

# Module 3.4

## Calculation of U-value Construction with thermal bridging

# Learning Outcomes

- On successful completion of this module learners will be able to
  - Describe the procedure for the calculation of U-values for constructions with thermal bridging.

# Forward.

- This document uses extracts from, and makes references to, EN ISO 6946 : 2007  
Building components and building elements -  
Thermal resistance and thermal transmittance -  
Calculation method.
- The content of this document is not a substitute for the standard. To properly apply the standard one must have the complete document.
- Standards available from [www.iso.org](http://www.iso.org).

# Introduction to thermal bridging.

- Thermal bridging occurs in building envelopes when materials with high thermal conductivity, such as steel and concrete, create pathways for heat loss that bypass thermal insulation.
- When these poor insulating materials provide an uninterrupted “short circuit” between the interior and exterior of a building, the thermal bridge can result in
  - a) accelerated heat loss through that area,
  - b) localised cold spots on the interior of a wall that may cause a risk of condensation.
- This effect is most significant in cold climates during the winter when the indoor-outdoor temperature difference is **greatest**. Reference: <http://wiki.aia.org/WikiPages/ThermalBridging.aspx>

- continued.
- Thermal bridging can also occur in building envelopes when gaps or breaks in the insulation envelope create pathways for heat loss that bypass thermal insulation.
- The reduced or missing insulation can allow warm inside air make contact with cold external surfaces.
- This bypass of the insulation will also cause accelerated heat loss through that area, and localised cold spots on the interior.

# Identification of thermal bridging.

- Take any heat loss surface, i.e. floor, wall, roof, etc.
- Thermal bridging must be considered if there is more than one possible heat flow path through that surface.
- Typical construction details around doors and windows are treated separately. They are not included when calculating thermal bridging for that wall.
- If the thermal bridge allows for two or more possible heat flow paths, in the main body of the floor, wall, roof, etc. then its effect must be considered.

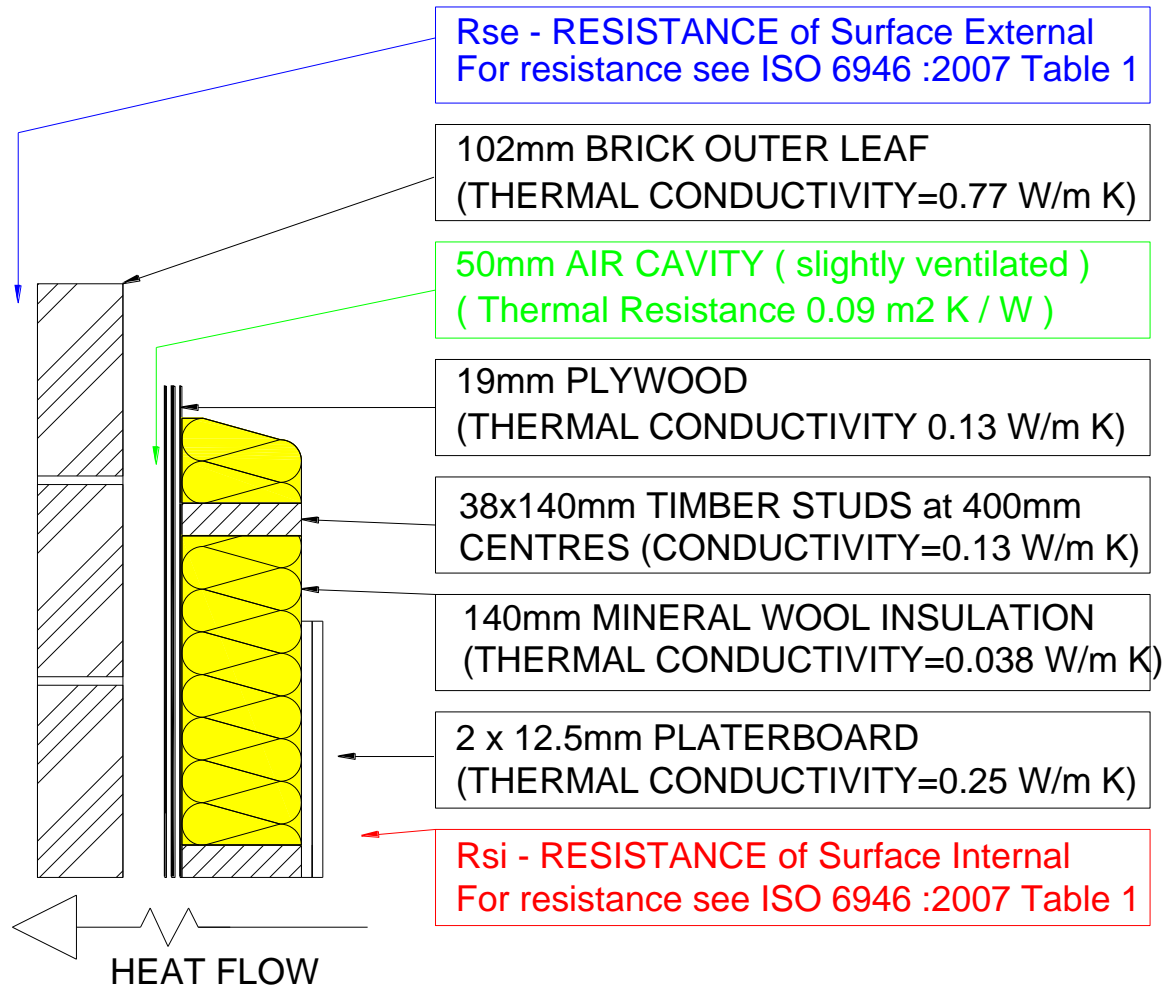
– continued.

