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Analysis of Air Flow in the Ventilated Insulating Air Layer of the External Wall

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Abstract
The paper deals with problems of impact of air flow in ventilated insulating air layer of the external wall on behaviour of thermal-technical parameters of the proposed external structure (according principles of STN 73 0549, which is not valid now), by comparing them in the calculation according to the valid STN standards, where air flow in the ventilated air layer is not taken into account, as well as by comparing them with behavior of thermal-technical parameters in the proposal of sandwich external wall with the contact heat insulation system without air cavity.

Key words: external structures, ventilated insulating air layer, air flow, thermal resistance of the structure with ventilated insulating air layer

1 Introduction

Façade protect the indoor environment against unfavourable impacts of outdoor climate and together with opening structures they participate in the creation of indoor environment in the crucial extent [1]. At the present time, with the growing construction of buildings, we can increasingly more often encounter ventilated facades. These structures gain ground thanks to new materials and methods of anchorage, but also thanks to their wide application from the point of view of architectonic requirements [2]. They also improve thermal-technical properties of external walls. A layer of air gap helps to continuous removal of moisture from the structure. And last but not least, structures of ventilated facades very effectively contribute to the increase of protection against noise.

2 External structures with ventilated insulating air Layer

Double-shell structure of the facade separates indoor environment from the outdoor one by two claddings with an air layer between them, which is located behind the thermal-insulation layer. External structures with ventilated air layer can be divided into two systems as follows:

1. Protective system – series of layers (external structure) has been designed and implemented without thermal insulation.
2. Thermal-insulation system (ventilated thermal insulation systems) [2].

From the point of view of physics related to construction, the ventilated facade is assessed as a whole up to the ventilated air layer with planned influence of thermal bridges.
Insulating air layer, which is interconnected with outdoor environment, can be weakly vented (ventilated insulating air layer) or intensively vented (insulating air layer being vented).

The air layer is considered intensively vented, if openings between the insulating air layer and outdoor environment exceed [3]:

- 1,500 mm^2 per each meter of the length of vertical insulating air layer,
- 1,500 mm^2 per each m^2 of horizontal ventilating air layer.

The ventilated air layer (also referred to as intensively ventilated insulating air layer) of the external structure represents a vertical cavity providing its venting.

2.1 Air flow in the boundary layer of the atmosphere

The wind is a most variable element in the ground layer of the atmosphere. Time variability of wind action is most expressive above all in the boundary layer of the atmosphere, which thickness ranges from 500 to 2,000 m above the Earth´s surface. The national standard STN EN 1991-1-4:2007 defines impact of the wind on buildings using a standard model of the atmospheric boundary layer defined by the vertical speed profile.

On the basis of analysis of average day wind speed, the territory of the Slovak Republic is divided into two basic wind areas. For the territory of the City of Kosice (temperature area 2, wind area 2), wind speed is $2\ m/s \leq v \leq 5\ m/s$. However, frequency or intensity of the wind is also affected by layout of urban build-up area. Depending on the height above ground and roughness of ground, average wind speed is changing. At elevated points (100 m above a lowland, valley and basin); it is possible to take into account speed of air flow $v > 5\ m/s$ [4].

2.2 Impacts of the wind on envelope structures of buildings

Air flow is considerably affected by buildings and their surroundings. Evaluation of natural venting and assessment of load of building envelope structures and their components (for example anchorage) caused by impacts of the wind, it is inevitable to know distribution of pressures on facades of buildings. Positive pressure acts on the leeward side of the building. The area of negative pressure (suction) is formed on leeward and lateral sides of the building. In the case of larger structures, high local positive or negative pressures (suctions) can act in due to modification of air flow in their surroundings. Impacts of the wind on buildings (pressure or suction) and their size is expressed using aerodynamic coefficients of external pressure C_{pe} (-), internal pressure C_{pi} (-) and overall pressure C_p (-).

