

Dew point temperature as overwetting indicator of enclosing structures

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Abstract. Overwetting of enclosing structures is a negative factor of their operation. Due to the fact that it reduces thermal protection, it causes the corrosion processes and leads to enclosing structures materials destruction on account of alternating freezing and thawing. Present investigations on the analysis of condensation of moisture vapor and moist condition of enclosing structures does not allow for definition of overwetting rate of enclosures in the preset climate. These questions are also not regulated in the current normative documents. Enclosing structures developed as a result of conservation of energy have unpredictable accumulation of condensation and overwetting rate under service conditions. The article examines a new concept «dew point temperature» that is a characteristic of construction solution of enclosing structures and used materials. The dew point temperature is numerically equal to external temperature at which we can observe condensation in-plane of maximum overwetting of enclosing structures for the first time. It was demonstrated that every construction solution of enclosure has its own dew point temperature, according to which the amount of condensation in identical climatic conditions will be formed. The result of investigation is the assumption about the introduction of a new characteristic called «dew point temperature of enclosing structure» into the scientific discourse and into the check-list of mandatory thermotechnical values of enclosing structures. The dew point temperature describes the capacity of construction solution of enclosure for overwetting in the preset climatic conditions.

Keywords: condensation, overwetting, moisture vapor pressure, temperature, climate.

1 Introduction

Buildings and structures operation comes with transport of heat and moisture vapor through enclosing structures into external air. In winter months these flows are at the highest rate; they slacken to summer and can reverse their course. The temperature loss of buildings, energy demand on heating system and, totally, energy efficiency of design decisions are determined by heat flow rate. For this reason greater attention is paid to providing thermal protection during enclosure design.

The flow of moisture vapor defines the moist condition of enclosing structures, and their overwetting goes with thermal protection loss, corrosion processes and materials

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destruction of outer layers of enclosure at alternating freezing and thawing. However, the check and forecasting of overwetting of enclosing structures during their design are not regulated by current specification documents. There are a lot of scientific studies about the investigation of moist condition of enclosing structures [1-7]. These are very rigorous researches, but recommendations for enclosing structures design with the purpose of forecasting and reduction of their overwetting at specified climate cannot be also observed there. The section of Code of Practice (CP) 50 [8] named «protection against overwetting» does not determine the overwetting rate of enclosing structures, because calculation formulas characteristics are determined at the annual average values of climatic factors.

Phokin's grapho-analytical method in the estimation of steam condensation in enclosing structures is widely known in the design practice [9]. Besides, this method also does not allow determining overwetting duration and condensate amount, because it has a rank of inexactitudes and ambiguities. In such a way, Phokin's method puts out of account resistance to the moisture exchange near surfaces of enclosure. In this design method external temperature is not regulated, for this reason the predicted results depend on an arbitrary choice of temperature and can be polar opposite [10].

As a result, the purpose of the present study is the development of the physically valid evaluation and forecasting method of overwetting rate of enclosing structures during their operation in the preset climate. Such method will be an efficient instrument in the design of enclosing structures with a view to preventing their overwetting. Individual aspects of the new method are set out in studies [11-14].

2 Materials and methods

This section is concerned with justification for initial parameters and measuring method development of the dew point temperature of the moisture vapor in enclosing structures.

The condensation of moisture vapor appears in that part of enclosing structures where saturation point E becomes equal to the partial pressure of moisture vapor e , $E=e$ or $(E-e)=0$. Herewith, the saturation point of moisture vapor E over enclosing structures sections is defined by the temperature in these sections which, in accordance with thermal conductivity of material layers, depends on the external temperature t_e .

If the external temperature is sufficiently high then the saturation point E will be over than partial pressure e . The difference in pressure is a positive value $(E-e)>0$. The air humidity is less than 100 % and there is no condensation of the moisture vapor in material's pores. If t_e is sufficiently low then the saturation point E will be lower than the partial pressure e . Then it is impossible from the physical standpoint. Difference in pressure will be negative $(E-e)<0$. The air humidity is 100% and the condensate appears. Herewith, the lower external temperature t_e , on the larger part of cross section of the enclosure condensation can be observed and condensation zone appears.

Between high t_e , when condensation cannot be found, and low t_e , when the condensation zone appears, there must be such a temperature value at which the moisture vapor condensation appears and the condensation plane begins to form for the first time in the section of maximum wetting. This external temperature is called «dew point temperature t_d ».