- Take heat loss through the timber frame construction show on the next page.
- One resistance layer is made up of two very different materials, timber and mineral wool insulation.
- The poor insulator, timber, provides an uninterrupted “short circuit” through the insulation, between the interior and exterior of a building.
- The timber create pathways for heat loss that bypass the insulation.
- This reduces the effectiveness of the insulation and its effect must be included in the calculation of the U-value of the wall.

# Procedure for Calculation of U-value

## – Thermal bridging

TIMBER  
FRAMED  
WALL  
(Plan view)





## - Procedure continued.

- For a thermally bridged construction, the U-value is calculated following five steps.

Reference – Examples of U-value calculations using BS EN ISO 6946:1997.

- Step 1 – Calculate Upper resistance limit ( $R_{upper}$ )
- Step 2 – Calculate Lower resistance limit ( $R_{lower}$ )
- Step 3 – Calculate Total thermal resistance ( $R_T$ )
- Step 4 – Calculate corrections / adjustments for
  - a) air gaps penetrating the insulation.
  - b) mechanical fixings penetrating the insulation.
- Step 5 – Calculate the final U-value by allowing for corrections.

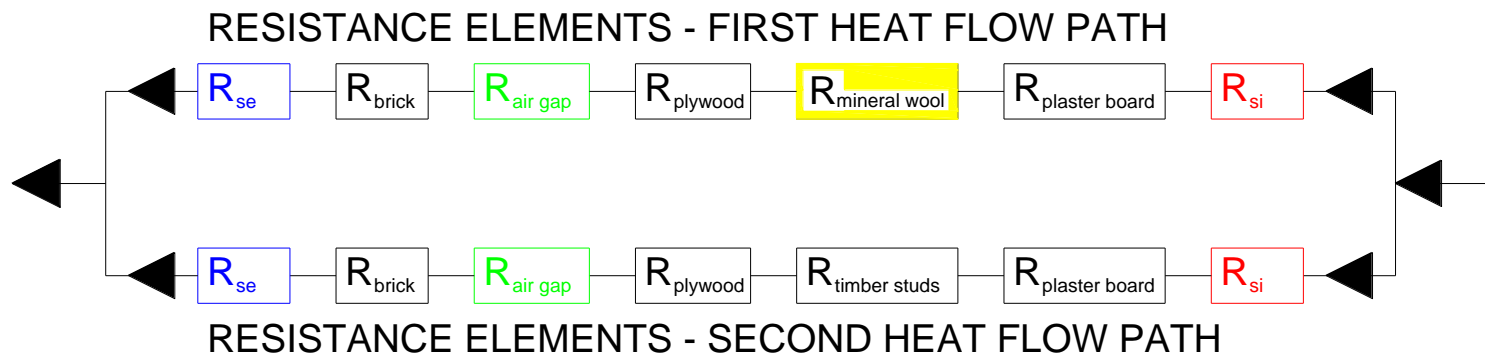
# - Procedure continued.

