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Thermal performance modelling of Gecko panels

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1 Introduction and description of work

The Building Research Establishment Limited (BRE) has been commissioned by Gecko Glazing Limited to:

(i) Estimate the U-value improvement of an example timber framed, single glazed window, when fitted with the Gecko panel secondary glazing system, and

(ii) Provide commentary on the product's potential applicability with regard to the Reduced Data Standard Assessment Procedure (RdSAP) methodology, as used for the energy performance assessment of existing homes.

The total heat loss from a window will be determined from:

- The U-value of the window frame. This is a measure of the quantity of heat that will flow through a unit area of the frame, per unit temperature difference between the internal and external environment. It is expressed in W/m²K.

- The U-value of the centre of the glazing. This is a measure of the quantity of heat that will flow through a unit area of the glass, per unit temperature difference between the internal and external environment (W/m²K.)

- The linear thermal bridges (ψ-values) which arise at junctions between different components of the connecting junctions between the frame and glazing i.e. at the window head, sill and jambs. This is a measure of additional heat losses at junctions and connections where geometric or constructional effects change the thermal behaviour. Values are multiplied by the length over which they apply. It is expressed in W/m·K.

The analysis derived a U-value for a simple solid timber frame window with single glazing of a standardised size and arrangement (i.e. 1.23m (w) x 1.48m (h) with a horizontal divider, as per the Glass & Glazing Federation Datasheet 2.2, as illustrated in Figure 1 below). Thereafter, the U-value of an equivalent window with the Gecko panel installed, was analysed to determine the relative improvement (ΔU) offered by the Gecko panel in the example case. The results are presented below.

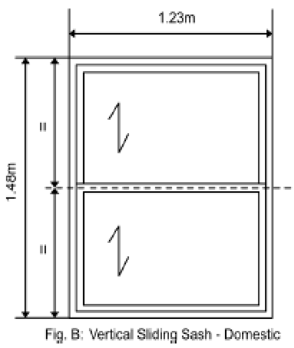

Figure 1: The window arrangement used as the basis for the analysis

1.1 Assessment standards

The assessment was undertaken in compliance with the latest versions of:

- BS EN ISO 10077-1 Thermal performance of windows, doors and shutters. Calculation of thermal transmittance. Part 1 - General
- BS EN ISO 10077-2 Thermal performance of windows, doors and shutters - Calculation of thermal transmittance. Part 2 - Numerical method for frames
- BS EN 673 – Glass in building – Determination of thermal transmittance (U-value) – Calculation method
- BS EN ISO 10211 – Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculations
- BS EN ISO 10456 – Building materials and products – Hygrothermal properties – Tabulated design values and procedures for determining declared and design thermal values
- BR 497 – Conventions for calculating linear thermal transmittance and temperature factors
- BR 443 – Conventions for U-value calculations
- SAP-2012 specification
- Draft SAP10.2 specification (referred in this report as SAP-10)

1.2 Software

The frame U-values and ψ-values were calculated using Physibel's TRISCO thermal modelling software. TRISCO has been validated against the detailed test reference cases contained within Annex A of the published standard ISO 10211.

The BRE U-value calculator was used for calculating the U-value of centre pane and the U-value of the whole window.

1.3 Geometry

For the models, the geometry was taken from drawings provided by the client, as indicated in Appendix A.

1.4 Temperatures and surface resistances used in models

The following parameters were used as the basis for the models:

Internal temperature = 20ºC
External temperature = 0ºC

The surface resistances used for thermal models were as follows:

Internal, horizontal heat flow	= 0.13 m^2K/W
Internal, upward heat flow	= 0.10 m^2K/W
Internal, downward heat flow	= 0.17 m^2K/W
External heat flow, exposed areas	= 0.04 m^2K/W

1.5 Thermal conductivities

The representative thermal conductivities used in the models were taken from BS EN ISO 10456:2007 based on the materials advised by the client, as detailed in Table 1. All air gaps within the construction were calculated according to BS EN ISO 6946. The colours used in the table correspond to the materials shown in the graphical representation results diagrams, as presented in Annexe B (any additional colours that are present in the diagrams but that are not represented in the table below represent calculated air gaps).