The studies show that «dew point temperature» turns up as a thermotechnical parameter of enclosing structures and helps to reappraise the regularities of the moisture vapor condensation of enclosures.

Firstly, the dew point temperature represents generalized parameter of the construction solution of enclosures and used materials, the characteristics of which define the difference in pressure in a maximum wetting plane and the condensation appearance. In this regard, it

is safe to assume that every construction solution of enclosure will have its own dew point temperature.

Secondly, the dew point temperature t_d becomes a boundary at the temperature scale of the external air of construction site and divides this scale into two parts. When the external temperature is higher than t_d there is no moisture vapor condensation in the enclosure. When the external temperature is lower than t_d moisture vapor will condense in the enclosure.

Thirdly, when comparing t_d of the enclosing structure with the annual cycle of the external temperature of the construction site it is possible to expect the condensation level and degree of wetting of a designed enclosure in the preset climate, Fig. 1.

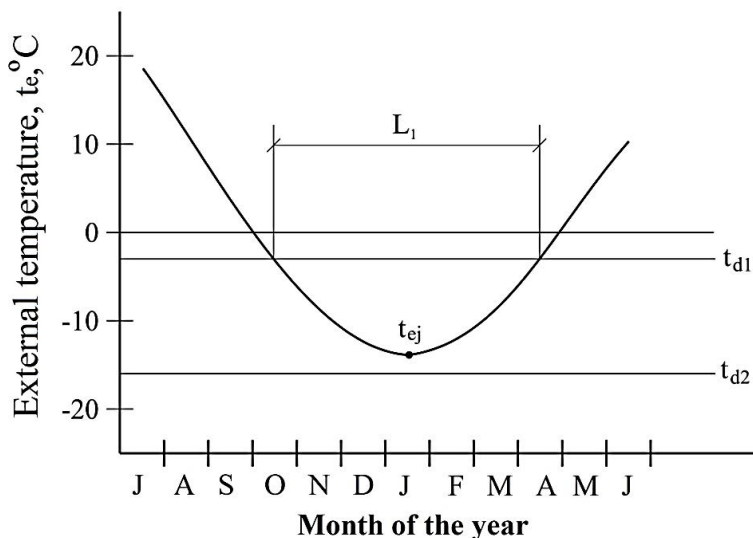


Fig. 1. Comparison of annual cycle of average monthly external temperatures with t_d of two relative enclosing structures.

In the enclosure #1 t_{d1} is higher than average temperature of the coldest month – January, t_{ej} and we can see long duration of the moisture vapor condensation L_1 and high «cold accumulation» based on the reduction t_e to t_{ej} and further to the minimum temperatures in the present climate.

In the enclosure #2 t_{d2} is situated lower than t_{ej} and we can expect a short duration and the amount of condensate based only on daily amphitheatres and eventual cold waves.

In such way, contrasting t_d with the annual cycle of t_e it is possible to predict the degree of the overwetting of enclosing structures during the operation on the stage of their design.

The definition of the dew point temperatures of the enclosing structures consists of two steps:

1. The resistance to the moisture exchange at internal R_{SI} and external R_{SE} surfaces, total resistance to the vapor transmissivity of the enclosing structures $R_{v10} = R_{SI} + R_{VT} + R_{SE}$ and the resistance to the vapor transmissivity of the part of enclosure from the internal air to the plane of maximum wetting are defined. At the base of definition of R_{SI} and R_{SE} the equality of flows of the moisture vapor on the all sections of the enclosing structure without condensation is underlined:

$$G_{\kappa} = \frac{e_i - e_{is}}{R_{is}} = \frac{e_{is} - e_{es}}{R_{vt}} = \frac{e_{es} - e_e}{R_{se}}, \text{ mg}/(\text{m}^2 \cdot \text{h}),$$

where R_{vt} is the resistance to the vapor transmissivity of material layers of enclosures.

The parameters e_{is} and e_{es} are determined through the temperatures of the enclosure surfaces τ_i and τ_e , the indoor relative humidity and the outside air humidity are determined by the formula $e = \varphi E / 100$, Pa.

2. The dew point temperature t_d is defined by the way of dependence $(E-e)$ on t_e creation by cross-section of maximum wetting at several external temperatures. Crossing of the dependence $(E-e)$ on t_e with horizontal $(E-e)=0$ points at the dew point temperature t_d .

