LOTUS Guidelines

Air layers and U-value calculation

1. Introduction

These guidelines aim to explain how air layers (or air gaps) should be considered when calculating U-values of assemblies. The content of these guidelines is mainly inspired by the ISO 6946 standard.

2. Definitions

The following definitions based on ISO 6946:2007 apply for the whole document:

Air layer: An air layer must:

- Be bounded by 2 parallel faces
- Be perpendicular to the direction of heat flow
- have a thickness (in the direction of heat flow) of less than 0,1 times each one of the other two dimensions (width and height), and not greater than 0,3 m

Ventilated air layer: An air layer with openings to the outside allowing the passage of air (there is an airflow in the layer)

Unventilated air layer: An air layer with no openings (or small openings) to the outside and which doesn't allow the passage of air (no airflow in the layer).

Heat flow direction:

In Vietnam, the aim being to limit the U-value in the summer conditions (where heat is coming from outside to inside the building), the heat flow directions to be considered are:

- heat flow downwards for roof systems
- heat flow horizontal for wall systems

3. Unventilated air layers

An air layer with small openings to the external environment, shall be considered as an unventilated air layer if these openings are not arranged so as to permit air flow through the layer and they do not exceed:

- 500 mm^2 per metre of length (in the horizontal direction) for vertical air layers,
- 500 mm^2 per square metre of surface area for horizontal air layer

In U-value calculations, an unventilated air layer should be considered as any other layer and the thermal resistance of the air layer should be included in the calculations.

Case 1: Emissivities of the surfaces bounding the air space are higher than 0.8

Design values of thermal resistance of the air layer are given in Table 1. The values under "horizontal" apply to heat flow directions ± 30° from the horizontal plane.

Table 1: Thermal resistance of unventilated air layers with high emissivity surfaces (same table as Table 4 in the Annex of QCVN 09:2013/BXD – VBEEC)

Air layer thickness (mm)	Heat flux direction	
	Horizontal (for vertical air layer)	Downward (for horizontal air layer)
0	0.00	0.00
5	0.11	0.11
7	0.13	0.13
10	0.15	0.15
15	0.17	0.17
25	0.18	0.19
50	0.18	0.21
100	0.18	0.22
300	0.18	0.23
***Note**: Intermediate values may be determined using linear interpolation.*		

Case 2: Emissivities of the surfaces bounding the air space are lower than 0.8

In the case of unventilated air layers which have bounding surfaces with low-emissivities, the thermal resistance of the air layer R_a is given by the following formula:

$$R_a = \frac{1}{h_a + h_r}$$

Where:

h_a is the conduction/convection coefficient (W/m^2.K)

h_r is the radiation coefficient (W/m^2.K)

h_a is determined by conduction in still air for narrow airspaces and by convection in wide cavities. For calculations, **h_a is the larger value** of 0,025/d and the value obtained from the formulae in Table 2.

In this Table, d is the thickness of the airspace in the direction of heat flow, in metres, and ΔT is the temperature difference across the airspace, in kelvins (or °C).

Table 2: Conduction/convection heat transfer coefficient

Direction of heat flow	ΔT	h_a (W/m^2.K)
Horizontal	≤ 5 K	1.25
	> 5 K	$0.12 \times d^{-0.44}$
Downwards	≤ 5 K	$0.73 \times (\Delta T)^{1/3}$
	> 5 K	$0.09 \times (\Delta T)^{0.187} \times d^{-0.44}$

To calculate ΔT, the indoor-outdoor temperature difference can be used. The outdoor temperature values to use are given in Table 3.

Table 3: External temperature values (from Table D.2 in Annex of the draft EEBC 2011)

Location	T_N external temperature (°C)
Hanoi	28.9
Da Nang	29.17
Buon Ma Thuot	25.43
Ho Chi Minh City	28.67

h_r is given by: $h_r = E \times h_{r0}$

where:

E is the intersurface emittance

$$E = \frac{1}{{}^{1}/_{\varepsilon_1} + {}^{1}/_{\varepsilon_2} - 1}$$

with ε_1 and e_2: hemispherical emissivities of the surfaces bounding the air space.

h_{r0} is the radiative coefficient for a black-body surface. Values from Table 4 should be used.

Table 4: Values of the black-body radiative coefficient

Mean temperature (°C)	h_{r0} (W/m^2.K)
10	5.1
20	5.7
30	6.3

Example:

A building in Ho Chi Minh City, designed to keep an indoor temperature of 26°C during hot conditions, has a roof system composed with the following elements:

- galvanised steel roofing sheet
- unventilated air gap with a thickness of 25 mm
- aluminum foil

1. Verification of the emissivity values

Aluminum Foil: ε = 0.04

Steel Galvanized New: ε =0.23

Emissivity values of the bounding surfaces are much lower than 0.8.

2. Calculation of h_a

Roof system in Ho Chi Minh City => heat flow is downwards

$\Delta T = 28.67°C – 25°C = 3.67°C$

Comparison of the two values:

- Using formula in Table 2: $0.73 \times (\Delta T)^{1/3} = 0.73 \times (3.67)^{1/3} = 1.126$ W/m^2.K
- 0,025/d = 0.025 / 0.025 = 1 W/m^2.K

Using the larger value, h_a is equal to 1.126 W/m^2.K.