Table 1: Representative thermal conductivities

Material	Thermal conductivity (W/m·K)	
Timber	0.13	
Glass	1.00	
Polymethylmethacrylate (PMMA, acrylic)	0.18 - 0.20	
Polycarbonate (PC)	0.20	
Ethylene propylene diene monomer (EPDM)	0.25	

2 Assessment results

2.1 Parameters of the single glazed window

Although the frame arrangement at the head, sill and jamb of the window is assumed to be unchanged, the relative orientation of each element introduces minor differences in the heat loss of each section of frame due to differing surface resistances. Three separate frame U-value and connection ψ-values have therefore been determined to support the assessment of the U-value of the whole window. These have been calculated according to the procedure in BS EN 10077-2 and are presented in Table 2.

The U-value of a centre pane glass is calculated using BRE U-value calculator; the calculation is based on the results of numerical modelling of U-values and ψ-values shown in Table 2 and is calculated in accordance with BS EN 673 and BS EN ISO 10077-1. Please refer to Appendix C for the details of the calculation of centre pane U-value.

Table 2: U-values and ψ-values for the reference single glazed window

Frame section	Glass centre-pane U-value, Ug, excluding frame, W/m^2K	Frame U-value, Uf, W/m^2K	Frame-glazing connection ψ-value, ψf, W/m^2K
Head	5.747 (Glass, singe)	2.42	0.027
Sill		2.29	0.021
Jamb		2.35	0.024

2.2 Parameters of the single glazed window with fitted Gecko panel

As with the window above, separate models were developed for the window head, sill and jamb but with the inclusion of the Gecko panel. Since the Gecko panel sits entirely within the area of the glazing, the frame U-values are taken to be the same as the baseline case, with the effect of the Gecko panel fixings allowed for in the respective frame-glazing connection ψ-values. The centre pane glazing U-value is also improved due to the presence of the secondary glazing. U-value and ψ-values for the Gecko panel example are presented in Table 3.

The U-value of a centre pane comprising a single glass (4mm thick, λ=1.0 W/m·K), 12 mm air gap and 2 mm polycarbonate (λ=0.20 W/m·K) or 2 mm polymethylmethacrylate (PMMA) (λ=0.18 W/m·K) was calculated using BRE U-value calculator; the calculation is based on the results of numerical modelling of U-values and ψ-values shown in Table 2, as calculated in accordance with BS EN 673 and BS EN ISO 10077-1. Please refer to Appendix B for representative images from the thermal calculations, and Appendix C for the details of the calculation of centre pane U-value.

Table 3: U-values and ψ-values for the single glazed window with the secondary glazing Gecko panel made of Polycarbonate or PMMA (12 mm air gap).

Frame section	Centre-pane U-value, Ug, W/m²K excluding frame	Frame U-value, Uf, W/m²K	Frame-glazing connection ψ-value, ψf, W/m²K
Head	2.801 (Polycarbonate) 2.792 (PMMA)	2.42	0.013
Sill		2.29	0.014
Jamb		2.35	0.013

2.3 The approach to establishing U-values with and without the Gecko panel

The U-value is that of the complete window or roof window, including the glazing and the frame.

The U-value of a window depends on:

(i) the U-value of the glazing (or other translucent material (centre-pane U-value)),

(ii) the U-value of the frame, and

(iii) the linear thermal transmittance of the junction between the glazing and the frame (which includes the effect of glazing spacers).

The thermal transmittance of the glazing is calculated using BS EN 673 for establishing the U-value of centre panel, and the linear thermal transmittance of the frame and frame/glazing junction is calculated according to BS EN ISO 10077-2.

As the thermal performance of glazing and frames are generally different, the U-value of a window depends on its size and configuration. Preferably, U-values should be based on the actual windows to be used in the building. Alternatively, a U-value can be established to represent all the windows in a dwelling using a ‘standard’ window i.e. 1.48 m high by 1.23 m wide, as defined by the Glass and Glazing Federation (GGF).

The U-value of windows with secondary glazing can be obtained using the procedure for a "double window" in BS EN ISO 10077-1, provided that the space between the main window and the secondary glazing is unventilated and the thermal transmittance of their frame sections is determined by measurement or by numerical calculation. If either of the gaps between the frames exceeds 3 mm, and measures have not been taken to prevent excessive air exchange with external air, the method does not apply.