2.2.1 Aerodynamic coefficient of external pressure

The wind acts on a building from the outer side by the force expressed by external aerodynamic coefficient C_{pe}. Aerodynamic coefficient of external pressure can be affected by a large number of parameters – geometry of the building, details on façade, positions on façade, speed and direction of the wind. Aerodynamic coefficients of external pressure can be expressed by:

- calculations according to national standards,
- experimental measurements in–situ – this measurement is relatively demanding, expensive and slow,
- experimental measurements in the aerodynamic tunnel [5], this is relatively quick measurement, which allows testing of different shapes of the building at various speeds of flow and orientations of the building, or to take into account the adjacent ground,
- simulations using CFD calculation software.

Calculations according to standards are simplest for designers, who are not specialists in aerodynamics of buildings. However, this method could be applied only on some of basic shapes of buildings, and it does not take into account different specifics for demands of the design of envelope structures.

2.2.2 Aerodynamic coefficient of internal pressure

However, action of external pressure induces counter pressure on the opposite side, which is characterized by internal aerodynamic coefficient C_{pi}. Air permeability of envelope structure is of great influence [6].

It is often forgotten, when determining load by the wind, to take into account internal pressure, which can considerably influence overall design load depending on geometrical shape of the building, size and location of openings and by many other factors. Knowledge of the value of internal aerodynamic coefficient is very important from the point of view of the engineering practice, because it can cause the change of the value of overall aerodynamic coefficient from positive (pressure) to negative (suction). Negligence of impact of internal pressure could result in increased values at leeward and lateral sides, and also on roof of the building, which frequently results in failures of anchoring elements of external and roof cladding.

2.3 Air flow in ventilated isolating air layer of the double-cladding external structure

Fact that what speed air is flowing and how temperature in a ventilated air layer, as well as the parameters are changed, and the thermal insulation properties of the structure cannot be exactly described. The main source of the processes taking places in the atmosphere as sunlight, so the effect of solar radiation on the air velocity in a ventilated air layer unquestionable [7].

The system of ventilated facades is based on venting the air gap with the thickness ranging from 20 to 50 mm located between thermal insulation and facade itself [2]. If the insulating air layer is connected to the outdoor environment, air is moved more intensively, by which its thermal resistance is reduced against thermal resistance of closed air layer [8]. More intensive movement of air in open air layer is induced by natural motoric forces – by temperature difference and by the wind [5]. Composite action of these forces results in overall air pressure difference Δp_c (Pa), which is determined as a sum of air pressure difference caused by temperature difference Δp_θ (Pa) and pressure difference caused by impact of the wind Δp_w (Pa). Laminar air flow occurs as a rule in ventilated insulating air layers, while turbulences occur only rarely at a few points by action of other factors (height and shape of the building, kind and type of grate, design of inlet and outlet openings etc.) [2]. In order to ensure correct function of the ventilated insulation air layer, it is necessary to propose inlet openings in the lower part of facade and outlet openings in the upper part of façade in most of systems. Openings for supply and discharge of air must have cross section surface of min. 50 cm^2/m. Principles of venting must also be preserved in areas of passages such as windows [1].

2.4 Principles of dimensioning of structures with ventilated insulation air layer

When designing structures with ventilated insulating air layer, the following principles shall be applied [9]:

1) Overall thermal resistance shall be determined from thermal resistance of layers of the first cladding $\boldsymbol{R_1}$ (i.e. from indoor environment to open air cushion).
2) Ventilated air layer of double-cladding external walls must be designed in such a way that no condensation of water steam would occur.
3) Elimination of condensation of steam in open air layer can be achieved by increasing thermal resistance $\boldsymbol{R_2}$ (m^2.K/W) of external cladding. R_2 = 0.1 m^2.K/W is recommended for vertical walls. Insertion of a moisture stop before the layer of thermal insulation is recommended.

Speed of air flow in open air layer will be determined approximately in two limit positions: $v_{min} = 0.3.\ v.A_1/A$ and $v_{min} = 0.9.v.A_1/A$, where A_1 - is the area of the inlet (outlet) opening (m^2), A - is the area of cross section, which is determined by speed of flow (m^2), v - is speed of flow of outdoor air (m/s). More accurate model of calculation, which take into account inserted resistances, type of air flow (laminar, turbulent) is stated in STN 73 0549 (Articles 13-16). Resulting speed of air flow in open air layer is affected mainly by structural design of points with higher inserted resistances, such as inlet and outlet opening [9].