- Step 1.

Calculate the upper resistance limit ( $R_{upper}$ )

This is done by combining, in parallel, the total resistances of all possible heat flow paths

(i.e. sections) through the sample construction on the previous pages.

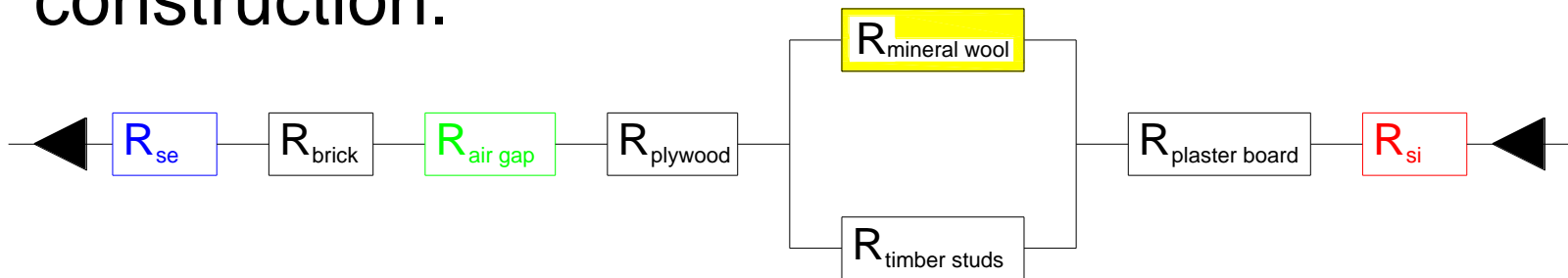


- Procedure continued.

- Step 2.

Calculate the lower resistance limit ( $R_{lower}$ )

This is done by combining, in parallel, the resistances of the heat flow paths of each layer separately and then summing the resistance of all layers (i.e. sections) through the given construction.



- Procedure continued.

- Step 3.

Calculate the total thermal resistance ( $R_T$ )

This is done using

$$R_T = \frac{R_{\text{upper}} + R_{\text{lower}}}{2}$$

## - Procedure continued.

- Step 4

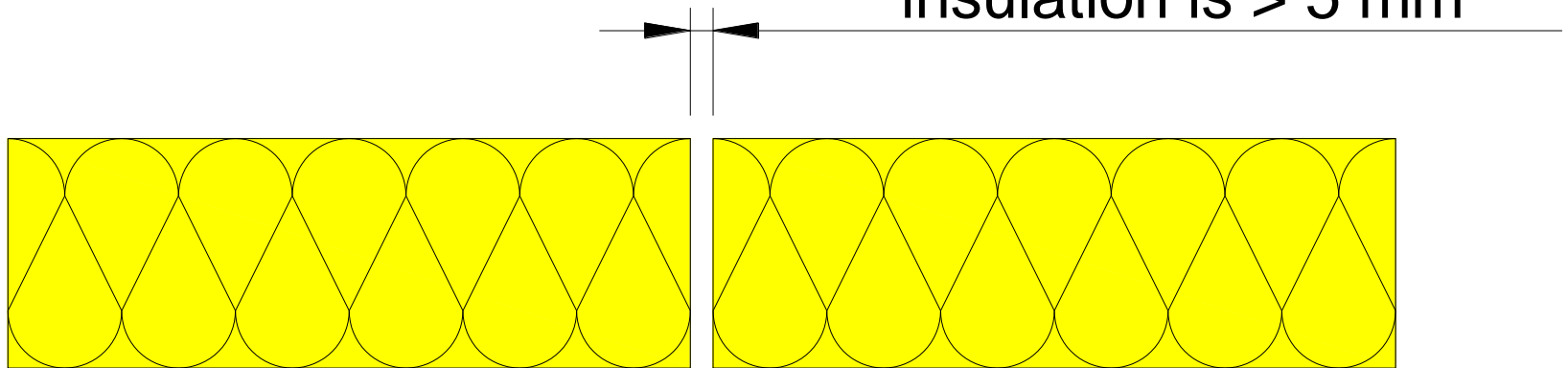
Procedure - Calculate, where appropriate,

- a) corrections for air gaps (  $\Delta U_g$  ) in the insulation layer.
- b) correction for mechanical fasteners (  $\Delta U_f$  ) in the insulation layer.

