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EVALUATION OF THE INFLUENCE OF THERMOTECHNICAL QUALITY OF THE EXTERNAL WALL ON THE TEMPERATURE IN THE CORNER OF THE ENCLOSURE ON THE EXAMPLE OF PROTECTION MADE OF CELLULAR CONCRETE

ABSTRACT

In this article, one cause for unsatisfactory condition of rooms is described and the engineering method for determination of temperature in outer corners of rooms intended for various purposes is offered.

It is demonstrated that, with water vapour condensation, several adverse effects arise that can be prevented as early as at the design stage. The study covered the causes of local temperature reduction resulting from variations of heat exchange conditions due to the corner geometry; as a result, temperature on the wall surface in a corner will always be lower than temperature on the "smooth surface" of an enclosing structure. The analysis of technical normative legal acts being in force in the territory of several ex-USSR countries has been carried out and, as a result, it was found that no design equations are available even for approximate assessment of temperature in a corner. The expressions available in reference and educational literature are valid only for a small range of thermal resistances of structures. The similar design procedure in terms of mould fungi growth is available in German norms for the design of thermal protection of buildings.

To find the design equation, calculations of temperature fields were carried out for outer corners of walls with various values of thermal resistance (up to 10 m²•K/W) and various values of heat exchange factor on the inner surface. In the first case, the factor was assumed to be the same *as the factor on the enclosure “smooth surface”; in the second and third case, its reduction was taken into consideration in accordance with data available from Belarusian scientists and from foreign norms.*

The result of this research is the derivation of the approximative function, f(R), depending on the thermal resistance of a structure. For convenience of use, the values of this function were tabulated. This design method may be recommended for application by design organizations, with the possible subsequent implementation in construction norms.

Keywords: approximation, standardization, thermal resistance, heat exchange, temperature field, the temperature in the outer corner.

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ОЦЕНКА ВЛИЯНИЯ ТЕПЛОТЕХНИЧЕСКИХ КАЧЕСТВ НАРУЖНОЙ СТЕНЫ НА ТЕМПЕРАТУРУ В УГЛУ ОГРАЖДЕНИЯ НА ПРИМЕРЕ ОГРАЖДЕНИЯ ИЗ ЯЧЕИСТОГО БЕТОНА

АННОТАЦИЯ

В статье излагается одна из причин неудовлетворительного состояния помещений и предлагается инженерный способ определения температуры в наружном углу помещений различного назначения.

Показано, что при конденсации водяного пара возникает ряд негативных последствий, которые можно предотвратить еще *на стадии проектирования. Рассмотрены причины локального понижения температуры, вызванные изменениями условий теплообмена вследствие геометрии угла, ввиду чего температура на поверхности стены в углу будет всегда меньше температуры по «глади» ограждающей конструкции. Проведя анализ технических нормативных правовых актов, действующих на территории некоторых стран бывшего СССР, было установлено отсутствие расчетных зависимостей для хотя бы приближенной оценки температуры в углу. Имеющиеся в справочной и учебной литературе выражения справедливы только для малого диапазона термических сопротивлений конструкции. В немецких нормах на проектирование тепловой защиты зданий встречается аналогичный расчет на образование плесневых грибов.*

Для выявления расчетной зависимости были проведены расчеты температурных полей наружных углов стен с различным термическим сопротивлением (до 10 м²•К/Вт) и различными значениями коэффициента теплообмена у внутренней поверхности. В первом случае коэффициент принимался таким же, как и на «глади» ограждения, во втором и третьем – с учетом его снижения по данным отечественных ученых и зарубежных норм.

Результатом исследования явилось получение аппроксимативной функции f(R), зависящей от термического сопротивления конструкции. Для удобства пользования значения данной функции были затабулированы. Данный метод расчета может быть рекомендован для использования проектными организациями с возможным последующим включением в строительные нормы.

Ключевые слова: аппроксимация, нормирование, термическое сопротивление, теплообмен, температурное поле, температура в наружном углу.

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INTRODUCTION

An unfavourable factor affecting the durability of enclosing structures, sanitary-engineering condition of rooms and comfort of human staying in them is condensation of water vapour on the inner surface, especially in outer corners, that takes place when the surface temperature is below the room air dew point. Moisture drops on a surface result in negative effects as follows:

– mould fungi growth;
– room interior finish damage;
– moisture penetration inwards the enclosure where it can freeze and destroy the structure (subject to good water permeability of materials).