3 Assessment of external structures of the reference building with ventilated insulating air layer

For the proposal of vertical envelope structure of the reference building located on the territory of the town Kosice with the height between inlet and outlet opening of the insulating open air layer $h = 5\ m$ was considered ceramic cladding ventilated air gap width of 40 mm. For analysis of thermal-technical properties of the envelope structure three basic types of external walls were proposed. Two types were proposed with a contact thermal insulation system made of piece building materials (ceramic bricks Porotherm 38) insulated with thermal insulation on the basis of mineral wool with the thickness of 100 mm. Surface finish of the first one consists of plaster; in the case of second type surface finish is solved with glued ceramic lining. The third type was proposed with ceramic lining ArGeton with open air layer with the width of 40 mm. Calculations were carried out using the Heat 2010 program. In calculation of thermal-technical parameters of individual types of structures, boundary conditions, which meet requirements of the locality Košice were taken into account. Calculation was carried out in accordance with valid thermal-technical standards STN 73 0540-2 and STN 73 0540-3. Within the framework of analysis of the external walls with ventilated air layer, calculation was also carried out according to invalid standard STN 73 0549.

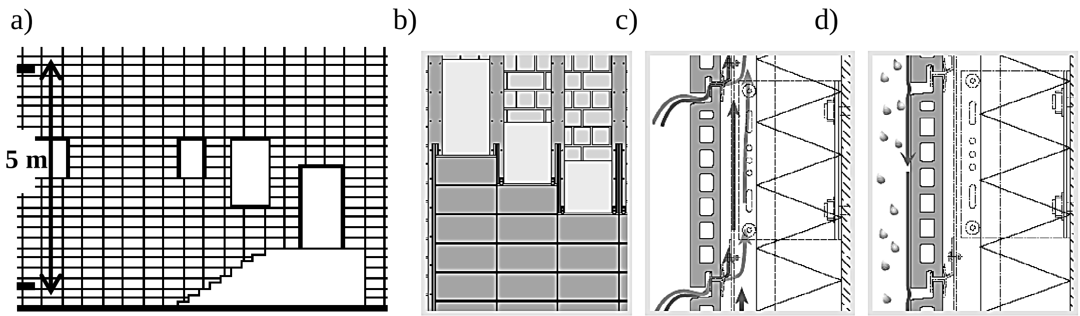

Figure 1: Schematic depiction of the reference building and ceramic lining ArGeton with ventilated insulating air layer

a) position of inlet and outlet openings, h = 5 m b) thermal insulation of external wall,
c) ventilated air layer, d) resistance of external structure against driven rain Source: http://wienerberger.cz/podklad-pro-navrhování-a-provádění-fasádního-systému- argeton.html

3.1 Determination of thermal resistance of the structure with ventilated insulating air layer

In order to determine thermal resistance of ventilated insulating air layer, it is necessary to determine behaviour of temperature in open air layer (average temperature of air in open air layer). In order to do it, it is necessary to know or to calculate the value of air flow speed in air, and subsequently the mass flow of air.
Indoor calculation temperature of air in indoor environment of buildings with effective protection of external structures according to STN 73 0540-3 (it is preliminary valid) [4]:
$\theta_{ai} = \theta_i = 20°C$ (θ_{ai} –indoor air temperature, θ_i – design indoor temperature)
Design outdoor calculation temperature in the winter season θ_{ae}:
$\theta_{ae} = \theta_e + \Delta\theta_e = -12° + (-0.5) = -13°C$
Calculation relative humidity of indoor air: $\varphi_i = 50\%$
Relative air humidity: $\varphi_e = 84\%$ (83.6%)

3.1.1 Calculation of air speed c_v in insulating air layer

The calculation was implemented for the reference building with the height between inlet and outlet opening of insulating air layer *h = 5 m*, with ventilated insulating air layer with the width of $d_{vv} =$ *40 mm*, in the area with wind speed *v = 5m/s*.
According to the former STN 73 0549 (Articles 13-16) [10], air flow speed is determined approximately from the following condition [8]:

$$\Delta pc = \Delta p_z \qquad (1)$$

Where Δp_C is pressure difference at inlet and outlet of ventilated insulating air layer (Pa), Δp_z – loss of pressure in ventilated insulating air layer (Pa).

