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Aspects of calculation of resistance vapor penetration of enclosing structures

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When determining the resistance to vapor penetration of the vapor barrier layer which is based on the zero balance of moisture accumulation per year and the value of the allowable increase in moisture content of the material during the period of moisture accumulation. The temperature and relative humidity of the outside air for the period of the three coldest months of the heating period or the period with average monthly negative temperatures are usually used in the calculations. Although, the duration of the moisture accumulation period may not coincide with this period, and the value of the resistance to vapor penetration of the vapor insulation in the enclosing structures may not be determined correctly. The clarification of the calculation methodology was suggested. It is necessary to determine the months, when moisture accumulation occurs in the insulation of the enclosing structure, after determining the average temperature and relative humidity of the outside air during these months and calculate the resistance to vapor penetration of the vapor insulation layer.

Keywords: resistance to vapor penetration, vapor barrier, moisture accumulation, enclosing structures

Аспекти розрахунку опору паропроникненню пароізоляції огороджувальних конструкцій

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Робота присвячена уточненню методики визначення розрахункових параметрів зовнішнього повітря (температури та відносної вологості) та величини опору паропроникненню шару пароізоляції. При визначенні опору паропроникненню шару пароізоляції виходять з нульового балансу вологонакопичення за рік та величини допустимого підвищення вологості матеріалу протягом періоду вологонакопичення. Зазвичай використовують у розрахунках температуру та відносну вологість зовнішнього повітря за період трьох найбільш холодних місяців опалювального періоду або періоду із середньомісячними від'ємними температурами. Але тривалість періоду вологонакопичення може не співпадати з цим періодом і величина опору паропроникненню пароізоляції в огороджувальних конструкціях, з умови підвищення вологості матеріалу протягом періоду вологонакопичення, може визначатися не вірно. Для підвищення точності розрахунку пропонується використовувати період місяців, коли відбувається вологонакопичення в утеплювачі огороджувальної конструкції. Було проведено перевірку на прикладі суміщеного покриття житлового будинку, побудовані графіки зміни парціального тиску насиченої водяної пари (E) та фактичного парціального тиску (e) у місяці року, коли відбувається накопичення вологи в огородженні (утеплювачі), виконано розрахунки вологонакопичення в шарі утеплювача з визначеною величиною опору паропроникненню пароізоляції. Було запропоновано уточнення методики розрахунку. Так, на початку, за методикою наведеною у ДСТУ-Н Б В.2.6-192:2013, необхідно визначити місяці коли відбувається вологонакопичення в утеплювачі огороджувальної конструкції. Потім визначити середні температуру та відносну вологість зовнішнього повітря протягом цих місяців та розрахувати опір паропроникнення шару пароізоляції.

Ключові слова: опір паропроникненню, пароізоляція, вологонакопичення, огороджувальні конструкції

Introduction

Heat-shielding features of building envelopes meaningfully depend on humidity conditions. The moisture condition of external enclosing structures may be influenced by many values. One of these values is the vapor penetration resistance of the vapor barrier layer. The deterioration of the moisture condition of the fence is the result of the inaccuracy in determining the latter. Eventually, it reduces its heat-protective power features.

Review of the research sources and publications

Many researchers have been investigating the method of determining the resistance to vapor penetration of a part of the enclosing structure located between the inner surface of the enclosure and the zone (or plane) of water condensation, or directly the vapor insulation layer. The most famous researchers who dedicated themselves to organizing around this issue are A. Perekhozhintsev, V. Kupriyanov, I. Safin, V. Gagarin, P. Khavanov, K. Zubarev. The results of their work are set out in [1-6], they propose to solve the problem of determining the resistance to vapor penetration of the vapor barrier layer by an analytical or graph-analytical method. The humidity mode of enclosing structures, including the resistance to vapor penetration of structural layers, considered by researchers Yu. Vytchikov, M. Saparev, A. Kostuganov, R. Černý, J. Podêbradská, J. Drchalová, M. Jerman [7-9] and others. The work is a continuation of the research of the authors [10-13], who study the temperature-humidity regime of enclosing structures and their impact on the energy efficiency of buildings in general.