Technical normative legal acts of the Republic of Belarus for construction thermal engineering [1] that differ only slightly from those that were in force in the Soviet Union (in some cases, the former are even worse than the latter) and, respectively, identical to those that are in force in the territories of the Russian Federation, the Republic of Kazakhstan, Ukraine and several other countries (with some revisions), contain no requirements for checking the temperature in an outer corner. However, the Western experience of design of enclosing structures, such as in Germany [2], includes the design in terms of mould fungi growth that consists of calculation of the relative humidity of inner air that results in hazard of mould growth. Below, easier method for determination of condensate formation potential will be given.

CAUSES FOR TEMPERATURE REDUCTION IN AN OUTER CORNER

Temperature in an enclosure corner is lower than temperature on the wall “smooth surface” due to several factors.

First, this is due to unequal areas on the inner and outer side of the corner, resulting in more intensive cooling. Let’s consider the heat balance equation for a corner: the heat flow given up by the inner surface of a corner from the inner air is equal to the heat flow given up from the outer surface to the outer air, i.e.

$$\alpha_i F_i (t_i - t_o) = \alpha_o F_o (t_{o.c} - t_o), \qquad (1)$$

where α_i and α_o are, respectively, the heat exchange factor at the inner surface and the outer surface of an outer wall, W/(m²•K);

F_i and F_o are the outer corner area by the inner and outer measurement, m²;

t_i and t_o are the design temperature of the inner and outer air, °C;

t_c and $t_{o.c}$ the design temperature on the inner surface and the outer surface of a corner, °C.

According to the data available in [3], disturbance of homogeneity of temperature field takes place at a distance within two enclosure gauges by the inner measurement. Here, the enclosure gauge means the nominal thickness of the equivalent homogeneous enclosure with the heat transfer resistance R_h, m²•K/W, and the heat insulation thermal conductivity factor λ_{in}, W/(m•K). Thus, the two-gauge width a_f, m, shall be

$$a_f = 2R_h\lambda_{in}.$$

For a wall with the height h, m, and thickness δ_w, m, the area by the inner measurement shall be $F_i = 2a_f h$, and the area by the outer measurement shall be $F_o = 2(a_f + \delta_w)h$. By substituting these data into the equation and expressing the temperature difference ratio, we obtain

$$\frac{t_i - t_c}{t_{o.c} - t_o} = \frac{a_o}{a_i}\frac{a_f + \delta_w}{a_f}. \qquad (2)$$

The enclosure heat transfer resistance

$$R_h = \frac{1}{\alpha_i} + \sum_{i=1}^{n} R_i + \frac{1}{\alpha_o},$$

where R_i is the thermal resistance of the layer of material of the enclosing structure, m²•K/W; for a uniform layer (except for closed air spaces), it is calculated as the ratio of thickness δ_i, m, to the material thermal conductivity λ_i, i.e. $R_i = \delta_i/\lambda_i$.

Thus, the minimal value of the single-layer homogeneous wall gauge will converge to the double width of an enclosure, $a_f^{min} \to 2\delta_w$. As a result, the equation shall be transformed as follows:

$$\left(\frac{t_i - t_c}{t_{o.c} - t_o}\right)_{max} = 1{,}5\frac{\alpha_o}{\alpha_i}. \qquad (3)$$

Assuming the normative values of heat transfer factors, α_i = 8.7 W/(m²•K) and α_o = 23 W/(m²•K) [1], we obtain that the difference of temperatures in a corner within a room will exceed the difference of temperatures outdoors 4 times maximum, and the higher is the enclosure heat transfer resistance, the closer is this ratio to its maximum value.

The second cause for temperature reduction in a corner is the reduction of the heat exchange factor α_i due to the reduction of heat transfer by radiation and reduction of convective currents near the surface. According to the data from Prof. K. F. Fokin [4], the radiant heat flow becomes two times less and, therefore, it is reasonable to assume α_i = 5.8 W/(m²•K). In DIN 4108-2 [2], the assumptions are α_i = 4 W/(m²·K), for heated rooms, and α_i = 6 W/(m²•K), for unheated rooms.