Overall pressure difference of air at inlet and outlet of insulating air layer is given by equation:

$$\boldsymbol{\Delta p_C = \Delta p_\theta + \Delta p_v} = h(\rho_{m2} - \rho_{m1})g + (A_n - A_z)\frac{v^2}{2}\rho_m \qquad (2)$$

where Δp_θ is pressure difference caused by gravity (air pressure difference caused by temperature difference), Δp_v is pressure difference caused by the wind, g – gravity acceleration = 9.81 m/s^2, A_n, A_z – aerodynamic coefficients, A_n= 0.6 (windward side), A_z = 0.3 (leeward side); ρ_{m1} = 1.358 kg/m and ρ_{m2} = 1.358 kg/m (specific weigh of air).

When calculating pressure difference of air caused by the wind, difference of aerodynamic coefficients a) $A_n - A_z = 0.3$ and b) $A_n - A_z = 0$ was taken into account, because this is a vertical cavity air space, and the reference building is located in the area protected against the wind, and is relatively low.

a) $\Delta p_v = (A_n - A_z)\frac{v^2}{2}\rho_m = 0.3.\frac{5^2}{2}1.358 = 5.0925\, Pa;$ *b)* $\Delta p_v = 0$

a) $\boldsymbol{\Delta p} = \Delta p_\theta + \Delta p_v = 0.265 + 5.0925 = \mathbf{5.3575\ Pa}$

b) $\boldsymbol{\Delta p} = \Delta p_\theta + \Delta p_v = 0.265 + 0 = \mathbf{0.265\ Pa}$

Loss of pressure will be determined from equation below:

$$\boldsymbol{\Delta p_z = \Delta p_{tr} + \Delta z} \qquad (3)$$

where Δp_{tr} is loss of pressure by friction (Pa), Δz is loss of pressure caused by inserted resistances (Pa).

Loss of pressure by friction will be determined from the equation below:

$$\boldsymbol{\Delta p_{tr}} = \lambda\frac{1}{d_{vv}}.\frac{c_v^2}{2}\rho_m \qquad (4)$$

λ is friction factor (m), d_{vv} is average of cross sections of insulating air layer (m).

In the case of laminar flow of air in ventilated cavity, the friction factor is given by the equation:

$\lambda = \frac{64}{\mathrm{Re}}$, $Re = \frac{c_v.d_{vv}}{\nu}$, ν = 12.276.10^{-6} m^2/s (kinematic viscosity of air) $\Rightarrow$ $\boldsymbol{\Delta p_{tr} = 0.332.c_v}$ (P_a)

Loss of pressure caused by inserted resistances will be determined using the following equation:

$$\Delta z = \sum \zeta \frac{c_v^2}{2}\rho_m \quad \text{(Pa)} \qquad (5)$$

where ζ is inserted resistance factor (Tab. 1.17 [9]). If ζ = 2.0 (input, at which air stream is bent), ζ = 2.5 (output with sharp bend of stream) $\Rightarrow$ Δz = $\mathbf{3.049.c_v^2}$

$$\boldsymbol{\Delta p_z} = \Delta p_{tr} + \Delta z = \mathbf{0.332.c_v + 3.049.c_v^2} \quad \text{(Pa)}$$

By the solution of quadratic equation we will obtain the value of air flow speed c_v in insulating air layer

a) when taking into account pressure difference of air caused by the wind ($A_n - A_z = 0.3$):