Definition of unsolved aspects of the problem

It is admitted that moisture accumulation per year and values of permissible increase in moisture content of material during the period of moisture accumulation are based on zero balance in the determination of resistance to vapor penetration of vapor insulation layer [14]. That is why the amount of moisture that accumulates in the enclosure during the year is equal to the amount of moisture removed from the enclosure; the increased moisture content of the material during the moisture accumulation period does not exceed the normalized value. Researchers, who deal with this issue, propose to use outside temperature and relative humidity in calculations for the three coldest months of the heating period or the period with average monthly negative temperatures. However, the duration of the moisture accumulation period may not coincide with this period. Therefore, the value of the vapor penetration resistance of the vapor insulation in the enclosing structures, based on the condition of increasing the moisture content of the material during the period of moisture accumulation, may not be determined quite right.

Problem statement

The purpose of the work was to clarify the method of determining the calculated parameters of the external air (temperature and relative humidity) and the value of resistance to vapor penetration of the vapor barrier layer. Thereby, the method of calculating moisture accumulation in the fence was used according to the [14] to manage this issue.

Basic material and results

Modern standards for assessing the thermal and moisture condition of enclosing structures [15] require the fulfillment of two requirements.

The first requirement is to increase the moisture content of the material in the thickness of the structure layer

$$\Delta w \; \Delta w_p \,, \qquad (1)$$

where Δw is the increase in moisture content of the material in the thickness of the structure layer, in which moisture condensation can occur, during the cold period of the year, % by weight;

Δw_p is the permissible increase in humidity of the material in the layer of which moisture condensation can occur, % by weight, set according to table 8 [15] depending on the type of material.

The following condition must be implemented for a negative or zero annual balance of moisture in the thickness of the enclosing structures.

The second requirement is zero annual moisture balance in the thickness of the enclosing structures.

$$W_{wp} \le W_{sp} \,, \qquad (2)$$

where W_{wp} is the amount of moisture accumulated in the thickness of the enclosing structure, which condensed over the period of moisture accumulation of the year, kg/m^2;

W_{sp} is the amount of moisture vaporizing from the fence during the moisture release period of the year, kg/m^2.

Vapor permeability resistance of vapor insulation layer in enclosing structures is determined by analytical or graphoanalytic method. The graphoanalytic method allows determining the resistance to vapor penetration of the vapor insulation layer only from requirement 2 (Figure 1).

Resistance permeability resistance of vapor insulation by the analytical method is determined according to [15] by the following formulas.

The first requirement

$$R_{e.vi} = \frac{0.0024 \cdot Z_0 \cdot (e_i - E_{w.c})}{\rho_c \cdot \delta_c \cdot \Delta W_p + \eta} - R_{e.i} \,, \qquad (3)$$

where Z_0 is the number of days of the period with negative average monthly ambient temperatures;

e_i – internal air vapor partial pressure, Pa;

$E_{w.c}$ – partial pressure of saturated water vapor, Pa, in the condensation plane for the period with negative average monthly temperatures;

ρ_c – density of the material layer in which condensable moisture accumulates, kg/m^2;

σ_c – thickness of the layer of material in which condensable moisture accumulates, m;

$R_{e.i}$ – resistance to vapor penetration, m^2 hour Pa, parts of the enclosing structure located between the condensation zone and the internal surface of the enclosure.