Note: Procedures for corrections may vary between countries. One procedure is described in BRE442 – Conventions for U-value calculations, 2006, sections 4.9.1, 4.9.2 and 4.9.3.

# Procedure – continued.

BRE 443 suggests that correction for air gap must be considered if gap in insulation is  $> 5$  mm



# Procedure – continued.

- BRE443 section 4.9.2 and 4.9.3 suggests that the effect of wall ties is negligible in an un-insulated cavity, and in any cavity if plastic ties are used.
- Otherwise the effect of wall ties needs to be considered.
- The correction requires knowledge of the thermal conductivity of the ties, their cross-sectional area, and the number per square metre of wall.
- For detailed procedure see BRE442 – Conventions for U-value calculations, 2006, sections 4.9.2 and 4.9.3.

- Procedure continued.

- Step 5

Calculate the final U-value from,

$$U = ( 1 / R_T ) + \Delta U_g + \Delta U_f$$

Note:  $\Delta U_g$  and  $\Delta U_f$  can be omitted,  
if taken together,

they amount to less than 3% of the U-value  
found from  $U = 1 / R_T$



# Example - Step 1 – Calculating $R_{\text{upper}}$

- Procedure.  
Combining, in parallel, the total resistances of all possible heat flow paths (i.e. sections) through the given timber frame construction
- For this construction shown on the preceding sketch, thermal bridging occurs only at one layer, that is the layer made up partly of 38 x 140mm timber and partly by 140mm mineral wool.

## Example Step 1 - $R_{\text{upper}}$ – continued.

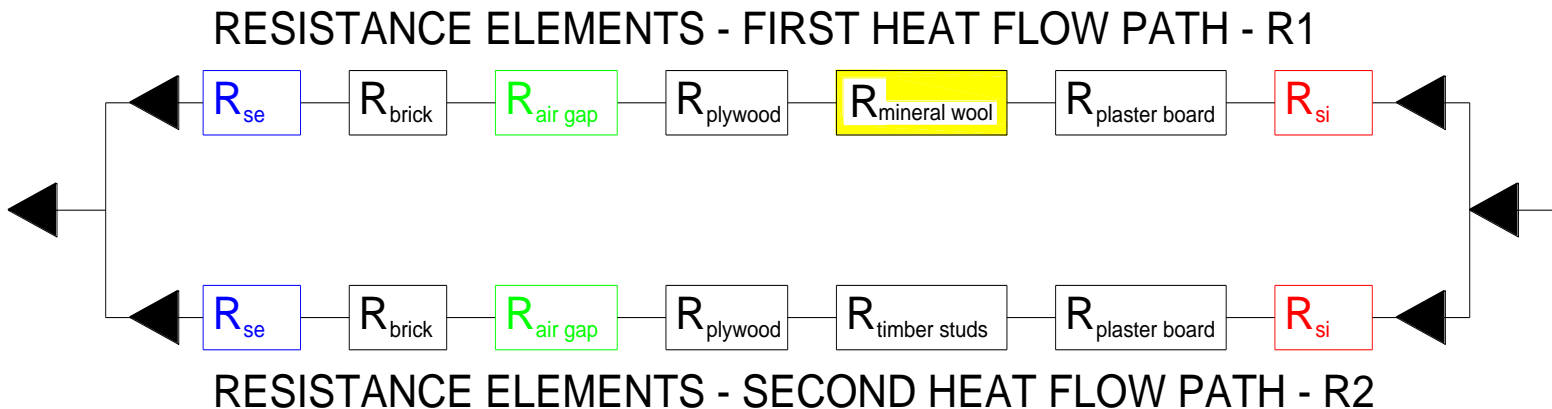
- For this construction there are two possible heat flow paths, between inside and outside.
- First heat flow path is through the insulation, i.e.
  - 2 x 12.5mm plasterboard
  - + 140mm mineral wool insulation
  - + 19mm plywood
  - + 50mm slightly ventilated air cavity
  - + 102mm brick outer leaf.