$\Delta p = \Delta p_z \Rightarrow 5.3575 = 0.332 c_v + 3.049 c_v^2 \Rightarrow 3.049 c_v^2 + 0.332 c_v - 5.3575 = 0 \Rightarrow$ ***c_v = 1.270 m/s***

b) with negligence of air pressure difference caused by the wind, i.e. $A_n - A_z = 0$:

$\Delta p = \Delta p_z \Rightarrow 0.2650 = 0.332 c_v + 3.049 c_v^2 \Rightarrow 3.049 c_v^2 + 0.332 c_v - 0.2650 = 0 \Rightarrow$ ***c_v = 0.245 m/s***

3.1.2 Behaviour of temperature in open air layer

The calculation was implemented according to former STN 73 0549 (Articles 10-12) [10]: The calculation of air temperature θ_x in open air layer at point in *x* from its beginning [8], [9]:

$$\theta_x = \frac{A + [\theta_0 (U_i + U_e) - A] \exp\left(- \frac{U_i + U_e}{G_m . c} x \right)}{U_i + U_e} \tag{6}$$

where $\theta_0 = \theta_e$ is temperature at the beginning of air layer (°C), *c* – specific heat capacity in air (J/kg.K), c = 1.010 J/kg.K [6] and $A = U_i.\ \theta_i + U_e.\ \theta_e$;

x – is distance from the beginning (m), U_i – is heat transfer coefficient in internal cladding in W/(m^2.K), θ_i – temperature of indoor air (°C), U_e – heat transfer coefficient in external cladding W/(m^2.K), θ_e – temperature of outdoor air (°C).

Average temperature of air in open air layer with the length of *l* shall be determined according to the formula below:

$$\bar{\theta}_x = \frac{A}{U_i + U_e} + \frac{G_m . c_v}{l} . \frac{(U_i + U_e)\theta_0 - A}{(U_i + U_e)^2} . \left[1 - \exp\left(- \frac{U_i + U_e}{G_m . c_v} . l \right) \right] \tag{7}$$

If air flow speed c_v, is known, we can determine air mass flow G_m:

$$\mathbf{G_m = d_w . c_v . \rho_m} \quad \text{in kg/(m.s)}$$

where d_w is the thickness of insulating air layer (m), ρ_m - volume weight of air (kg/m^3), c_v - air flow speed in insulating air layer (m/s).

a) if c_v = 1.270 m/s $\Rightarrow$ $\mathbf{G_m} = d_w.c_v.\rho_m$ = 0.04.1,270.1,353 = **0.0687** kg/(m.s)
b) if c_v = 0.245 m/s $\Rightarrow$ $\mathbf{G_m} = d_w.c_v.\rho_m$ = 0.04.0.245.1,353 = **0.01326** kg/(m.s)

$$\boldsymbol{U_i} = \frac{1}{R_{si} + R_1 + R_{ev}} = \frac{1}{0.13 + 5.15 + 0.08} = 0.1866 \text{ W/(m}^2\text{.K)}$$

$$\mathbf{U_e} = \frac{1}{R_{ev} + R_2 + R_{se}} = \frac{1}{0.08 + 0.0297 + 0.04} = 6.68 \text{ W/(m}^2\text{.K)}$$

R_{ev} (resistance in heat transfer coefficient through insulating air layer) the value is preliminary used R_{ev} = 0.08 (m^2.K)/W, R_{si} = 0.13 (m^2.K)/W and R_{se} = 0.04 (m^2.K)/W [4].

$A = U_i.\ \theta_i + U_e.\ \theta_e$ = 0.1866.20 + 6.68.(-13) = - 83.1

Temperature of air in open air layer at point *x* from its beginning:

a) if G_m = 0.06870 kg/(m.s) $\Rightarrow$ $\boldsymbol{\theta_x} =$ **-12.1 – 0.898.exp(-0.9895.x)**

b) if $G_m = 0.01326$ kg/(m.s) $\Rightarrow$ $\boldsymbol{\theta_x = -12.1 - 0.898.\exp(-0.5127.x)}$

