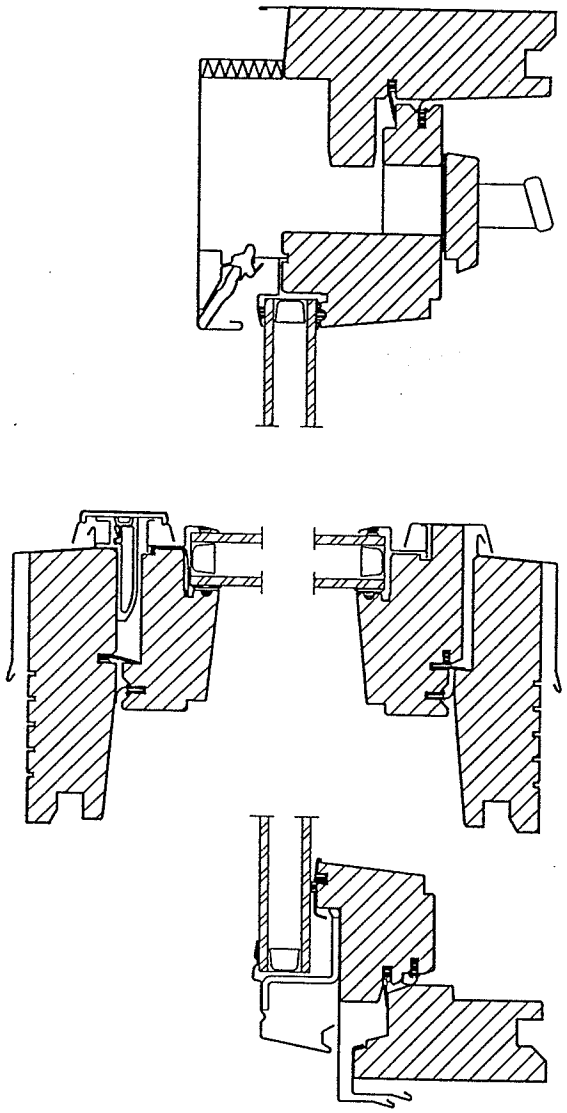

Figure 1. Sections of the roof window top, side and bottom frame.

3 CALIBRATION PANELS

Two calibration panels have been constructed in order to carry out the hot box calibration procedure. The panels measure 1400mm high x 1140mm wide and 1215mm high x 990mm wide respectively and have both a total thickness of 28 mm.

The core material is polyurethane which prior to the assembling has been ground plane in order to avoid or at least reduce variations in the material thickness. The core thickness is 20 mm.

The glazings on both sides of the core are 4 mm hardened glass with normal emissivity.
The panels are assembled simply by means of heavy duty tape, no glue has been used in this process.

The thermal conductivity λ has been measured for the sample thicknesses of 20 mm. The measurements were performed on material samples produced in the same batch as the material samples that were used in the calibration panels.
The thermal conductivity was determined at three mean temperatures of the polyurethane: 16, 21 and 26°C. A linear temperature dependency for the thermal conductivity of the polyurethane was found in this range and it is asumed that the same linear change in the thermal conductivity as a function of temperature can be used also outside the measured range. The λ-values at the relevant temperatures during calibrations were found using the following expression:

$$\lambda_t = \lambda_{21} - \frac{(21-t)\cdot\Delta\lambda\cdot\lambda_{21}}{100}$$

where t is the actual temperature of the core material during calibrations and $\Delta\lambda$ is the temperature dependency of the thermal conductivity of polyurethane.

The results of the measurements are:

λ_{21} = 0.0294 W/mK

$\Delta\lambda$ = 0.3 %/K

4 GUARDED HOT BOX

The hot box measurements were performed in a guarded hot box. Maximum sample size is 1500 x 1250 mm and the meetering box measures 1600 x 1350 mm inside. The guarded hot box is build and the measurements are performed in accordance to ISO 8990, CEN prEN 12412:1996 and the ISO/CD12567 proposal with the following exceptions:

- No wind speed measurements are carried out during measurements but the windspeed on the cold side has previously been measured to ensure that the windspeed here is at least 2 m/s.