## Example Step 1 - $R_{\text{upper}}$ – continued.

- Second heat flow path is through the timber, i.e.
  - 2 x 12.5mm plasterboard
  - + 38 x 140mm timber studs
  - + 19mm plywood
  - + 50mm slightly ventilated air cavity
  - + 102mm brick outer leaf.

# Example Step 1 - $R_{upper}$ – continued.

- The two parallel heat flow paths are shown conceptually below.



Since the relative cross sectional area of the timber is not the same as that of the mineral wool insulation, the fractional areas of each must be considered when calculating  $R_{upper}$ .

# Example Step 1 - $R_{\text{upper}}$ – continued.

- The upper limit of resistance is calculated from

$$R_{\text{upper}} = \frac{1}{\frac{F_1}{R_1} + \frac{F_2}{R_2}}$$

$F_1$  = the fractional area of first (insulation) heat loss path

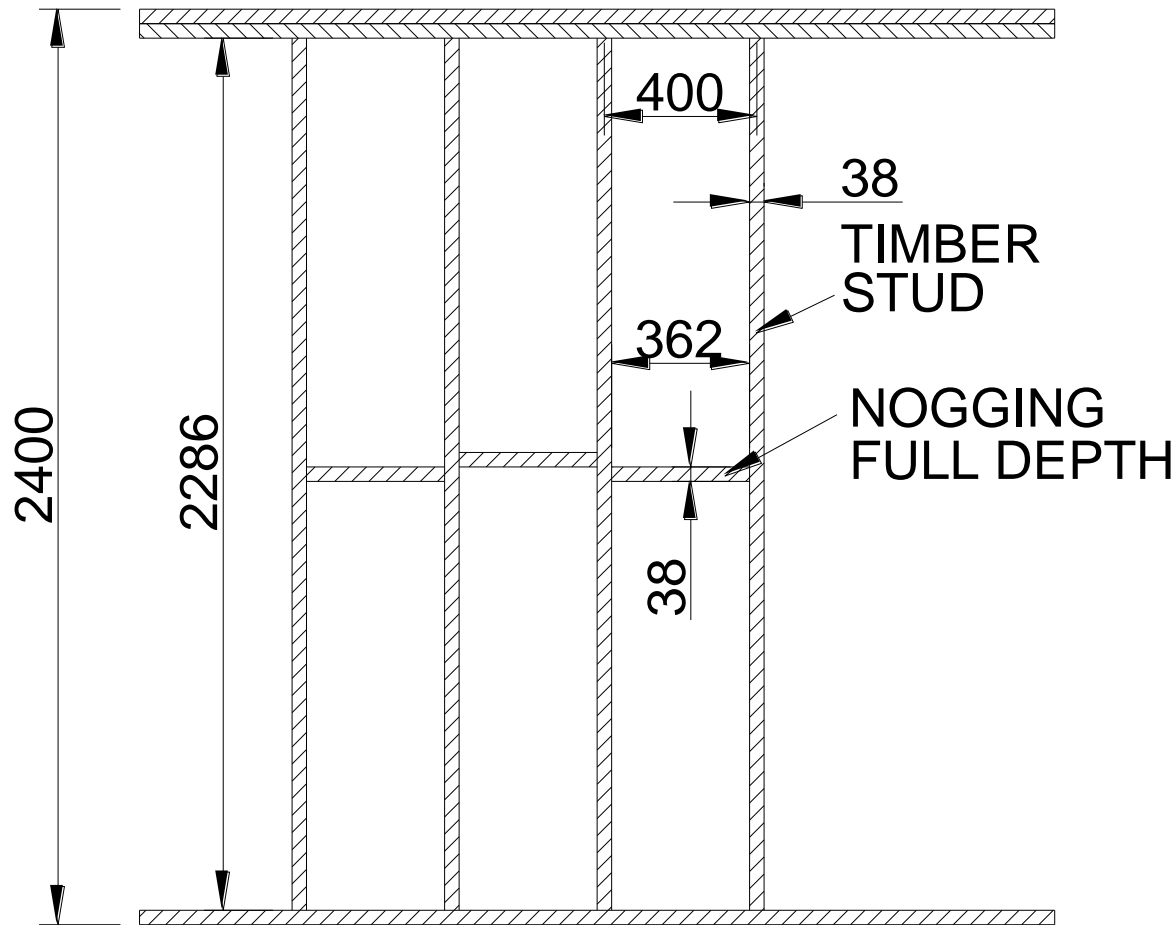
$F_2$  = the fractional area of second (timber) heat loss path

$R_1$  = the total resistance of first (insulation) heat loss path

$R_2$  = the total resistance of second (timber) heat loss path

# Example Step 1 - $R_{upper}$ – continued.

- Fractional area of timber and mineral wool.