The choice of the design outdoor air temperature is based on the following requirements: the one value must be sufficiently high when there is knowingly no condensation of the moisture vapor; the other value is sufficiently low when the condensation zone is formed in the enclosure; and between these 1-2 values of t_d the dependence $(E-e)$ on t_e is chosen for graphical construction.

The studies found that the optimum set of the design outdoor air temperature consisted of three values:

1. The average annual temperature;
2. The average monthly temperature of the coldest month – January;
3. The average monthly temperature of January decreased by the maximum daily amplitude.

3 Results

The measuring method of the dew point temperature t_d becomes a design tool of the enclosing structure. The value t_d is an indicator of the overwetting level prediction of the design enclosure at specified conditions of operation.

The developed measuring method of the dew point temperature is illustrated by numeric parameters.

Example. Define dew point temperature of three-layered enclosing structure.

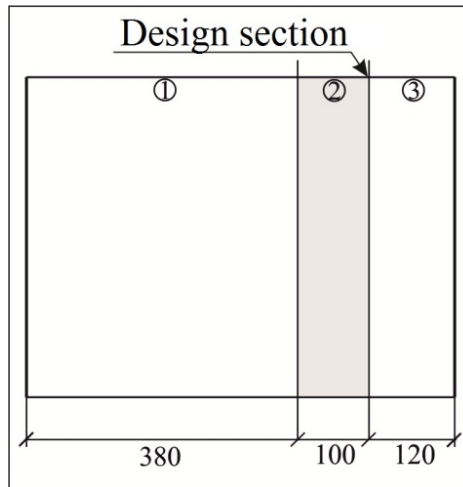


Fig. 1. Analytic model

The parameters of layers:

1. Ceramic brick, $\mu = 0.11 \text{ mg}/(\text{m} \cdot \text{h} \cdot \text{Pa})$, $\delta = 0.38 \text{ m}$ $\lambda = 0.7 \text{ Watt}/(\text{m} \cdot ^\circ\text{C})$,
2. Mineral wool, $\lambda = 0.042 \text{ Watt}/(\text{m} \cdot ^\circ\text{C})$, $\mu = 0.32 \text{ mg}/(\text{m} \cdot \text{h} \cdot \text{Pa})$, $\delta = 0.1 \text{ m}$.
3. Ceramic brick, $\lambda = 0.7 \text{ Watt}/(\text{m} \cdot ^\circ\text{C})$, $\mu = 0.11 \text{ mg}/(\text{m} \cdot \text{h} \cdot \text{Pa})$, $\delta = 0.12 \text{ m}$.

Indoor climate: $t_e = 20^\circ\text{C}$, $\varphi_e = 50\%$, $E_e = 2338 \text{ Pa}$, $e_e = 0.5 \cdot 2338 = 1169 \text{ Pa}$

The estimated climate parameters (Kazan):

1. The average annual temperature, $t_e = +4.2^\circ\text{C}$, $\varphi_e = 76\%$
2. The average monthly temperature of the coldest month – January, $t_e = -11.6$ °, $\varphi_e = 80\%$
3. The average monthly temperature of January decreased by the maximum daily amphitheater, $t_e = -21.8$ °, $\varphi_e = 84\%$

Basic thermotechnical parameters:

$$R_{T0} = 3.24 (\text{m}^2 \cdot ^\circ\text{C})/\text{Watt}, R_{T,3/\mu} = 3.2 (\text{m}^2 \cdot ^\circ\text{C})/\text{Watt},$$

$$R_{T,2/3} = 3.03 (\text{m}^2 \cdot ^\circ\text{C})/\text{Watt}, R_{vt} = 4.85 (\text{m}^2 \cdot \text{h} \cdot \text{Pa})/\text{mg},$$