3. Calculation of E, the intersurface emittance

Aluminum Foil: $\varepsilon 1= 0.04 \Rightarrow 1/\varepsilon 1 = 25$

Steel Galvanized New: $\varepsilon 2 = 0.23 \Rightarrow 1/\varepsilon 2=4.34$

$E = 1 / (25 + 4.34 - 1) = 0.035$

4. Calculation of h_r

Value of h_{r0} at 30°C will be used: 6.3 $W/m^2.K$

$h_r = 0.035 \times 6.3 = 0.2205$ $W/m^2.K$

5. Calculation of R_a

$R_a = 1 / (1.126 + 0.2205) \Rightarrow$ $\mathbf{R_a = 0.74\ m^2.K/W}$

Comparing this result with the value that is given in Table 4 in the Annex of QCVN 09:2013 (where R_a would be equal to 0.19 $m^2.K/W$ for a 25mm air layer), a big difference can be noticed. The R-value of the air layer calculated with the present method will always be a lot larger than the values given in VBEEC table.

VGBC strongly recommends projects to follow this method instead of using the values from VBEEC in cases where emissivities of the bounding surfaces are lower than 0.8.

4. Ventilated air layers

a. Well-ventilated air layers

A well-ventilated air layer is one for which the openings between the air layer and the external environment are equal to or exceed:

- 1 500 mm^2 per metre of length (in the horizontal direction) for vertical air layers,
- 1 500 mm^2 per square of metre of surface area for horizontal air layers.

The total thermal resistance of a building component containing a well-ventilated air layer shall be obtained by disregarding the thermal resistance of the air layer and all other layers between the air layer and external environment, and including an external surface resistance corresponding to still air.

The surface resistance is given by the following equation:

$$R_a = \frac{1}{h_c + h_r}$$

Where:

h_c is the convective coefficient (W/m^2.K)

h_r is the radiation coefficient (W/m^2.K)

At internal surfaces, or external surfaces adjacent to a well-ventilated air layer:

$h_c = h_{ci}$

where:

h_{ci} = 2,5 W/(m^2·K) for heat flow horizontal;

h_{ci} = 0,7 W/(m^2·K) for heat flow downward

h_r is given by: $\mathrm{h_r} = \varepsilon \times \mathrm{h_{r0}}$

Where:

ε is the hemispherical emissivity of the surface

h_{r0} is the radiative coefficient for a black-body surface (see Table 4), in W/(m^2·K)

Example:

A building in Ho Chi Minh City, has a roof system composed with the following elements:

- galvanised steel roofing sheet
- well-ventilated air gap (more than 1 500 mm2 per square of metre of surface area)
- aluminum foil

1. Determination of h_c

Heat flow is downwards, so h_c is equal to 0.7 W/m^2.K.

2. Determination of ε

Aluminum Foil: $\varepsilon = 0.04$

3. Calculation of h_r

Value of h_{r0} at 30°C will be used: 6.3 $W/m^2.K$

$h_r = 0.04 \times 6.3 = 0.252$ $W/m^2.K$

4. Calculation of R_a

$R_a = 1 / (0.7 + 0.252)$ => $\mathbf{R_a = 1.05\ m^2.K/W}$

b. Slightly ventilated air layers

A slightly ventilated air layer is one in which there is provision for limited air flow through it from the external environment by openings of area, Av, within the following ranges:

- > 500 mm^2 but< 1 500 mm^2 per metre of length (in the horizontal direction) for vertical air layers;
- > 500 mm^2 but < 1 500 mm^2 per square metre of surface area for horizontal air layers.

In U-value calculations, a slightly ventilated air layer should be considered as any other layer and the thermal resistance of the air layer should be included in the calculations.

The effect of ventilation depends on the size and distribution of the ventilation openings. As an approximation, the total thermal resistance of a component with a slightly ventilated air layer may be calculated as:

$$\mathrm{R}_T = \frac{1500 - A_v}{1000} R_{T,u} + \frac{A_v - 500}{1000} R_{T,v}$$

Where:

$R_{T,u}$ is the total thermal resistance of an unventilated air layer in accordance with section 2

$R_{T,v}$ is the total thermal resistance of a well-ventilated air layer in accordance with section 4.a.

Example:

A building in Ho Chi Minh City, designed to keep an indoor temperature of 26°C during hot conditions, has a roof system composed with the following elements:

- galvanised steel roofing sheet
- slightly ventilated air gap with 1 000 mm^2 of openings per square metre of surface area
- aluminum foil

Values from above examples:

$R_{T,u}$ = 0.74 m^2.K/W

$R_{T,v}$ = 1.05 m^2.K/W

$$\mathrm{R}_T = \frac{1500 - 1000}{1000} \times 0.74 + \frac{1000 - 500}{1000} \times 1.05$$

R_T = 0.895 m^2.K/W