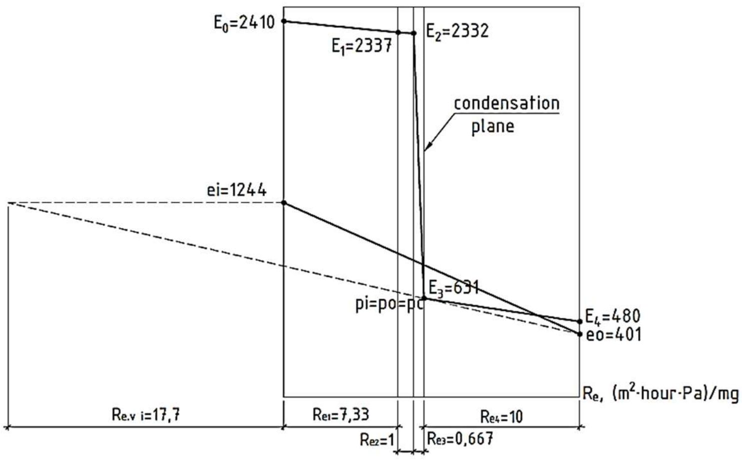

Figure 1 – Determination of vapor permeable layer resistance of vapor insulation

Value η determined by formula

$$\eta = \frac{0.0024 \cdot Z_0 \cdot (E_{w.c} - e_i)}{R_{e.o}} , \quad (4)$$

where e_o – partial pressure of water vapor, Pa, outdoor air for the period with negative average monthly temperatures;
$R_{e.o}$ – vapor permeability resistance, m^2 hour Pa, part of enclosing structure located between condensation zone and external surface of enclosing.

The second requirement

$$R_{e.vi} = \frac{e_i - E_{w.c.year}}{E_{w.c.year} - e_o} - R_{e.i} , \quad (5)$$

where $E_{w.c.year}$ – annual average partial pressure of saturated water vapor, Pa, in the condensation plane.

Typically, the resistance to vapor penetration of vapor insulation is defined by formulas (3) and (4), more frequently than formula (5). Therefore, we consider only formulas (3) and (4). They have gotten the duration of the moisture accumulation period and the average partial pressure of outdoor water vapor that is taken as a period with negative average monthly temperatures. However, the duration of the period with negative average monthly temperatures may differentiate from the period of moisture accumulation in the fence. This may affect the accuracy of determining the vapor permeability resistance of the vapor barrier layer. To verify this statement, the vapour penetration resistance value was calculated, the moisture accumulation value was determined with a certain vapour insulation resistance and an increase in the humidity of the insulation during the moisture accumulation period.

The examination was carried out for the combined coverage (Figure 2) of a residential building in Poltava.

Insulation was taken from mineral wool with density 100 kg/m^2. The period of months with negative temperatures consisted of three months: December, January, and February. The average outside air temperature for these months was t_o = –4.57ºC. Accordingly, the relative humidity was φ_o = 84.7 %.

Value of resistance to vapor penetration of the vapor insulation layer, which was determined by formulas (3) and (4), was $R_{e.vi}$=2.37 m^2 hour Pa/mg.

Graphs of changes in the partial pressure of saturated water vapour (E) and actual partial pressure (e) during the months of the year when moisture accumulates in the enclosure (insulation) are given in Figure 3.

The results of the calculation of moisture accumulation in the mineral wool layer with a certain value of the vapor penetration resistance of the vapor insulation are shown in Table 1.

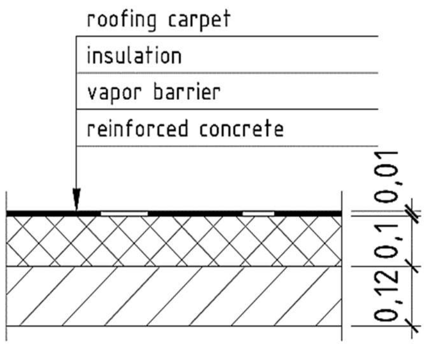

Figure 2 – Design diagram of a combined coating

Table 1 – Amount of moisture that accumulates in the condensation plane

Month of year	Amount of accumulated moisture W_{wp}, kg/m^2
October	0.0013
November	0.055
December	0.0812
January	0.0909
February	0.0859
March	0.0571
	W_{wp}= 0.371