Calculation of average temperature of air $\bar{\theta}_x$ in open air layer with the length *l = 5 m*

$$\bar{\theta}_x = \frac{A}{U_i + U_e} + \frac{G_m.c}{l}.\frac{(U_i + U_e)\theta_0 - A}{(U_i + U_e)^2}.\left[1 - \exp\left(-\frac{U_i + U_e}{G_m.c}.l\right)\right] \qquad (8)$$

a) if $G_m = 0.06870$ kg/(m.s) $\Rightarrow$ $\bar{\theta}_x$ = **-12.81°C**

b) if $G_m = 0.01326$ kg/(m.s) $\Rightarrow$ $\bar{\theta}_x$ = **-12.423°C**

Particular values of air temperature in open air layer are depicted on the basis of temperature θ_x dependence on the distance of outdoor air entry into air layer *x* (*Graph 4.1*).

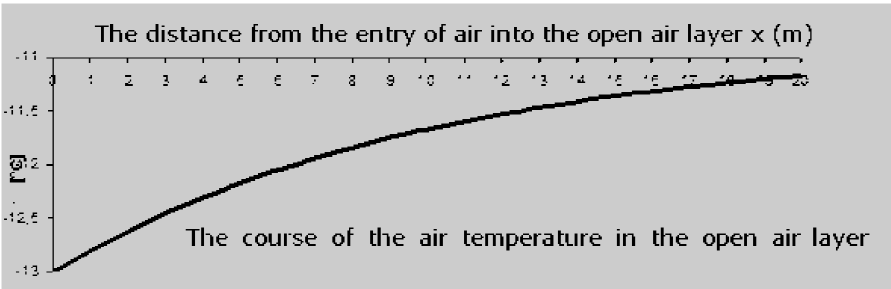

Figure 2: Behaviour of temperature θ_x in open air layer depending on the distance of outdoor air entry into air layer [11]

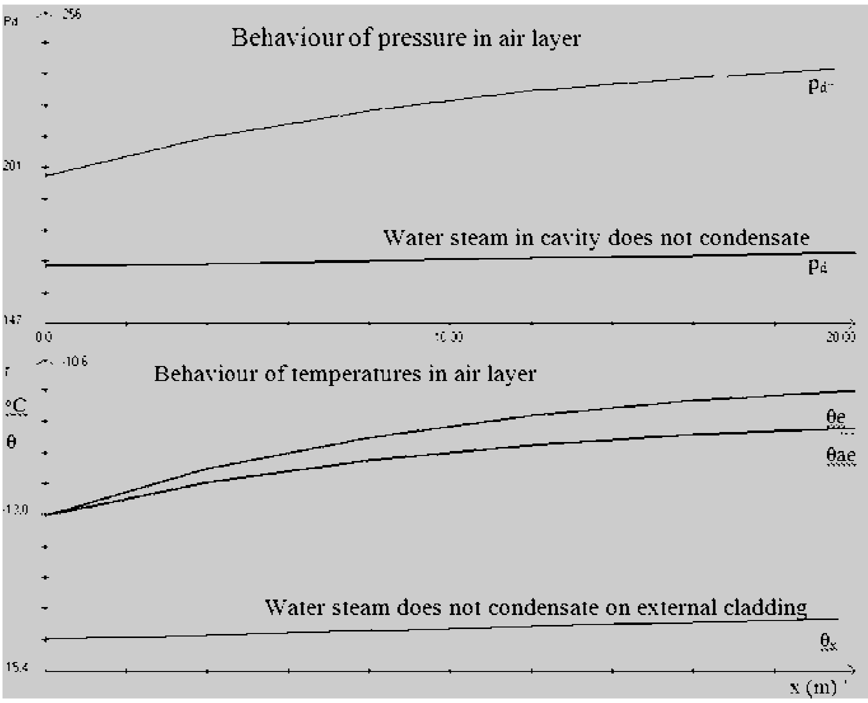

Figure 3: Behaviour of pressures p_d and temperatures θ_x (variant a) in insulating air layer according to program Gap 2014 (approximate behaviours) [11]

