Study of heat protection of translucent external envelope in winter period

Nurlan Zhangabay[1],*, *Adham* Giyasov[2], *Sultan* Ybray[3], and *Timur* Tursunkululy[1]

[1]Department of «Architecture and urban planning», M. Auezov South Kazakhstan University, 160012 Shymkent, Kazakhstan
[2]Department of Architectural and Construction Design and Physics of the Environment, Moscow State University of Civil Engineering (MGSU), 129337 Moscow, Russia
[3]The Department of "Thermal Power Engineering" of the Kazakh Scientific Research Agrotechnical University named after S. Seifullin, 010000 Astana, Kazakhstan

Abstract. This article presents the results of thermophysical studies conducted in the cold period by non-destructive testing of translucent exterior building envelopes for heat protection and illumination of the room with natural light. As an object of study was chosen 3-room apartment on the fifth floor of the 17-storey residential complex “Sport Towers”, located in Astana, where the survey was conducted in the daytime. The window openings of the respective rooms were selected as translucent exterior envelope. As a result of the survey it was found that the internal temperature of the living rooms has a deviation of 3.5% from the optimal norm on the parameters of microclimate of the premises, which leads to a violation of the norm and overconsumption of heat energy for heating due to inadequate thermal protection of translucent exterior envelopes. At humidity 48.1% and internal temperature of the room 19.3 ºC that the dew point was 8.1 ºC. The value of the surface temperature including in the zone of adjoining to opaque elements of the considered structures showed deviation from -16.3ºC to 8.0ºC, which exceeds the dew point temperature in some cases in 3 times. The total area that does not meet the norm of the examined fragments of translucent exterior envelopes was from 5.9% to 100%. It is noted that the above deviations in heat protection of buildings can lead to the appearance of mold on the inner surface of the envelopes. The qualitative and quantitative indicators obtained as a result of thermophysical studies are the basis for the design of translucent parts of the exterior envelope when they work together with the blind wall part of the façade systems and in the future will be taken into account by designers in the development of new energy-saving exterior envelope structures, which are planned to be implemented throughout the Republic of Kazakhstan, taking into account climatic features.

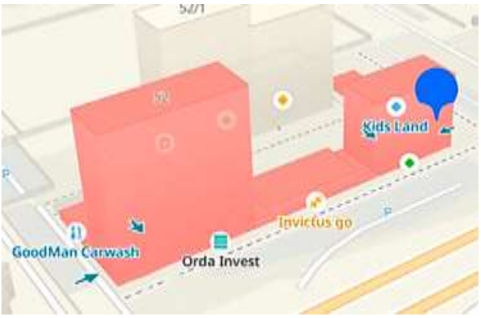
* Corresponding author: Nurlan.Zhanabay777@mail.ru

1 Introduction

In the last decade, the task of energy saving and energy efficiency of buildings becomes paramount worldwide and is one of the main directions of strategic development of the policy of the Republic of Kazakhstan [1-3], where in the structure of final energy demand the largest part is occupied by the residential sector 33%, industrial sector 32%, and much smaller demand of 18% and 16% is occupied by the transport and commercial sectors, respectively [4]. It is known that energy saving in buildings in solving practical problems of reducing the total consumption of non-renewable energy resources is carried out by using effective thermal insulation materials, energy-efficient designs of exterior walls, etc. [5-13] with the use of modern structural solutions [14-19]. In this case, the main ways of heat loss in heated buildings are windows [20,21]. To increase the heat protection of windows, designs with increasing glazing layers, with double-glazed windows and heat-reflecting or heat-absorbing glass in different bindings are used [22]. Increasing the heat transfer resistance of windows is also achieved by improving its individual structural elements, such as geometric, thermophysical properties of walls, windows, lintels and joints [23]. Energy saving with the help of building automation systems in the form of numerical study of intelligent windows were considered in the works [24]. The conducted review of works on improvement of external envelope structures including translucent ones requires additional research, where at the first stage there is a need to study the thermal protection of envelopes and the issue of heat resistance by non-destructive testing method [25,26], in the context of climatic conditions of the Republic of Kazakhstan, as the territory is divided into several climatic zones [27], and when developing designs it is necessary to consider these circumstances. In this regard, the purpose of this study is to determine the heat protection of translucent envelopes in conjunction with a blind wall part in the conditions of Northern Kazakhstan in the cold season, which is subsequently a prerequisite for the development of energy-efficient exterior envelopes.