- Due to limitations in the cooling system it has not been possible to obtain a cold side temperature below -8°C during calibration.

- The calibration panel is >20 mm.

- The calibration procedure has been changed as explained in section 5.

Prior to each calibration or U-value measurement the meetering box is tested for air tightness in order to assure that no air will be exchanged between hot and cold side.

5 CALIBRATION MEASUREMENTS

As the roof window was going to be measured with 22 mm of the frame mounted in the surround panel reveal and the rest of the counstruction exposed to the cold side ambient, the calibration procedure differed from the procedure outlined in CEN prEN12412:1996. The calibration was carried out in two steps using the following procedure:

1. First the surround panel heat exchange coefficient H_{sur} was found using the 1400x1140x28 mm calibration panel.
   The calibration panel was mounted flush with the face of the cold side surround panel. See figure 2. Three measurements were carried out with 20°C on the warm side and 0°C, -5°C and +10°C respectively on the cold side. During the first measurement the voltage for the wind simulator fan on the cold side was regulated in order to obtain the standard surface resistance in accordance to the CEN standard.

2. Next the window with the second calibration panel was mounted in the surround panel. See figure 3. Four series of measurements were carried out:

2a. One measurement with the calibration panel mounted with tape and performing the measurement with the same wind simulator voltage as in 1. T_{warm}=20°C and T_{cold}=0°C.
The purpose of this measurement was merely to observe the change in surface resistance when mounting the window.
2b. Three measurements were carried out with 20°C on the warm side and 0°C, -8°C and +10°C respectively on the cold side. During the first measurement the voltage for the wind simulator fan on the cold side was regulated again in order to obtain the standard surface resistance in the new glazing plane.
2c. One measurement with the calibration panel mounted with the alu-profiles from the window, windspeed from 2b. T_{warm}=20°C and T_{cold}=0°C
2d. One measurement with the calibration panel mounted with the alu-profiles and all metal covering mounted on the cold side, windspeed from 2b. T_{warm}= 20°C and T_{cold}=0°C.

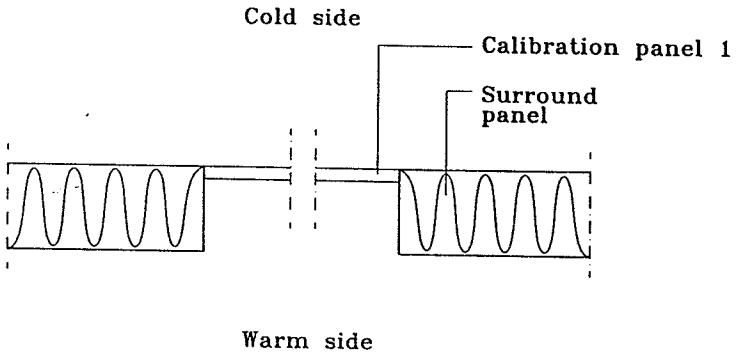

Figure 2. Mounting of calibration panel 1 (calibration step 1).

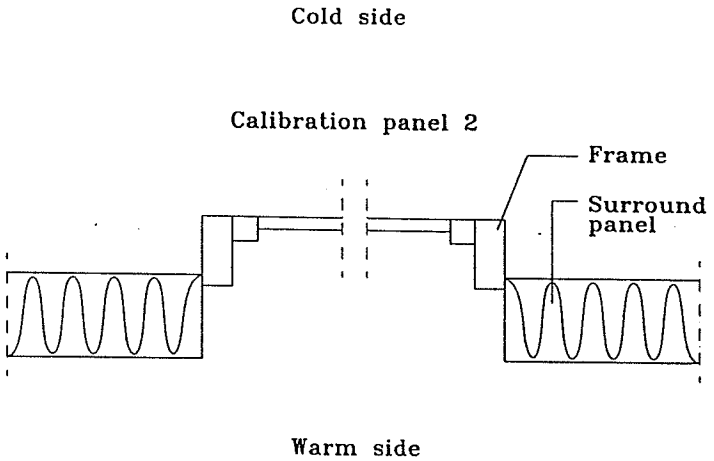

Figure 3. Mounting of calibration panel 2 (calibration step 2).