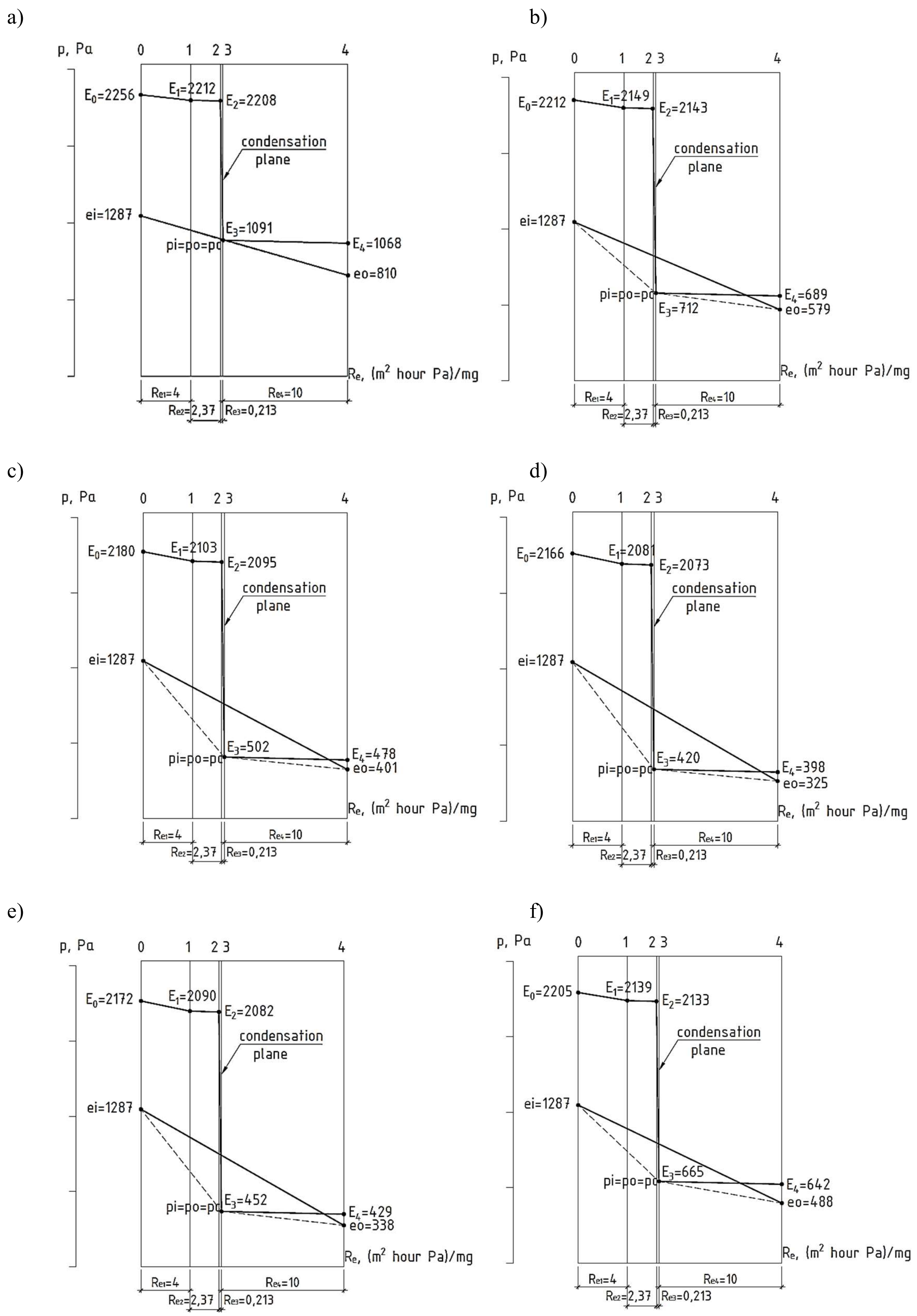

Figure 3 – Graphs of changes in partial pressure of saturated water vapour (E) and actual partial pressure (e):
a) in October; b) in November; c) in December;
d) in January: e) in February; f) in March.