## Example Step 1 - $R_{upper}$ – continued.

- When considering the fractional area of timber different countries may use different procedures.
- To provide inputs for this worked example the procedures described in BRE443 section 4.5.1 have been used.
- The wall area is taken as a number of repeatable rectangles 2400mm high x 400mm wide.
- The percentage timber in this repeatable area is calculated as follows.

# Example Step 1 - $R_{upper}$ – continued.

- Fractional area of timber  $F_2$  and mineral wool  $F_1$ .

- Overall repeatable area

$$2.400 \times 0.400 = 0.960 \text{ m}^2$$

- Area of timber

$$\text{Vertical } 2.400 \times 0.038 = 0.091 \text{ m}^2$$

$$\text{Horizontal } 0.362 \times 0.038 \times 4 = \underline{0.055} \text{ m}^2$$

$$\text{Total } 0.146 \text{ m}^2$$

- Fractional area of timber( $F_2$ )  $(0.146 / 0.960)$  0.15

- Fractional area insulation( $F_1$ )  $(1 - 0.15)$  0.85



# Example Step 1 - Calculation of $R_1$ - Sum of thermal resistance through insulation.

Layer / Surface	Thickness (d) ( m )	Conductivity ( $\lambda$ ) ( W / m K )	Resistance ( $R=d/\lambda$ ) ( m <sup>2</sup> K / W )
External surface (Rse)	---	---	0.040
Outer leaf brick	0.102	0.77	0.132
Air cavity (Ra)	0.500	---	0.090
Plywood	0.019	0.13	0.146
Insulation	0.140	0.038	3.684
Plaster board	0.025	0.25	0.100
Internal surface (Rsi)	---	---	0.130
Total Resistance	---	---	4.322

Note: Values of Rse, Ra and Rsi taken from I.S. EN ISO 6946 Table 1 and Table 2.  
 Thermal conductivity values used are indicative only.  
 Certified values should be used, if available.

# Example Step 1 - Calculation of $R_2$ - Sum of thermal resistance through timber.

Layer / Surface	Thickness (d) ( m )	Conductivity ( $\lambda$ ) ( W / m K )	Resistance ( $R=d/\lambda$ ) ( m <sup>2</sup> K / W )
External surface (Rse)	---	---	0.040
Outer leaf brick	0.102	0.77	0.132
Air cavity (Ra)	0.500	---	0.090
Plywood	0.019	0.13	0.146
Timber	0.140	0.13	1.077
Plaster board	0.025	0.25	0.100
Internal surface (Rsi)	---	---	0.130
Total Resistance	---	---	2.525

Note: Values of Rse, Ra and Rsi taken from I.S. EN ISO 6946 Table 1 and Table 2.  
 Thermal conductivity values used are indicative only.  
 Certified values should be used, if available.

# Example Step 1 - Calculation of $R_{upper}$

- The upper limit of resistance is now calculated from

$$R_{upper} = \frac{1}{\frac{F_{insul}}{R_{insul}} + \frac{F_{timber}}{R_{timber}}}$$

$$R_{upper} = \frac{1}{\frac{0.85}{4.322} + \frac{0.15}{2.525}}$$

$$R_{upper} = 3.906 \text{ m}^2 \text{ K} / \text{W}$$

## Example Step 2 – Calculating $R_{\text{lower}}$

- Procedure.  
Combining, in parallel, the resistances of the heat flow paths of each layer separately and then sum the resistance of all layers (i.e. sections) through the given construction.
- For this construction, thermal bridging occurs only at one layer, that is the layer made up partly of 38 x 140mm timber and partly by 140mm mineral wool.