Appendix C gives the details of the calculations of U-values for a whole window.

Table 4 gives the calculated overall window U-value for a ‘standard’ size window both with and without the Gecko panel.

The modelling suggests that the inclusion of the Gecko panel as secondary glazing, on this configuration of window, improves the U-value by approximately by 48% (almost by a factor of 2) compared to the baseline single glazed window.

Table 4: U-values for windows 1.23m x 1.48m without and with Gecko panel.

Window	The whole window U-value, Uw (W/m^2K) including the glazing and the frame, 12 mm gap
Single Glazed	5.367 (rounded to 5.4)
Secondary glazed with Gecko panel (Polycarbonate, λ=0.20 W/m·K)	2.793 (rounded to 2.8)
Secondary glazed with Gecko panel (PMMA, λ=0.18 W/m·K)	2.786 (rounded to 2.8)
Difference, ΔU	2.6

The modelling suggests that installing Gecko panels (made of clear polycarbonate or PMMA) installed on single-glazed sash windows can significantly improve the thermal performance of the window (as modelled). The modelled and calculated U-value being very close to the U-value of air-filled double-glazed window in this example.

Gecko panels (made of clear polycarbonate or PMMA) could therefore potentially be useful, low-cost, alternatives to double-glazed windows due to their good thermal properties and transparency. That said, it is recommended that additional investigation be undertaken in relation to other key parameters that were out with the scope of this study e.g. the durability, strength, fire resistivity, etc.

2.4 Method for calculating the overall U-value for a window of any size

The values in Table 4 were assessed for a ‘standard’ window of 1.23m (width) x 1.48m (height) as defined by the GGF.

The overall U-value of a window of other dimensions can be calculated using the following formula, where both U-values and ψ-values of the frames are available, and U-value of centre pane is calculated.

The calculation can be completed by using the following equation:

$$Uw = \frac{(Ug \times Ag) + \sum(Uf \times Af) + \sum(\psi f \times Lf)}{Aw}$$

Where:
Uw = U-value of the whole window
Ug = U-value of the glazing (centre pane)
Uf = U-value of the respective frame components; i.e. the head, sill and jamb
ψf = ψ-value of the respective frame-glazing connections, i.e. at head, sill and jamb
Aw = Area of the whole window
Ag = Visible area of the glazing
Af = Visible area of the respective frame components, i.e. the head, sill and jamb
Lf = Length of the respective frame-glazing connections, i.e. at head, sill and jamb

Note that respective Uf and Af values need to first be multiplied together (i.e. U_{head} x A_{head}), before the resulting heat losses are summed. The same applies to the ψ-values and their respective lengths.

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3 Considerations in the context of RdSAP and EPCs

3.1 Compliance of results with ISO Standards, BR 443 and SAP

The SAP-2012 and RdSAP-2012 default for single glazed window is U=4.8 W/m^{2}K (SAP-2012 Table 6e and Table S14 respectively), which is lower than the baseline case determined in this study of 5.4 W/m^{2}K assessed for the sash windows with the specified dimensions. The higher value in RdSAP is due to the use of a standardised frame factor, FF=30%, according to Table 6c in the SAP-2012 specification.

The secondary glazing default value in RdSAP-2012 is U=2.4 W/m^{2}K, regardless of the fenestration material, thickness of air gap, configuration and frame type. However, this default has been revised and thus will not be applicable in SAP-10 or RdSAP-10 versions. Table 5 shows the default values for secondary glazing in the SAP-10 specification.

Table 5: RdSAP-10 secondary glazing default U-values

	6 mm gap	12 mm gap	16+ mm gap
U-value of a single window with secondary glazing	3.3 W/m^{2}K	3.0 W/m^{2}K	2.9 W/m^{2}K

It is worth noting that SAP-10 is introducing U-values for secondary glazing that include either glass or clear polycarbonate. Thus, once SAP-10 / RdSAP-10 is formally introduced assessors will be able to utilise the values as defined in the forthcoming SAP-10 specification.

This study confirms that the U-value for standard single glazed window with secondary glazing by Gecko panel (U=2.8 W/m^{2}K) is better than the default U-value for secondary glazed window in the SAP-10 update. The difference between the SAP-10 default values and the calculated U-values of single glazed sash windows fitted with Gecko panels is due to better thermal performance of polycarbonate or PMMA in comparison with the glass.