STANDARDIZATION OF WALL SURFACE TEMPERATURE IN AN OUTER CORNER

See 1 for the depiction of temperature fields in an outer corner of a wall with the thickness 400 mm, made of gas silicate with the density 400 kg/m³, for the design air temperature in a room t_i = 20 ºC and the outer air temperature t_o = –24 ºC, corresponding to the temperature of a cold five-day period, with the occurrence 0.92, for the conditions of the city of Minsk.

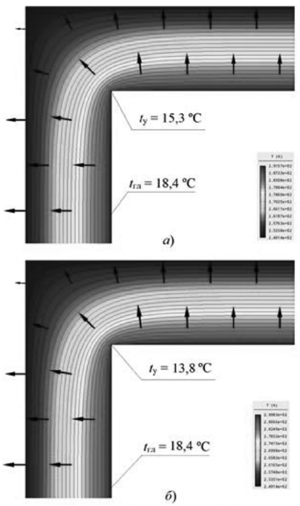

Figure 1. Temperature fields in an outer corner of a single-layer outer wall *a*) for α_i = 8.7 W/(m²·K), *b)* for α_i = 5.8 W/(m²·K)

The software Agros2D was used to calculate the temperature fields. The heat exchange factors near an inner surface are assumed to be 8.7 W/(m²•K) and 5.8 W/(m²•K); near an outer surface, 23 W/(m²•K). The interval between isotherms is 2 °C. Arrows indicate the heat flow direction.

We see from the modeling data that the temperature in an outer corner, with the conditions approximating the near-real conditions (α_i = 5.8 W/(m²•K)), is t_c =13.8 °C, i.e. it exceeds by 3.1 °C the dew point t_d = 10.7 °C (for the temperature 20 °C and the relative humidity 55 %). However, at the same time, the temperature in a corner is less by 4.6 °C than the temperature on the enclosure "smooth surface".

Generally, the temperature in a corner does not depend on a wall thickness; it is predetermined only by the values of the thermal resistance of a wall and the difference between the inner and outer air temperatures. See 2 for the plot of the function of temperature difference on the wall "smooth surface" and in the corner, with the difference between the inner and outer air temperatures 44 °C and with various heat exchange factors near the inner surface (the factor near the outer surface was assumed to be α_o = 23 W/(m²•K)). The similar plot, for $t_i - t_o$ = 40 °C, was built by Prof. K. F. Fokin [4, Figure 49] for values of the heat exchange factor near the inner surface 8.1 W/(m²•K) and 5.8 W/(m²•K).

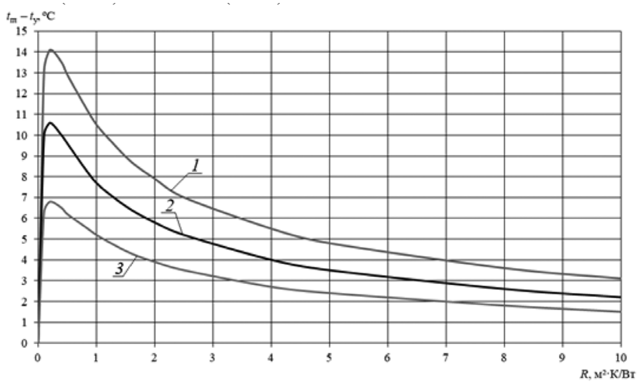

Figure 2. Temperature difference on the wall "smooth surface" and in an outer corner versus the thermal resistance of a structure (for $t_i - t_o$ = 44 °C)
1 – α_i = 8.7 W/(m²·K); *2* – α_i = 5.8 W/(m²·K); 3 – α_i = 4.0 W/(m²·K)

To calculate the temperature in a corner, the following formula is applicable (with the heat transfer resistance within the range from 0.5 m²•K/W to 2.5 m²•K/W [3])

$$t_c = t_{st} - 0{,}18\ (t_i - t_o)\ (1 - 0{,}23R_h), \qquad (4)$$

where t_{st} is the surface temperature, ºC, on the enclosure "smooth surface", calculated for $\alpha_i^{st} = 8.7$ W/(m²·K)

$$t_{st} = t_i - \frac{t_i - t_o}{R_h \alpha_i^{st}}. \qquad (5)$$

However, the formula results in a significant error when the heat exchange factor variation near the inner surface is not taken into consideration in calculations: for 8.7 W/(m²•K), the error is up to 0.4 ºC.