From the known thermal resistance of the calibration panels it is now possible to find the surround panel heat exchange coefficient H_{sur} as a function of surround panel mean temperature as well as the surface resistance R_s as a function of heat flux density through the calibration panel. The results are shown in figure 4 and 5.
In Annex A is shown the key results from all calibrations.

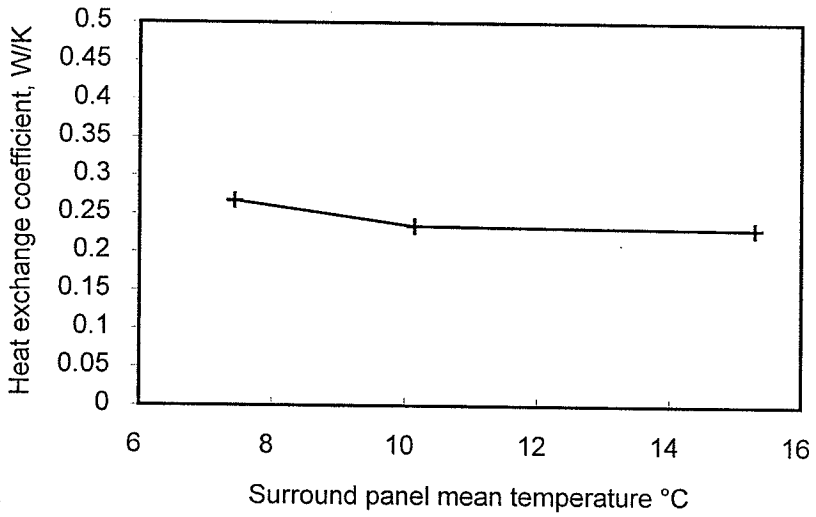

Figure 4. *Surround panel heat exchange coefficient. From calibration step 1.*

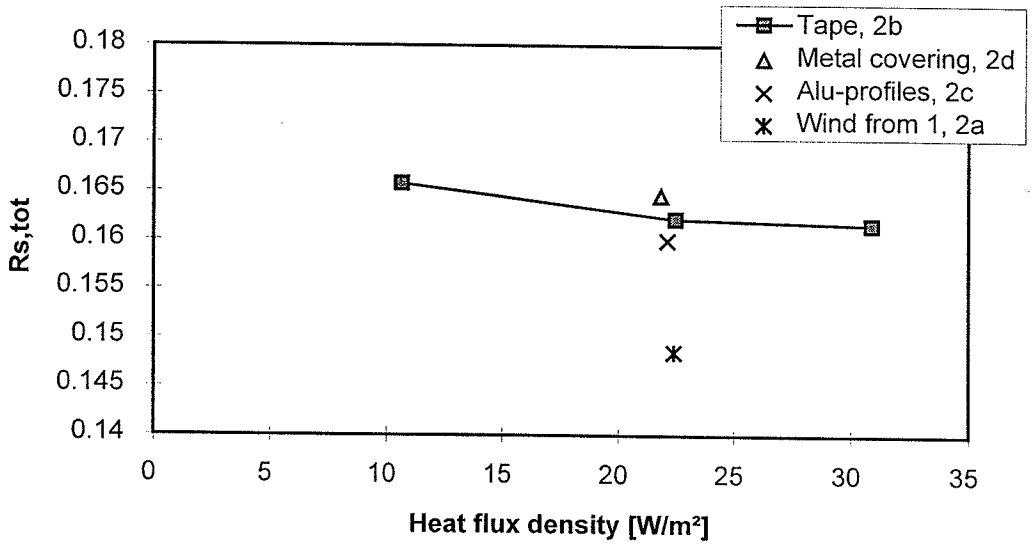

Figure 5. *Total surface resistance versus heat flux density. Calibration step 2.*