3.2 Potential Impact of Gecko panels on SAP and EPC ratings

The impact of installing Gecko secondary glazing on SAP ratings and CO_2 emissions depend on many site specific variables (which will vary significantly from dwelling to dwelling) including the fraction of window area versus the total floor area, the built form, and the level of heat loss via building elements, etc. This section presents the results of some simplified RdSAP calculations to give an indication of the potential impact of Gecko panels on SAP rating and EPC rating, however a site specific assessment should be undertaken to assess the potential impact accurately and robustly.

Example 1a: a 77.4 m^2 top floor flat with a window area of 17.5% of total floor area, uninsulated stone walls, heated by a regular 90% efficient gas boiler; windows are North facing.

Table 6: Simplified RdSAP assessment showing SAP rating, EPC band and CO_2 emissions for the ‘Example 1a’ dwelling.

Window U-value, W/m^{2}K	SAP rating	EPC band	CO_2, t/year
5.4 (assessed for this study for sash window with frame dimensions as given in Appendix A)	69.31	C	3.1
2.8 (assessed for this study for sash window with Gecko secondary glazing)	71.35	C	2.8

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Example 1b: the same flat with an increased window area 25% of total floor area:

Table 7: Simplified RdSAP assessment showing SAP rating, EPC band and CO_2 emissions for the 'Example 1b' dwelling.

Window U-value, W/m²K	SAP rating	EPC band	CO_2, t/year
5.4 (assessed for this study for sash window with frame dimensions as given in Appendix A)	68.48	D	3.2
2.8 (assessed for this study for sash window with Gecko secondary glazing)	71.37	C	2.8

In the above case there is an increase of 2.89 SAP points.

Example 2: a 148 m² detached house built with window area of 25% of total floor area, uninsulated stone walls, heated by regular 84% efficient gas boiler:

Window U-value, W/m²K	SAP rating	EPC band	CO_2, t/year
5.4 (assessed for this study for sash window with frame dimensions as given in Appendix A)	50.54	E	6.22
2.8 (assessed for this study for sash window with Gecko secondary glazing)	53.26	E	5.86

In the above case there is an increase of 2.72 SAP points.

Note: the above examples provide some simplified examples for illustrative purposes only and actual results will vary significantly based on an individual dwelling specification. Also, the SAP increase may be smaller when the assessment is based on the default U-values for typical windows. Furthermore, while one of the above examples shows an improvement in EPC band this may not always be the case and a site specific assessment would need to be undertaken to asset the potential impact.

4 Conclusion

This report includes an assessment of the U-value for a 'standard' size (as defined by the Glass and Glazing Federation i.e. 1.48 m high by 1.23 m wide) single glazed timber sash window when fitted with a Gecko panel secondary glazing system comprising the dimensional details presented in Appendix A (i.e. a 12 mm air gap and corresponding dimensions of the frame) and made of clear Polycarbonate or PMMA.

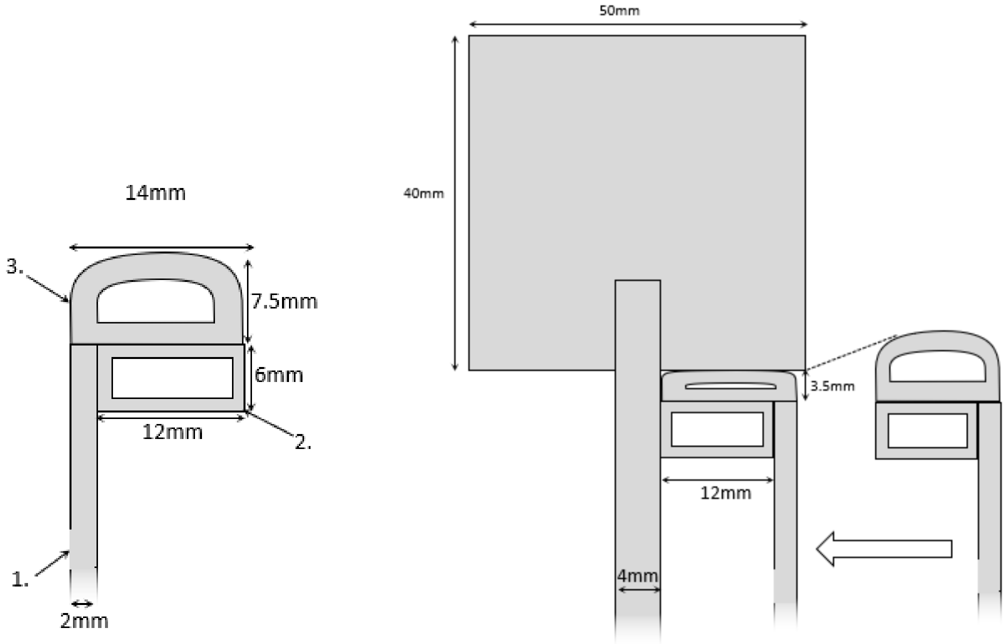
Thermal modelling of a typical sash window frame and consequent U-value calculation (with and without the Gecko panel) has demonstrated that the U-value for the 'standard' window case was reduced from U=5.4 W/m^2K (without the secondary Gecko panel) to U=2.8 W/m^2K (with the secondary Gecko panel) which is a significant reduction of heat loss. While it did not form part of this study, it is likely that increasing the air gap, for example to 16-20mm, could potentially improve the thermal performance further.