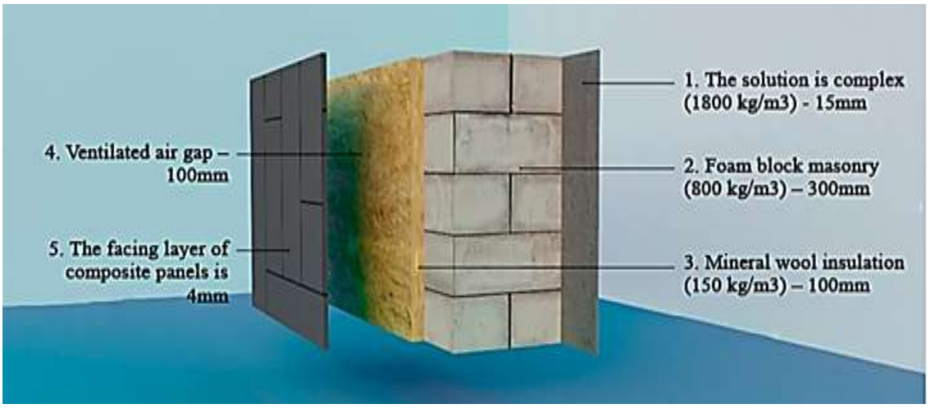
2 Methods and materials

In the work as an object of study was chosen a characteristic 17-storey residential complex “Sport Towers”, located at the address, Republic of Kazakhstan, Astana, Turan Avenue 52/1, block D, apartment 297, 5th floor (Figure 1a). The general view of the exterior envelope with ventilated façade is presented in Figure 1b, and the design of the ventilated façade with geometric characteristics is presented in Figure 1c.



a

b



c

Fig. 1. Object of study: a - situation diagram; b - general view of the façade; c - exterior envelope structure.

As a translucent structure of the surveyed 2-room apartment (Figure 2) were examined structures with the size of 1.7×1.5 m consists of a two-chamber double-glazed window made of polyvinyl chloride (PVC), Figure 3.

The survey was carried out in the cold period (Table 2) by non-destructive testing of translucent exterior envelope structures for heat protection by appropriate devices (Table 1), which is a continuation of the authors' work [28,29]. In this part of the authors' work, a 2-room apartment on the fifth floor of the 17-storey residential complex “Sport Towers”, located in Astana, was chosen as the object of study (Figure 1). The survey was conducted in the daytime, the parameters of indoor microclimate are presented in Table 3. The window openings of the corresponding rooms, shown in Figures 4-9, were selected as translucent exterior envelope.

According to the requirements of the norms [30,31] the living rooms and the kitchen are provided with natural lighting. The ratio of the area of light apertures to the floor area of living rooms and kitchen according to this adopted 1:6.5 and 1: 7.6, which corresponds to the ratio limit of no more than 1:5.5 and no less than 1:8.