Moisture gain in insulators is $\Delta w = 3.71$ %, which exceeds the allowable value of heat insulation characteristics of material humidity increase Δw_p. Looking at eable 8 [15], this value is Δw_p =2.5 % for mineral wool. It means that the resistance to vapor penetration of the vapor insulation is insufficient to implement requirement 1 (formula 1). It ought to be explained by the fact that moisture accumulation lasts six months, and the duration, which is accepted, when determining the vapor penetration resistance of the vapor insulation layer lasts only three months during the period with negative ambient air temperatures. In order to improve the accuracy of calculation of vapor penetration resistance of vapor insulation according to formulas (3) and (4), it is proposed to use the period of months when humidity increases in the insulator instead of a period with negative ambient air temperatures. The application of this change requires clarification of the calculation order. In the beginning, it is essential to identify the months when moisture accumulation occurs. It is necessary to figure out the average temperature and relative humidity of the outside air during these months. Afterward, it is quite important to determine resistance to vapor penetration of vapor insulation by formulas (3) and (4). Appropriate calculations have been made to verify the proposed changes.

To sum up, the period of damp accumulation lasts from October to March from previous studies. The average outside air temperature for these months was t_o = –0.73°C. Accordingly, the relative humidity was φ_o = 82.5 %.

The value of resistance to the vapor penetration of the vapor insulation determined by formulas (3) and (4), is $R_{e.vi}$=5.03 m^2 hour Pa/mg.

The results of the calculation of moisture accumulation in the mineral wool layer with a certain value of vapor penetration resistance of the vapor insulation are shown in Table 2.

Table 2 – Amount of moisture that accumulates in the condensation plane

Month of year	Amount of accumulated moisture W_{wp}, kg/m^2
October	0.005
November	0.036
December	0.056
January	0.063
February	0.059
March	0.037
	W_{wp}= 0.256

Moisture gain in heat insulation material is Δw =2.56 %. This gain exceeds the allowable value of heat insulation characteristics of material humidity increase Δw_p =2.5 %. This result is most likely due to the rounding of ambient temperature and relative humidity values used in the determination $R_{e.vi}$ and with rounding the amount of moisture accumulating in the heat insulation material in different months of the year. To prevent such a situation, it is proposed to increase the resistance to vapor penetration of the vapor insulation by 4%. It means that it is necessary to apply an increasing coefficient $k_{inc} = 1{,}04$ in formula (3). Consequently, the formula will take the form

$$R_{e.vi} = \left(\frac{0.0024 \cdot Z_0 \cdot (e_i - E_{w.c})}{\rho_c \cdot \delta_c \cdot \Delta W_p + \eta} - R_{e.i} \right) k_{inc} \,, \qquad (6)$$

Using this formula, the resistance to vapor penetration of the vapor insulation is $R_{e.vi}$=5.23 m^2 hour Pa/mg.

The results of the calculation of moisture accumulation in the mineral wool layer with a certain value of the vapor penetration resistance of the vapor insulation are shown in Table 3.

Table 3 – Amount of moisture that accumulates in the condensation plane

Month of year	Amount of accumulated moisture W_{wp}, kg/m^2
October	0.005
November	0.035
December	0.054
January	0.062
February	0.057
March	0.036
	W_{wp}= 0.249

Moisture gain in insulators is Δw =2.49 %, that does not exceed the allowable value of heat insulation characteristics of material humidity increase Δw_p =2.5 %.

Conclusions

During the usage of the vapor insulation layer in the calculation of vapor penetration resistance for the period of months with negative ambient air temperatures, the increase of insulation humidity exceeds the normalized value explained in [15]. This is because the duration of moisture accumulation is usually longer than the period with negative ambient temperatures.

It is proposed to use the period of months in formulas (3) and (4) when moisture accumulation occurs material of the enclosing structure of the heat insulation to improve the accuracy of the calculation.

It is also proposed to use an increasing coefficient k_{inc} = 1.04 (Formula 6).

The implementation of this proposal strongly requires a change in the calculation method. In the beginning, it is necessary to determine the months according to the procedure given in [14], when moisture accumulation occurs in the insulation of the enclosing structure. Therefore, determine the average temperature and relative humidity of the outside air during these months and calculate the vapor penetration resistance of the vapor insulation layer by formulas (6) and (4).

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