The analysis suggests that Gecko panels installed on the types and size of windows, as modelled, can significantly improve the thermal performance of the window. With the resulting U-value being close to the U-value of air-filled double-glazed window Gecko panels could therefore be a useful low-cost alternative to double-glazed windows for this application when considered from a purely thermal performance perspective.

The assessment of other important aspects (such as durability, strength, fire resistivity, etc.) were out with the scope of this study.

Appendix A: Client drawings

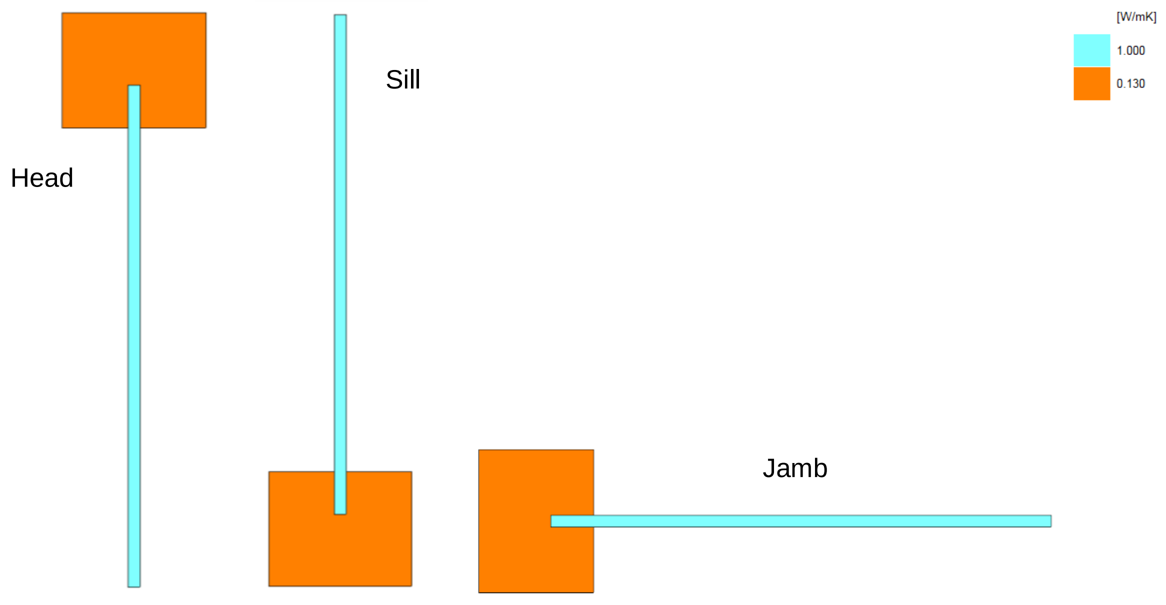
Gecko panel frame arrangement (left) and installation in sample single glazed window frame (right)