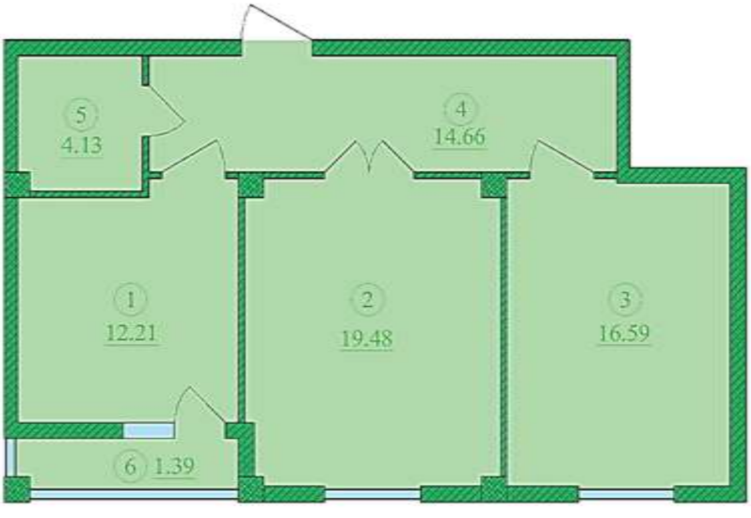


Fig. 2. Planning scheme of the surveyed apartment: 1 - kitchen room; 2 - hall; 3 - bedroom; 4 - hallway; 5 - bathroom.

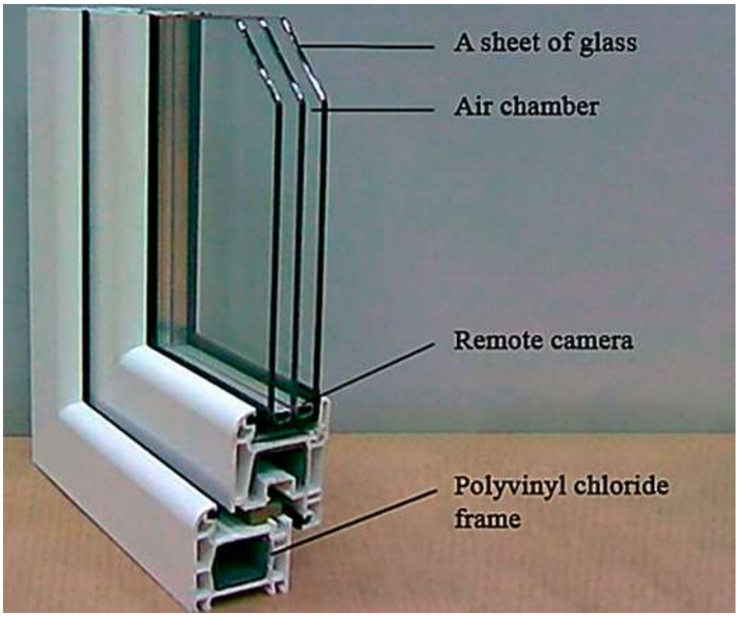


Fig. 3. Design of translucent exterior envelope.

The total thickness of the sheet of glass and air chambers was adopted as the most common type, which is 32 mm (4-10-4-10-4), where fours denote the glazing, tens denote the spaces between them. Double glazing of ordinary glass was adopted as the infill. At the design stage, the thermal resistance, shading coefficient and relative light transmission of solar radiation was assumed to be equal to R0=0.44 m2×C/W, t=0.65/0.6 and k=0.62 respectively.

Translucent envelope structure includes window opening, window unit, facing details of jambs, sill board, etc. [32]. In this regard, the analysis of the impact of temperature differences is made, including, considering the above elements of translucent envelope.

Investigations of translucent openings to determine the areas with disturbed heat protection properties were carried out according to the method of thermovisional survey [33]. In the study were used the devices specified in Table 1, corresponding to the norm.

Table 1. Name and characteristics of instruments.

No.	Survey instruments	Technical characteristics of the instruments	Compliance
1	Thermal imaging camera (testo 875-2i)	Low temperature version (measurement from -30ºC, display from -50ºC)	[33, 34, 36, 36]
2	Thermohygrometer (xiaomi)	Temperature and humidity sensor (measuring range: temperature 0ºC~60ºC; humidity 0~99.6%)	[33, 37]
3	Measuring tape (mechanical)	Metal, measuring parameters up to 10m	[38]

Climatic parameters of outdoor environment and indoor microclimate of living rooms at the time of the study on 10.12.2023 (15:00h) are shown in Tables 2 and 3 respectively.

Table 2. Climatic parameters of the outdoor environment at the time of the survey [39].