To calculate the temperature in a corner as a function of the thermal resistance of an enclosure, the following equation can be used:

$$t_c = t_{st} - (t_i - t_o)\ f(R), \qquad (6)$$

where $f(R)$ is the approximative function, with the following expressions used to calculate its values:

– for the thermal resistance of an enclosure less than or equal to 1.0 m²•K/W

$$f(R) = \frac{1}{44}\frac{C_4 R}{C_1 R^2 + C_2 R + C_3}; \qquad (7)$$

– for the values of R from 1 m²•K/W to 10 m²•K/W inclusive

$$f(R) = \frac{1}{44}\left(C_5 - C_6 \ln R\right), \qquad (8)$$

where C_1–C_6 are the approximation constants taken from the table 1, depending on the heat transfer factor near the inner surface, α_i;

44 is the difference between temperatures of inner and outer air assumed for these calculations, ºC.

It should be noted that these factors are calculated for the heat exchange factor near the outer surface equal to 23 W/(m²•K).

Table 1

Value of approximation factors

Approximation factors	Value of factors for the heat transfer factor αi		
	4.0 W/(m²•K)	5.8 W/(m²•K)	8.7 W/(m²•K)
C1	2 186	1 649	965
C2	62 340	52 881	28 230
C3	46 300	40 870	19 000
C4	1 163 673	734 580	250 164
maximum error	±0.1		

Table 1 (ending)

Approximation factors	**Value of factors for the heat transfer factor αi**		
	4.0 W/(m²•K)	**5.8 W/(m²•K)**	**8.7 W/(m²•K)**
C5	10.25	7.54	5.08
C6	3.25	2.41	1.61
maximum error	±0.3	±0.2	±0.1

The values of the approximative function $f(R)$ are listed in 2.

Table 2

The value of the function f(R)

Thermal resistance of an enclosure R. m²•K/W	Value of f(R) for the heat transfer factor αi		
	4.0 W/(m²•K)	5.8 W/(m²•K)	8.7 W/(m²•K)
0.2	0.0899	0.0648	0.0461
0.4	0.1478	0.1072	0.0747
0.5	0.1695	0.1233	0.0852
0.6	0.1878	0.1369	0.0940
0.8	0.2168	0.1586	0.1078
1.0	0.2386	0.1750	0.1180
1.5	0.2030	0.1492	0.1006
2.0	0.1818	0.1334	0.0901
2.5	0.1653	0.1212	0.0819
3.0	0.1518	0.1112	0.0753
3.5	0.1404	0.1027	0.0696
4.0	0.1306	0.0954	0.0647
5.0	0.1141	0.0832	0.0566
6.0	0.1006	0.0732	0.0499
7.0	0.0892	0.0648	0.0443
8.0	0.0794	0.0575	0.0394
9.0	0.0707	0.0510	0.0351
10.0	0.0629	0.0452	0.0312

Note: intermediate values may be calculated by linear interpolation.

The compliance with norms is checked by calculation of temperature of the wall surface in a corner t_c, °C, with the following expression used to calculate it

$$t_c = t_i - (t_i - t_o)\left(\frac{1}{R_h \alpha_i^{st}} + fR\right). \qquad (9)$$

This value must be greater than the dew point temperature t_d, °C, listed in the "Construction Thermal Engineering" Technical Code of Practice [1], Annex M, i.e. the following condition must be met: $t_c > t_d$.

If this requirement is not met, provisions must be made for possible local resistance rise in a corner, such as outer heat insulation, edge beveling or rounding, or installation of a heating system standpipe [4].

CONCLUSION

Prevention of moisture condensation on inner surfaces of outer corners must be implemented at the building design stage. Knowledge in processes of heat exchange taking place in enclosures and their elements as well as their practical application must ensure comfortable conditions for human life and work.

Existing norms for the design of buildings being in force in Belarus contain the requirements for temperature in an outer angle but do not provide any calculation methods except for calculation of temperature fields that must be carried out in special software programs; however, these programs are not always available for the designers. With this fact taken into consideration, quite easy engineering calculation method is offered here that can be considered for implementation in technical normative legal acts.

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