The resistance to the moisture exchange at the internal R_{si} and external R_{se} surfaces at $t_e = +4.2^\circ\text{C}$ (with no condensation of the moisture vapor):

$$\tau_i = t_i - \frac{t_i - t_e}{R_{T0}} \cdot R_{ni} = 20 - \frac{20 - 4.2}{3.24} \cdot 0.11 = 19.5^\circ\text{C}, E = 2266 \text{ Pa}$$

$$e_i = 0.5 \cdot 2266 = 1133 \text{ Pa}$$

$$\tau_e = t_e - \frac{t_i - t_e}{R_{T0}} \cdot R_{T,3/\mu} = 20 - \frac{20 - 4.2}{3.24} \cdot 3.2 = 4.4^\circ\text{C}, E = 836 \text{ Pa},$$

$$e_i = 0.76 \cdot 836 = 635 \text{ Pa}$$

The flow of moisture vapor through the enclosure:

$$G_k = \frac{e_{is} - e_{es}}{R_{vt}} = \frac{1135 - 635}{4.85} = 103 \text{ mg}/(\text{m}^2 \cdot \text{h}),$$

$$R = \frac{e_i - e_{is}}{G_k} = \frac{1169 - 1133}{103} = 0.35 (\text{m}^2 \cdot \text{h} \cdot \text{Pa})/\text{mg},$$

$$R = \frac{e_{es} - e_e}{G_k} = \frac{635 - 627}{103} = 0.08 (\text{m}^2 \cdot \text{h} \cdot \text{Pa})/\text{mg},$$

$$R_{vt0} = R_{se} + R_{vt} + R_{se} = 0.35 + 4.85 + 0.08 = 5.28 (\text{m}^2 \cdot \text{h} \cdot \text{Pa})/\text{mg},$$

$$R_{vt,2/3} = R_{si} + \frac{\delta_1}{\mu_1} + \frac{\delta_2}{\mu_2} = 0.35 + \frac{0.38}{0.11} + \frac{0.1}{0.32} = 4.11 (\text{m}^2 \cdot \text{h} \cdot \text{Pa})/\text{mg},$$

The difference in pressure ($E - e$) at the design section 2/3:

$$\text{At } t_e = +4.2^\circ\text{C}, \varphi_e = 76\%, E_e = 825 \text{ Pa}, e_e = 0.76 \cdot 825 = 627 \text{ Pa}$$

$$\tau_{2/3} = t_i - \frac{t_i - t_e}{R_{T0}} \cdot R_{T,2/3} = 20 - \frac{20 - 4.2}{3.24} \cdot 3.03 = -5.2^\circ\text{C}, E_{2/3} = 885 \text{ Pa},$$

$$e_{2/3} = e_i - \frac{e_i - e_e}{R_{vt0}} \cdot R_{vt,2/3} = 1169 - \frac{1169 - 627}{5.28} \cdot 4.11 = 747 \text{ Pa}$$

Difference in pressure $(E - e) = 885 - 747 = 138 \text{ Pa}$

At $t_e = -11.6^\circ\text{C}$, $\varphi_e = 80\%$, $E_e = 225 \text{ Pa}$, $e_e = 0.8 \cdot 225 = 180 \text{ Pa}$

$$\tau_{2/3} = t_i - \frac{t_i - t_e}{R_{T0}} \cdot R_{T,2/3} = 20 - \frac{20 + 11.6}{3.24} \cdot 3.03 = -9.5^\circ\text{C}, E_{2/3} = 268 \text{ Pa},$$

$$e_{2/3} = e_i - \frac{e_i - e_e}{R_{vt0}} \cdot R_{vt,2/3} = 1169 - \frac{1169 - 180}{5.28} \cdot 4.11 = 399 \text{ Pa}$$

The difference in pressure $(E - e) = 268 - 399 = -131 \text{ Pa}$

At $t_e = -21.8^\circ\text{C}$, $\varphi_e = 84\%$, $E_e = 87 \text{ Pa}$, $e_e = 0.84 \cdot 87 = 73 \text{ Pa}$

$$\tau_{2/3} = t_i - \frac{t_i - t_e}{R_{vt0}} \cdot R_{vt,2/3} = 20 - \frac{20 + 21.8}{3.24} \cdot 3.03 = -19.1^\circ\text{C}, E_{2/3} = 11.2 \text{ Pa},$$

$$e_{2/3} = e_i - \frac{e_i - e_e}{R_{vt0}} \cdot R_{vt,2/3} = 1169 - \frac{1169 - 73}{5.28} \cdot 4.11 = 316 \text{ Pa}$$

The difference in pressure $(E - e) = 11.2 - 316 = -204 \text{ Pa}$

The calculation data of the difference in pressure $(E - e)$ are presented in the diagram, Fig. 3. As it can be seen from the figure, the dew point temperature of three-layered enclosing structure is $t_e = -3^\circ\text{C}$.