## Example Step 2

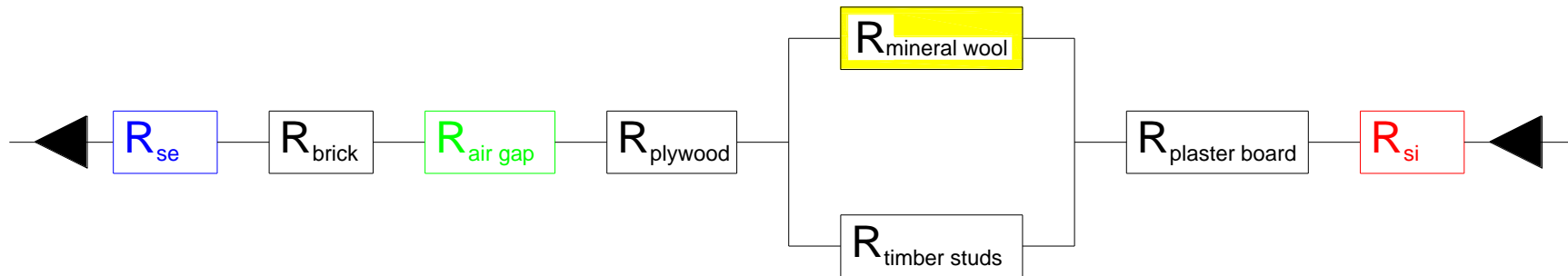
### – Calculating $R_{\text{lower}}$ – continued

- For this construction there is only one layer with two possible heat flow paths, i.e. the layer with a combination of 140mm mineral wool insulation and 38 x 140 timber studs.
- The heat flow path will be
  - 2 x 12.5mm plasterboard
  - + (Combination of mineral wool and timber)
  - + 19mm plywood
  - + 50mm slightly ventilated air cavity
  - + 102mm brick outer leaf.

# Example Step 2

- Calculating  $R_{\text{lower}}$  – continued.

- The heat flow path for the timber frame example is shown conceptually below.



Since the relative cross sectional area of the timber is not the same as that of the mineral wool insulation, the fractional areas of each must be considered when calculating  $R_{\text{lower}}$ . This has already been calculated when calculating  $R_{\text{upper}}$  on previous slides.

# Example Step 2

## - Calculating $R_{\text{lower}}$ – continued.

- The resistance of the bridged layer is now calculated from

$$R_{\text{bridged}} = \frac{1}{\frac{F_{\text{insul}}}{R_{\text{insul}}} + \frac{F_{\text{timber}}}{R_{\text{timber}}}}$$

$F_{\text{insul}}$  = the fractional area of first (insulation) heat loss path

$F_{\text{timber}}$  = the fractional area of second (timber) heat loss path

$R_{\text{insul}}$  = the total resistance of first (insulation) heat loss path

$R_{\text{timber}}$  = the total resistance of second (timber) heat loss path

# Example Step 2

## - Calculating $R_{\text{lower}}$ – continued

- From previous timber frame sketch and calculations in this module.

Fractional area of timber	0.15
Fractional area of insulation	0.85
Resistance of insulation	3.684 m <sup>2</sup> K/W
Resistance of timber	1.077 m <sup>2</sup> K/W



# Example Step 2 - $R_{\text{lower}}$ – continued.

- The resistance of the bridged layer is now calculated from

$$R_{\text{bridged}} = \frac{1}{\frac{F_{\text{insul}}}{R_{\text{insul}}} + \frac{F_{\text{timber}}}{R_{\text{timber}}}}$$

$$R_{\text{bridged}} = \frac{1}{\frac{0.85}{3.684} + \frac{0.15}{1.077}}$$

$$R_{\text{bridged}} = 2.703 \text{ m}^2 \text{ K} / \text{W}$$

# Example Step 2 - $R_{\text{lower}}$ – continued.

Sum of thermal resistance through all layers

Layer / Surface	Thickness (d) ( m )	Conductivity ( $\lambda$ ) ( W / m K )	Resistance ( $R=d/\lambda$ ) ( m <sup>2</sup> K / W )
External surface (Rse)	---	---	0.040
Outer leaf brick	0.102	0.77	0.132
Air cavity (Ra)	0.500	---	0.090
Plywood	0.019	0.13	0.146
Bridged layer	---	---	2.703
Plaster board	0.025	0.25	0.100
Internal surface (Rsi)	---	---	0.130
Total Resistance	---	---	3.341

$$R_{\text{lower}} = 3.341 \text{ m}^2 \text{ K / W}$$

## Step 3 – Calculate total thermal resistance.

- Procedure.