6 U-VALUE MEASUREMENTS

6.1 Mounting of the window

The window was mounted in the hot box aperture with the frame inserted 22 mm into the surround panel and the rest of the window exposed to the cold side ambient. The interface between the surround panel and the window was taped on both warm and cold side to secure that no air could penetrate the interface. The parts of the window that can be opened were taped on the warm side only. The U-value of the window was found with the metal covering mounted on the cold side, see figure 6.

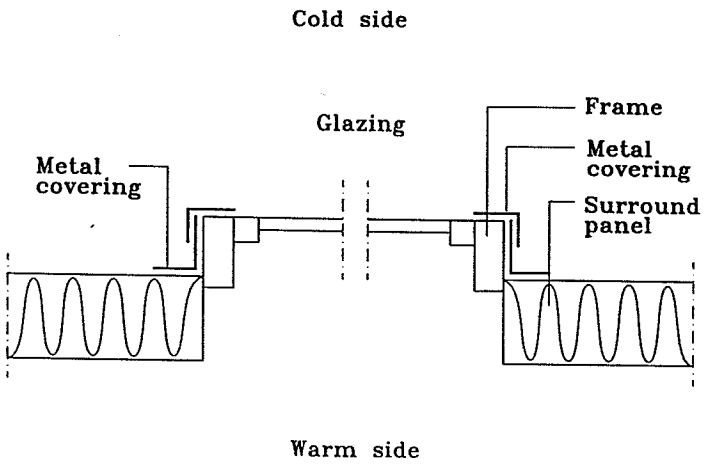

Figure 6. Mounting of the window including metal covering on the cold side.

6.2 Sensor locations

Nine thermocouples were mounted on each side of the window measuring the surface temperature of the glazing part of the window and additional seven sensors were used to measure the surface temperature of the warm side of the wooden frame.

6.3 Results

The following results were obtained from the U-value measurement:
(See also annex B)

Warm side:
Air temperature $\vartheta_{a,i,me}$ 20.00°C
Baffle temperature $\vartheta_{b,i,me}$ 19.77°C
Reveal temperature $\vartheta_{p,i,me}$ 18.43°C
Glazing temperature: 16.51°C
Average frame surface: 14.81°C

Cold side:
Air temperature $\vartheta_{a,e,me}$ -0.13°C
Baffle temperature $\vartheta_{b,e,me}$ 0.07°C
$\Delta T_{surround\ panel}$ 18.52°C
Glazing temperature: 1.40°C

Electrical input to warm side heater: 63.93 W

Heat flux through surround panel: 4.33 W

$q_c =$ 37.3 W/m²

$\Delta T_n =$ 19.82 K

U_m = 1.88 W/m².

ΔT_n has been calculated in accordance to ISO 12567 Annex A using the mean surface temperature of the glazing in the window as the sample surface temperature.

Due to the relatively large thermal resistance of the calibration panel the R_s-curve in figure 5 does not cover the actual heat flux density from the U-value measurement. However the slope of the curve is decreasing with increasing heat flux density and from an extrapolation of the curve in figure 5, the total surface resistance coefficient during the U-value measurement is estimated to:

$R_{s,tot} = 0.161$ m²K/W

Now the standard U-value can be found from the following expression:

$U_{st} = [1/U_m + 0.17 - R_{s,tot}]^{-1}$

U_{st} = 1.85 W/m²K

ANNEX A
Calibrations

Calibration

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0006	0.2758	17.2966	1.54675	19.7315	0.44469	18.6671	0.82747	18.6311

Panel temperature 9.42165
Panel resistance: 0.71463

Power input
39.5309

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.4	1.14	0.142	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.11121	0.05604	0.16725	0.23382	22.0392	10.143