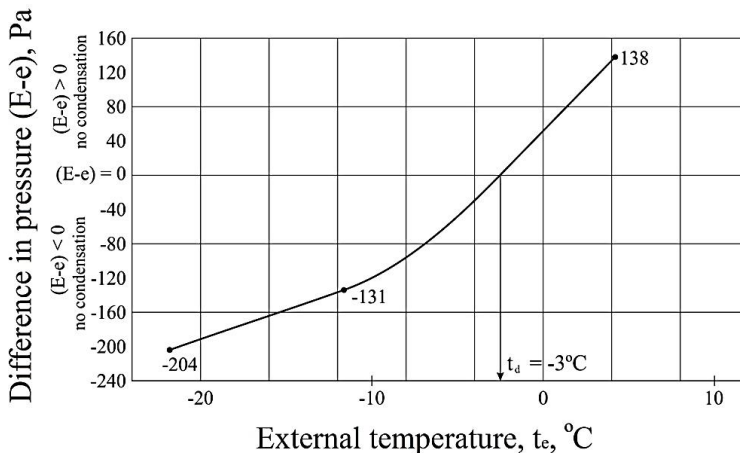


Fig. 3. The definition of the dew point temperature t_d of three-layered enclosure by the dependence $(E-e)$ on t_e .

The dew point temperatures of some enclosing structures that vary in the design solution and used materials (Table 1) are computed using analogous algorithm. The research results included in Table 1 are previously received [13], (1-st and 4-th lines). The sixth table column «T, hours» represents the duration of the external temperature operation lower than

t_d [15, 16]. The seventh column shows the amount of condensate grams in 1 m² of enclosure $\sum Q_c$ which will accumulate in enclosure in a time T.

Table 1. The dew point temperatures of some enclosing structures.

No.	Enclosing structure	$R_{T0},$ $\frac{m^2 \cdot ^\circ C}{Watt}$	$R_{vt0},$ $\frac{m^2 \cdot h \cdot Pa}{mg}$	$t_d,$ $^\circ C$	T, hours	$\sum Q_c,$ g/m ²
1	2	3	4	5	6	7
1	Multilayered with construction layer made of brick and monolithic aerated concrete heat insulation	2.40	3.86	0	4101	631.9
2	Three-layered made of ceramic brick and mineral-wool heat insulation	3.24	5.28	-3	2918	144.4
3	One-layered made of ceramic brick with the thick of 77 cm	1.25	8.69	-13	1130	42.5
4	Multilayered with construction layer made of cast reinforced concrete and extruded foam polystyrene heat insulation	3.62	23.02	-16	885	6.6

4 Discussion

Table 1 shows that t_d of enclosing structures goes from 0 °C to -16 °C. It confirms the previously made assumption that every enclosing structure has its own dew point temperature. It can be also seen that in the same climate in different enclosing structures the moisture vapor condensation will begin at different external temperatures and, consequently, there will be different duration of condensation period (T, hours) and different amount of condensate ($\sum Q_c$, g/m²). In such a way, in the enclosing structure #1 ($t_d = 0^\circ C$), T=4101 hour and $\sum Q_c = 631.9$ g/m², and in the enclosing structure #4 ($t_d = -16^\circ C$), T=885 hour and $\sum Q_c = 6.6$ g/m².

Thus, with a decrease of t_d both the duration of wetting (T, hours) and the amount of condensate ($\sum Q_c$, g/m²) decrease. It confirms the function of a parameter «dew point temperature t_d » as the overwetting level indicator of enclosing structures.

To protect against the overwetting it is required to design enclosures with the decreased value of t_d . In addition, the optimum level of «decreasing t_d » can be based on the comparison of t_d with annual cycle of temperature of outside air (in equivalent to Fig. 1).

It should be noted that the resistance to the vapor transmissivity of enclosing structures R_{v0} (column 4 of the table) is correlated in a definite way with t_d , T and $\sum Q_c$. It seems that R_{v0} appears as a primary parameter during the design of enclosing structures with decreased value of t_d .

5 Conclusion

1. The research results have shown that the dew point temperature of enclosing structures represents the generalized parameter of the design solution and used materials, appears as a new thermotechnical parameter and the indicator of their overwetting during operation.

2. The developed measuring method of the dew point temperature is a new instrument of designing. It provides means for predicting the overwetting level of enclosing structures in the preset climate in the design process and makes allowances to design solutions and to the choice of materials.

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