No.	Time, h	Actual temperature, ºC	Air humidity, %	Pressure, mm.Hg	Wind speed, m/s
1	0:00	-24	56	746	0.1
2	3:00	-25	64	746	0.1
3	6:00	-26	66	745	0.1
4	9:00	-27	73	745	0.5
5	12:00	-22	62	746	0.7
6	15:00	-22	53	744	0.8
7	18:00	-23	60	744	0.3
8	21:00	-24	67	744	0.5
9	24:00	-25	67	744	0.4

Table 3. Internal microclimate of living rooms at the time of the survey.

No.	Survey time, h	Actual temperature, ºC	Air humidity, %	Dew point, ºC	Heating battery temperature, ºC
1	15:00	19.3	48.1	8.1	48.2

The main thermal conductive characteristics of the translucent opening taking into account their design features were adopted at the design stage according to [40], Figure 3.

3 Results and discussions

Figures 4 - 9 show thermograms of the external envelope in the form of translucent openings of the apartment located on the 5th floor at the time of the survey according to Table 3.

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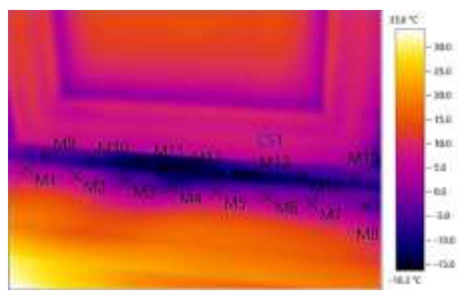

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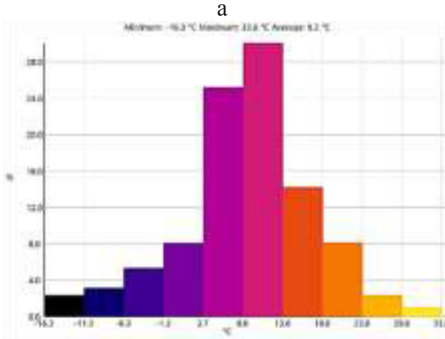

c

№	Temp, °C	№	Temp, °C
M1	3.0	M9	-5.0
M2	2.8	M10	-8.8
M3	-3.6	M11	-13.1
M4	-5.5	M12	-14.7
M5	-0.3	M13	-13.8
M6	0.4	M14	-8.9
M7	1.1	M15	-5.2
M8	-2.8	CS1	-16.3

d

Fig. 4. Fragment of the right part of the external translucent envelope of the bedroom with vulnerable points: a - full-scale photo of the fragment; b - thermogram with vulnerable characteristic points; c - diagram of temperature values with percentage ratio; d - table of points with temperature values.

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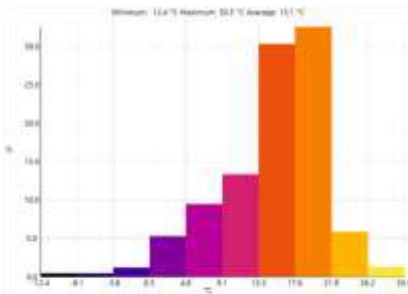
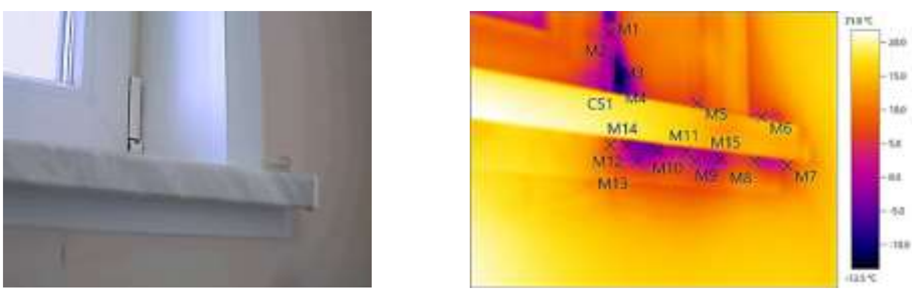
a b



№	Temp, °C	№	Temp, °C
M1	6.8	M9	4.2
M2	3.8	M10	3.8
M3	-0.1	M11	5.9
M4	-2.7	M12	5.8
M5	5.9	M13	0.1
M6	5.2	M14	3.5
M7	1.0	M15	4.5
M8	4.9	CS1	-12.4

c d

Fig. 5. Fragment of the left part of the external translucent envelope of the bedroom with vulnerable points: a - full-scale photo of the fragment; b - thermogram with vulnerable characteristic points; c - diagram of temperature values with percentage ratio; d - table of points with temperature values.