First calibration in step 1

Calibration

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0009	-5.1153	16.6093	-3.4973	19.6659	-4.9127	18.3581	-4.4256	23.7277

Panel temperature 6.55603 °C

Panel resistance: 0.72096 m2K/W

Power input
50.8443

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.4	1.14	0.142	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.1105	0.05655	0.16705	0.26695	27.8886	7.43826

Second calibration in step 1

Calibration

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0002	10.593	18.6135	11.2187	19.8328	10.7106	19.2728	10.872	8.86233

Panel temperature 14.9161
Panel resistance: 0.7028

Power input
18.8371

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.4	1.14	0.142	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.117	0.05679	0.17379	0.23064	10.522	15.3031

Third calibration in step 1

Calibration

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0017	-0.3102	17.0418	0.81198	19.7822	-0.1695	16.98	0.20849	19.2699

Panel temperature 8.92687 °C

Panel resistance: 0.71571 m2K/W

Power input
59.3326

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.215	0.99	0.37	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.09871	0.04836	0.14707	1.66354	22.6764	9.84346

Calibration 2a (step 2)

Calibration

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0015	-0.3278	17.0626	0.98036	19.7819	-0.1711	17	0.28805	19.1847

Panel temperature 9.02147
Panel resistance: 0.71551 m2K/W

Power input
58.3026

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.4	1.14	0.262	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.10543	0.05671	0.16214	1.16915	22.4767	9.88039

First calibration in calibration serie 2b (step 2)
(obtaining correct surface resistance)

Calibration

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0002	-8.2164	16.0166	-6.3808	19.7224	-8.0289	15.64	-7.3902	26.6382

Panel temperature 4.8179 °C

Panel resistance: 0.72486 m2K/W

Power input
81.5655

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.4	1.14	0.262	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.10341	0.05819	0.16159	1.21069	30.899	5.9289

Second calibration in calibration serie 2b (step 2)

Kalibrering

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0012	10.3861	18.5123	11.0224	19.8655	10.4974	18.35	10.6911	9.07853

Panel temperature 14.7674

Power input 27.269

Panel resistance: 0.70311 m2K/W

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.4	1.14	0.262	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.10859	0.05722	0.16581	1.13099	10.6525	15.2304

Third calibration in calibration serie 2b (step 2)

Calibration

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0001	0.05836	17.1008	1.29594	19.7943	0.21397	17	0.67733	18.8076

Panel temperature 9.19838

Panel resistance: 0.71512 m2K/W

Power input
57.488

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.4	1.14	0.262	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.10559	0.05455	0.16014	1.18115	22.1011	10.0811

Calibration 2c (step 2)

Calibration

Air warm	Air cold	Panel warm	Panel cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20.0006	0.19901	17.109	1.49935	19.8088	0.36692	17.03	1.25289	18.2346

Panel temperature 9.30416
Panel resistance: 0.71489 m2K/W

Power input
53.7488

Dimensions in m:

Height	Width	Reveal warm	Reveal cold
1.4	1.14	0.262	0.00001

Therm. properties of calib. panel:

lambda	0.0294
at [°C]	21
panthick	0.02
dlamd/dT	0.3

Results:

R si	R se	R s,tot	H sur	qc	Tm,surr
0.1067	0.05787	0.16457	1.03649	21.8351	10.3702

Mellemberegninger ses i faneblad benævnt "Mellemberegninger".

Calibration 2d (step 2)

ANNEX B
U-value measurement

Measured average temperatures:

Air warm	Air cold	Glazing warm	Glazing cold	Baffle warm	Baffle cold	Reveal warm	Reveal cold	Temp.dif surround
20	-0.127	16.5072	1.39962	19.7744	0.06679	18.43	0.963	18.5181

Heat flux through surround panel is (in W): 4.334

Power input
63.9284

Dimensions in m

Height	Width	Reveal varm	Reveal cold	Total Height	Total Width
1.4	1.14	0.262	0.0001	1.4	1.14

Results:

diff.Tn	Um
19.8234	1.88363

U-VALUE