3.1.3 Determination of thermal resistance of the structure with ventilated insulating air layer

For any selection of the distance x (m) in open air layer from its beginning (entrance), heat transfer coefficient "*U*" of the structure with ventilated insulating air layer will be determined according to the formula below [8], [9], [10]:

$$U = U_i \frac{\theta_i - \theta_x}{\theta_i - \theta_e} \quad \text{W/(m}^2\text{.K)} \tag{9}$$

where θ_x is temperature of air in insulating air layer at „x" from entrance

Thermal resistance "R" of the structure with ventilated insulating air layer will be determined at this point as follows:

$$R = \frac{1}{U} - (R_i + R_e) \quad \text{(m}^2\text{K)/W} \tag{10}$$

When we know the average temperature of air in air layer "$\overline{\theta}_x$", we can determine the value of heat transfer coefficient "$\overline{U}$ "according to the equation:

$$\overline{U} = U_i \frac{\theta_i - \overline{\theta}_x}{\theta_i - \theta_e} \quad \text{W/(m}^2\text{.K)} \tag{11}$$

and the average value of thermal resistance of the structure with ventilated insulating air layer according to the equation:

$$\overline{R} = \frac{1}{\overline{U}} - (R_i + R_e) \quad \text{(m}^2\text{.K)/W} \tag{12}$$

a) For the average value of air temperature in air layer $\overline{\theta}_x$ = **-12.81°C:**

$\overline{U}$ = 0.1855 W/(m^2.K) a $\overline{R}$ = **5.22** m^2.K/W

b) For the average value of air temperature in air layer $\overline{\theta}_x$ = **-12.423°C:**

$\overline{U}$ = **0.1834** W/(m^2.K) a $\overline{R}$ = = **5.283** m^2.K/W

Thermal resistance of open (ventilated) air layer will be determined from the formula below:

$$\boldsymbol{R_{w,otv}} = \overline{R} - (R_1 + R_2) \quad \textit{(m}^2\textit{.K)/W} \qquad R_1 \text{ and } R_2 \tag{13}$$

a) **R$_{w,otv}$** = $\overline{R} - (R_1 + R_2)$= 5.220 – (5.15 + 0.0297)= **0.040** (m^2.K)/W

b) **R$_{w,otv}$** = $\overline{R} - (R_1 + R_2)$= 5.283 – (3.798 + 0.165)= **0.103** (m^2.K)/W

4 Assessment of proposed external structures of the reference building

The proposed structures of external wall were assessed according to STN 73 0540-2/Z1 [12], [13]. The following thermal-physical parameters were assessed for the given boundary conditions on the basis of evaluation of the Heat 2010 program: minimum thermal resistance of the structure, surface temperature of structures with critical temperature for the production of fungi, the quantity of condensed and evaporated water steam in the structure [14]. The calculated values of parameters are stated for individual types of structures -Table 1.

Standard values for assessment of individual structures:

STN 73 0540-2/Z1, Tab.1 $U_{r1} = 0.22$ W/(m^2.K) for external walls
STN 73 0540-2, Tab. 4 $\Delta\theta_{si} = 0.5$ K for uninterrupted heating
$M_c < M_{av}$: yearlong balance of condensed and evaporated water steam inside the structure, where M_{av} is yearlong quantity of evaporated water steam in kg/(m^2·a).

4.1 Assessment of thermal-technical parameters of proposed structures A to C3

Structure A: masonry with plaster
Structure B: masonry with glued ceramic lining
Structure C1: masonry with ventilated insulating air layer insulating air layer and with ceramic lining at the temperature $\theta_e = -13$ °C
Structure C2: masonry with ventilated insulating air layer and with ceramic lining at the temperature $\theta_e = \overline{\theta}_x = -12.81$ °C
Structure C3: masonry with ventilated insulating air layer and with ceramic lining at the temperature $\theta_e = \overline{\theta}_x = -12.423$ °C