Calculate the total thermal resistance ( $R_T$ )

using

$$R_T = \frac{R_{\text{upper}} + R_{\text{lower}}}{2}$$

$$R_T = \frac{3.906 + 3.341}{2}$$

Total thermal resistance  $R_T = 3.624 \text{ m}^2 \text{ K} / \text{W}$

## Step 4 – Calculate corrections.

- Procedure - Calculate, where appropriate,
  - a) corrections for air gaps (  $\Delta U_g$  ) in the insulation layer. That is if a gaps exceeding 5mm width penetrates the insulation.
  - b) correction for mechanical fasteners (  $\Delta U_f$  ) in the insulation layer.

Note: Procedures for corrections may vary between countries. One procedure is described in BRE442 – Conventions for U-value calculations, 2006, sections 4.9.1, 4.9.2 and 4.9.3.

## Step 4 - Corrections - continued.

- Corrections for air gaps (  $\Delta U_g$  ) in the insulation layer.
- In this example no corrections are applicable, i.e. the insulation is installed in such a way that there are no air gaps penetrating the entire insulation layer and no air circulation is possible on the warm side of the insulation.
- For the three possible levels of correction for air gaps see I.S. EN ISO 6946 Annex D.
- For examples of such corrections see –  
 “Examples of U-value calculations using BS EN ISO 6946 : 1997” published by BRE.

## Step 4 - Corrections - continued.

- Correction for mechanical fasteners (  $\Delta U_f$  ) in the insulation layer.
- In this example no corrections are applicable, i.e. no mechanical fasteners penetrating the entire insulation layer.
- For the formula related correction for mechanical fasteners see I.S EN ISO 6946 Annex D.
- For examples of such corrections see –  
“Examples of U-value calculations using BS EN ISO 6946 : 1997” published by BRE.

# Step 5 – Calculate the final U-value

- Procedure

$$U = ( 1 / R_T ) + \Delta U_g + \Delta U_f$$

$$U = ( 1 / 3.624 ) + 0 + 0$$

$$U = 0.28 \text{ W /m}^2 \text{ K}$$

# Module Summary.

- When calculating U-values for constructions with thermally bridged elements, 5 steps are used.
- Task.  
Outline each of these 5 steps.



# Module Summary.

- Step 1 calculates the upper resistance limit

$R_{\text{upper}}$

- Task.

Describe this step in detail and draw a sketch to show how the resistance paths should be arranged.

# Module Summary.

- Step 2 calculates the upper resistance limit

$R_{\text{lower}}$

- Task.

Describe this step in detail and draw a sketch to show how the resistance paths should be arranged.

# Module Summary.

- Step 3 calculates the total thermal resistance limit  $R_T$ .
- Task.

Describe the formula needed to calculate  $R_T$ .

# Module Summary.

- Step 4 calculates the corrections for
  - a) air gaps penetrating the insulation
  - b) mechanical fixings penetrating the insulation.
- Task.

Describe some examples where these correction factors need not be applied.

# Module Summary.

- Step 5 calculates the thermal transmittance value of U-value.
- Task.

Describe the formula needed to calculate the U-value.

## National procedures – UK, Ireland.

- When considering the fractional area of timber included in calculations BRE 443 Section 4.5.1 states :-

For timber frame construction which conforms with the designs in Accredited Construction Details, additional heat loss at corners, window surrounds, between floors etc is limited and the associated timbers are not counted as part of the timber fraction. This is comparable with masonry construction where items such as lintels and cavity closers are not counted.

- continued.
- BRE 443 suggests a default fraction for typical timber frame construction as 0.15.
- A lower fraction of 0.125 may be used if specific conditions are met.
- For further information see BRE 443 section 4.5.

# Acknowledgements:

- The authors and publishers of this document wish to thank the National Standards Authority of Ireland for permission to reproduce extracts from copyright material EN ISO 6946 : 2007 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method.



# References:

- International standards.
- I.S. EN ISO 6946 : 2007 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method.
- National standards + others.
- BRE 443 : 2006 – Convention for U-value calculations. ISBN 1 86081 924 9
- Examples of U-value calculations using BS EN ISO 6946 : 1997 published by BRE.
- <http://wiki.aia.org/WikiPages/ThermalBridging.aspx>