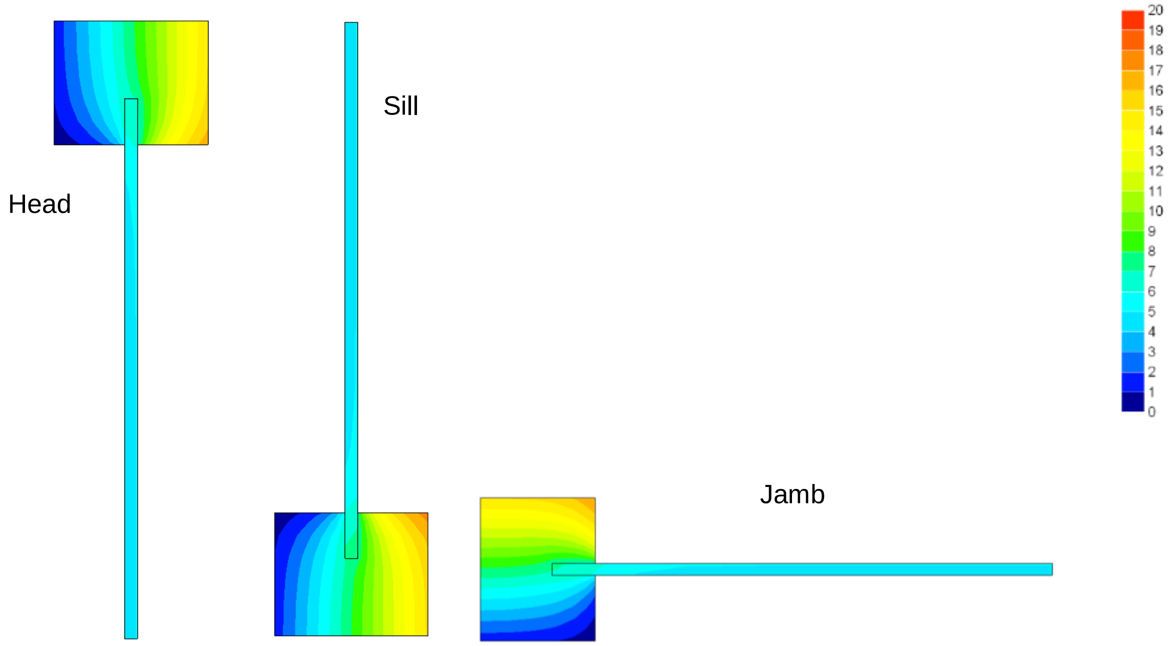
Appendix B: Thermal calculations – Graphical representations