Table 1 Calculated values for individual types of structures

Parameter		Struct. A	Struct. B	Struct. C1	Struct. C2	Struct. C3
Internal surface temperature θ_{si} °C		18.53	18.49	18.48	18.49	18.51
Heat transfer coefficient *U* W/(m^2.K)		0.182	0.187	0.188	0.188	0188
Quantity of water steam M_c, M_{av} kg/(m^2.a)		cond. 0.786	cond. 1.723	cond. 0.011	cond. 0.010	cond. 0.006
		evap. 5.210	evap.1.564	evap. 10.938	evap. 10.938	evap. 10.938

Note to Table 1: Struct. = Structure; yearlong balance of moisture; cond. = quantity of condensed water steam, evap. = quantity of evaporated water steam

Table 2 Comparison with standard values

Parameter	Struct. A	Struct. B	Struct. C1	Struct. C2	Struct. C3
Internal surface temperature θ_{si} °C	18.53 > 13,12	18.49 > 13,12	18.48 > 13,12	18.49 > 13,12	18.51 > 13,12
Heat transfer coefficient *U* W/(m^2.K)	0.182 < 0,22	0.187 < 0,22	0.188 < 0,22	0.188 < 0,22	0.188 < 0,22
Quantity of water steam $M_c < M_{av}$ kg/(m^2.a)	0.786< 5.210	1.723 > 1.564 Does not meet	0.011 < 10.938	0.010 < 10.938	0.006 < 10.938

As it follows from *Tab.2*, structures A and C meet standard requirements. In the case of variant “B”, in which external structure is proposed with glued ceramic lining on the side of exterior, the proposal does not meet standard requirement of yearlong balance of condensed and evaporated water steam inside the structure. The better values are achieved by structure C, in which water steam is condensed during year only in a very small quantity, which is negligible against evaporated quantity of water steam.

4.2 Comparison of structure C1 with structures C2 and C3

In the case of structure C1, standard value of outdoor air temperature θ_e = *-13°C* (according to the area) was taken into account in the calculation. In the case of structure C2, the value of outdoor temperature was increased by influence of open air layer, so the values $\theta_e = \overline{\theta}_x =$ *-12.81°C* and $\theta_e = \overline{\theta}_x =$ *-1.423°C* were taken into account in the calculation, where $\overline{\theta}_x$ is the average temperature of air in open air layer. Due to difference of values of outdoor air temperature, different results of evaluation of the structure were achieved (*Tab.3*) in calculation carried out according to STN 73 0540-2/Z1 (Table 1) in comparison with the calculation according to STN 73 0549 (cancelled).

Table 3 Comparison of structure C1 with structures C2 and C3

Parameter	C1	C1/C2	Percentage difference [%]	C1/C3	Percentage difference [%]
Internal surface temperature θ_{si} [°C]	18.48	18.49	-	18.51	0.12
Heat transfer coefficient *U* [W/(m^2.K)]	0.188	0.188/0.1855	1.33	0.188/0.1834	2.45

On the basis of comparison of structure C1 with structures C2 and C3 (Tab. 3) we can see that difference between the values of surface temperature θ_{si} is minimal. Differences in the calculation of values of heat transfer coefficient are also negligible against the value of heat transfer coefficient U_{r1} recommended by the standard.

5 Conclusion

On the basis of the evaluation of thermal-technical parameter results of proposed external structures of the reference building, variant of the external structure with ventilated insulating air layer and ceramic lining meets valid standards and requirements. Thanks to air layer between the façade cladding and external wall, flow of air and elimination of moisture are ensured. In summer, air gap prevents excessive heating of the building, and improve effectiveness of thermal insulation. In winter, thermal insulation in cooperation with ventilated air gap provides smaller consumption of thermal energy for heating.

In addition to the aforementioned facts, it is necessary to care of anchorage of external claddings. The existing practice in dimensioning anchorage of external claddings takes into account only their load by external pressure. In the case of non-bearing structure, this is not sufficient, and it is necessary to take into account effects of internal pressure. In the case of certain operating situations in the building (for example opening windows), internal pressure can be increased, and when this effect is neglected for overall load, defects and even failure of anchorage of external claddings can subsequently occur.

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