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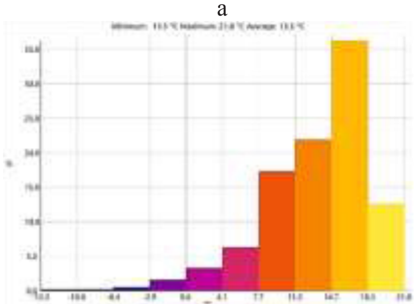
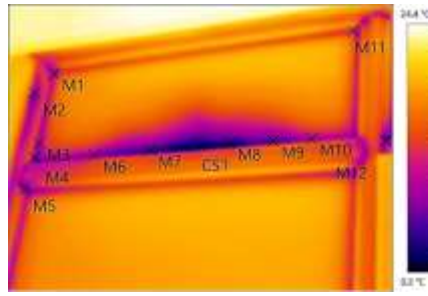


№	Temp, °C	№	Temp, °C
M1	-4.7	M9	0.2
M2	0.8	M10	2.0
M3	-4.2	M11	-2.1
M4	-13.5	M12	0.7
M5	5.1	M13	0.6
M6	5.7	M14	6.9
M7	5.3	M15	2.7
M8	4.4	CS1	-13.5

c d

Fig. 6. Fragment of the lower sill part of the external translucent envelope of the bedroom with vulnerable points: a - full-scale photo of the fragment; b - thermogram with vulnerable characteristic points; c - diagram of temperature values with percentage ratio; d - table of points with temperature values

a



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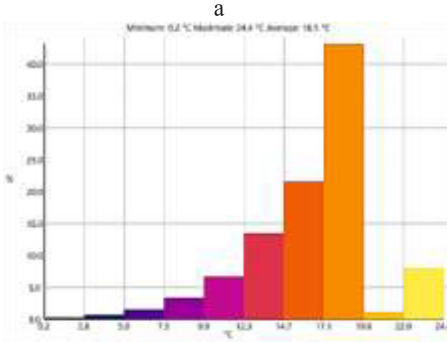


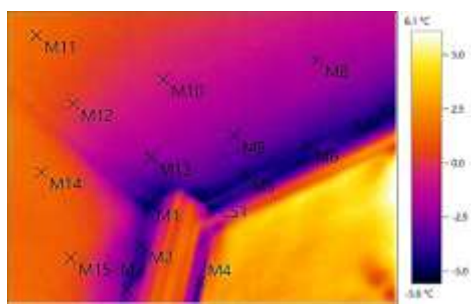
c

№	Temp, °C	№	Temp, °C
M1	8.0	M9	4.9
M2	6.5	M10	7.9
M3	8.0	M11	8.0
M4	6.1	M12	5.1
M5	6.8	M13	7.9
M6	6.6	M14	6.7
M7	3.8	M15	6.1
M8	2.2	CS1	0.2

d

Fig. 7. Fragment of the front part of the external translucent envelope of the hall room with vulnerable points: a - full-scale photo of the fragment; b - thermogram with vulnerable characteristic points; c - diagram of temperature values with percentage ratio; d - table of points with temperature values.

a



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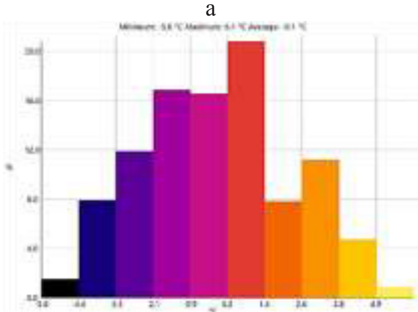