Single glazed window

Materials

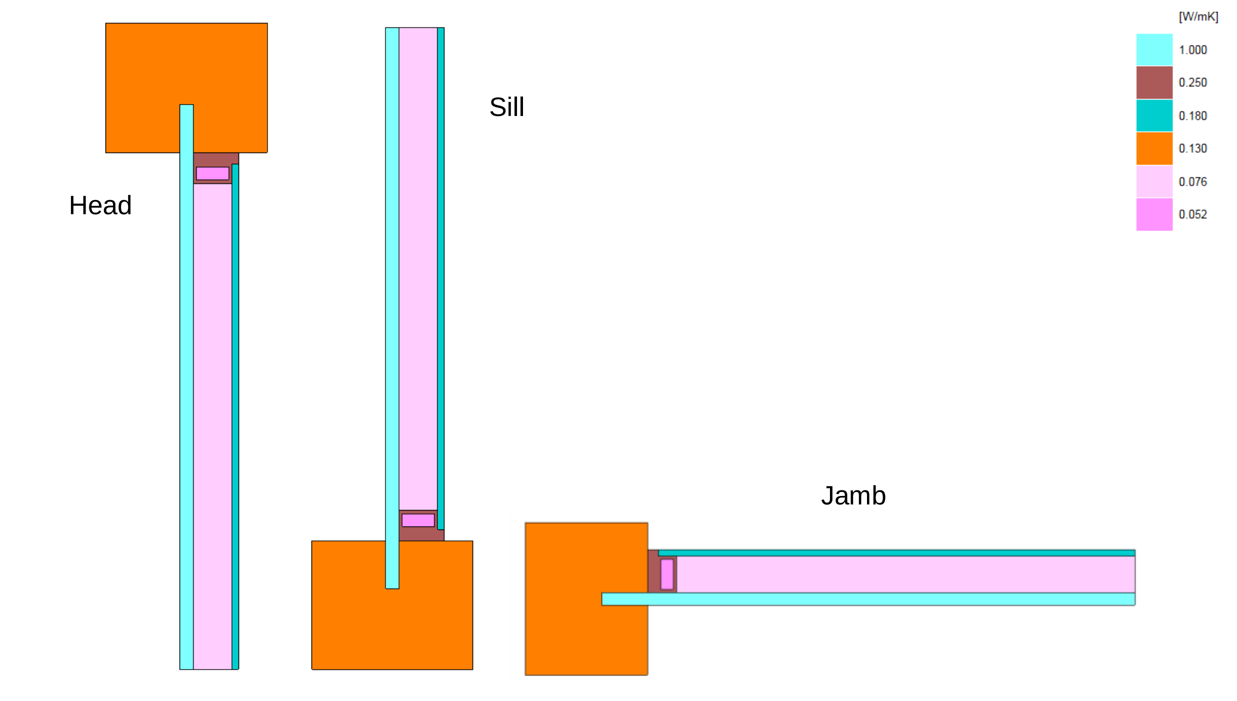


Temperature profile

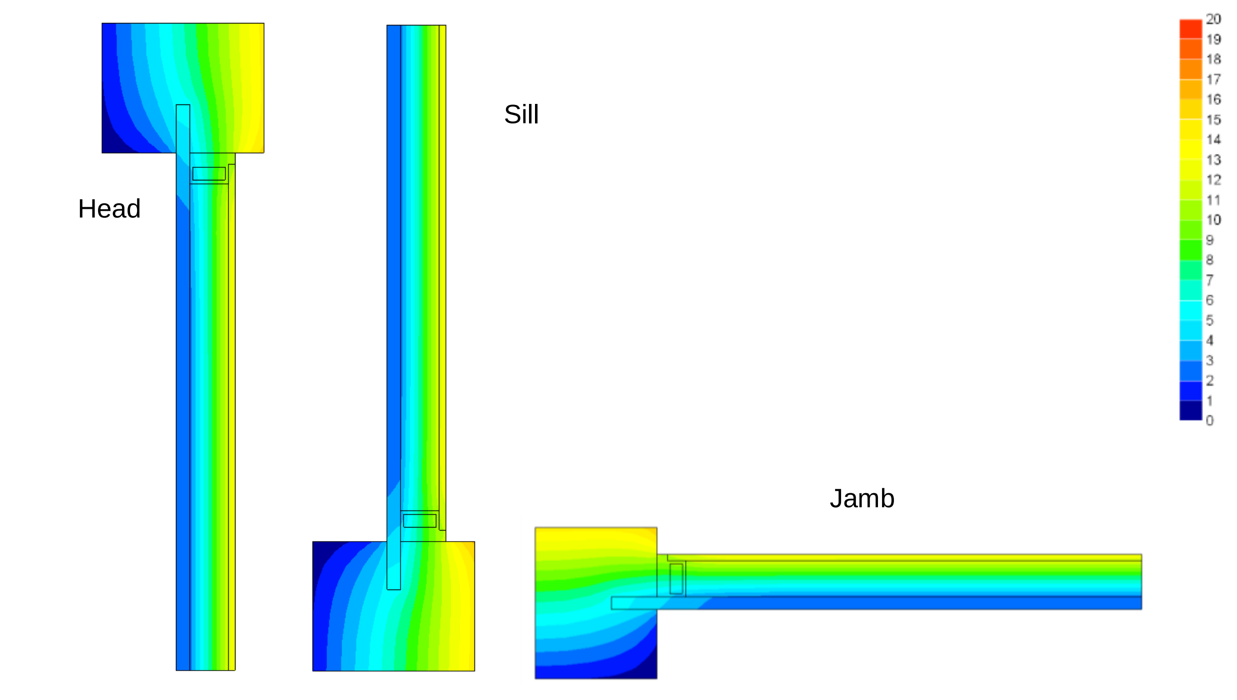


Single glazed window with Gecko panel

Materials



Temperature profile



Appendix C: Details of calculating U-values

Element type: Window - Wooden frame - Single glazed
Calculation Method: BS EN 673, BS EN ISO 10077-1 and -2

Window height:	1480 mm	
Window width:	1230 mm	
Horizontal divider:	height of top part (from edge of window to centre of divider):	615 mm
	height of bottom part (from centre of divider to edge of window):	865 mm
Angle to horizontal:	90° (vertical window)	

Glazing

Glazing U-value calculated by method in BS EN 673

Layer	d (mm)	λ glass	emiss.1	emiss.2	gas	% fill	R layer	Description
							0.130	Rsi
1	4	1.0					0.004	Glass
							0.040	Rse
	4 mm (total glazing thickness)						0.174	

Glazed area: 1.564 m²
Centre-pane U-value: 5.747 W/m²K

Frame	Top part	Divider	Bottom part	
Frame width:	40	40	40	mm
Frame area:	0.094	0.049	0.114	m²
Frame U-value:	2.420	2.290	2.350	W/m²K (numerical calculation)
Frame/glazing				
Glazing perimeter:	2260	2300	2760	mm
Linear Ψ-value:	0.027	0.021	0.024	W/m·K (numerical calculation)

Window area: 1.82 m², Glazed area: 1.56 m² (85.9%), Frame area: 0.26 m² (14.1%)

U-value 5.367
U-value (rounded) 5.4 W/m²K (applicable for the whole window including flame and glazing)

Element type: Window - Wooden frame – Secondary Glazing (Polycarbonate)
Calculation Method: BS EN 673, BS EN ISO 10077-1 and -2

Window height:	1480 mm	
Window width:	1230 mm	
Horizontal divider:	height of top part (from edge of window to centre of divider):	615 mm
	height of bottom part (from centre of divider to edge of window):	865 mm
Angle to horizontal:	90° (vertical window)	

Glazing
Glazing U-value calculated by method in BS EN 673

Layer	d (mm)	λ glass	emiss.1	emiss.2	gas	% fill	R layer	Description
							0.130	Rsi
1	4	1.0					0.004	Glass
2	12		0.890	0.890	Air		0.173	Gas space
3	2	0.2					0.010	PC
							0.040	Rse
	18 mm (total glazing thickness)						0.357	

Glazed area: 1.564 m²
Centre-pane U-value: 2.801 W/m²K

Frame	Top part	Divider	Bottom part	
Frame width:	40	40	40	mm
Frame area:	0.094	0.049	0.114	m²
Frame U-value:	2.420	2.290	2.350	W/m²K (numerical calculation)
Frame/glazing				
Glazing perimeter:	2260	2300	2760	mm
Linear Ψ-value:	0.013	0.014	0.013	W/m·K (numerical calculation)

Window area: 1.82 m², Glazed area: 1.56 m² (85.9%), Frame area: 0.26 m² (14.1%)

U-value 2.793
U-value (rounded) 2.8 W/m²K

Element type: Window - Wooden frame - Secondary glazed PMMA
Calculation Method: BS EN 673, BS EN ISO 10077-1 and -2

Window height:	1480 mm	
Window width:	1230 mm	
Horizontal divider:	height of top part (from edge of window to centre of divider):	615 mm
	height of bottom part (from centre of divider to edge of window):	865 mm
Angle to horizontal:	90° (vertical window)	

Glazing
Glazing U-value calculated by method in BS EN 673

Layer	d (mm)	λ glass	emiss.1	emiss.2	gas	% fill	R layer	Description
							0.130	Rsi
1	4	1.0					0.004	Glass
2	12		0.890	0.890	Air		0.173	Gas space
3	2	0.18					0.011	PMMA
							0.040	Rse
	18 mm (total glazing thickness)						0.358	

Glazed area: 1.564 m²
Centre-pane U-value: 2.792 W/m²K

Frame	Top part	Divider	Bottom part	
Frame width:	40	40	40	mm
Frame area:	0.094	0.049	0.114	m²
Frame U-value:	2.420	2.290	2.350	W/m²K (numerical calculation)
Frame/glazing				
Glazing perimeter:	2260	2300	2760	mm
Linear Ψ-value:	0.013	0.014	0.013	W/m·K (numerical calculation)

Window area: 1.82 m², Glazed area: 1.56 m² (85.9%), Frame area: 0.26 m² (14.1%)

U-value 2.786
U-value (rounded) 2.8 W/m²K