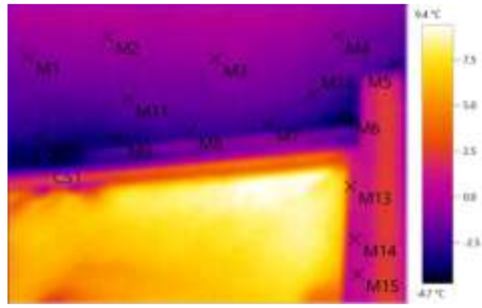
c

№	Temp, °C	№	Temp, °C
M1	-4.6	M9	-2.6
M2	-3.5	M10	-0.7
M3	-3.6	M11	1.4
M4	-4.1	M12	0.3
M5	-4.4	M13	-2.2
M6	-4.5	M14	1.4
M7	-4.5	M15	1.0
M8	-1.7	CS1	-5.6

d

Fig. 8. Fragment of the left upper part of the external translucent envelope of the kitchen room with vulnerable points: a - full-scale photo of the fragment; b - thermogram with vulnerable characteristic points; c - diagram of temperature values with percentage ratio; d - table of points with temperature values.

a



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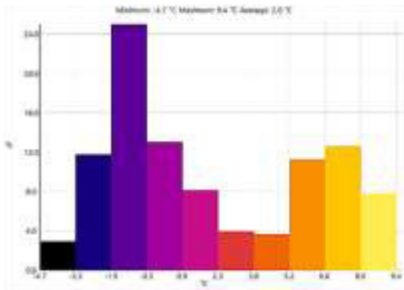

c

№	Temp, °C	№	Temp, °C
M1	-1.0	M9	-3.5
M2	-0.4	M10	-3.1
M3	-0.7	M11	-1.7
M4	-1.1	M12	-1.8
M5	-2.7	M13	2.5
M6	-4.0	M14	0.9
M7	-2.5	M15	1.0
M8	-2.5	CS1	-4.7

d

Fig. 9. Fragment of the upper right part of the external translucent envelope of the kitchen room with vulnerable points: a - full-scale photo of the fragment; b - thermogram with vulnerable characteristic points; c - diagram of temperature values with percentage ratio; d - table of points with temperature values

As a result of the study, it was found that the internal temperature of living rooms has a deviation of 3.5% from the optimal norm on the parameters of indoor microclimate [41], which leads to a violation of the norm and overconsumption of thermal energy for heating in general.

Thus, the analysis of thermograms of the fragment of the right part of the external translucent envelope of the bedroom room showed (Figure 4a) that the surface temperature of the sill part of the structure significantly exceeds the dew point (Table 3). At humidity 48.1% and internal temperature of the room 19.3 ºC dew point was 8.1 ºC, and the thermogram of Figure 4 (b) indicates that the minimum surface temperature including in the zone of adjoining to opaque elements of the considered structure was from -16.3 ºC to 3.0 ºC (Figure 4d), which does not correspond to the dew point temperature up to 3.01 times [42], and the total area not corresponding to the norm of the specified fragment was 44.1% (Figure 4c). Inspection of the left part of the exterior translucent envelope of the bedroom room showed (Figure 5a) that the surface temperature of the sill portion of the structure also significantly failed to meet the dew point (Figure 4b), where the minimum surface temperature ranged from - 12.4ºC to 6.8ºC (Figure 5d), which does not meet the dew point temperature up to 2.53 times [38], and the total area not meeting the norm of the specified fragment was 16.5% (Figure 5c). Inspection of the sill part of the exterior translucent envelope of the bedroom showed (Figure 6a) that the surface temperature of the sill part does not correspond to the dew point (Figure 6b), where the minimum temperature on the surface was from - 13.5ºC to 6.9ºC (Figure 6d), which does not correspond to the dew point temperature up to 2.66 times [40], and the total area that does not correspond to the norm of the specified fragment amounted to 29.4% (Figure 6c).

Examination of the front part of the exterior translucent envelope of the common room showed (Figure 7a) that the surface temperature in the area adjacent to the opaque part does not correspond to the dew point (Figure 7b). The minimum surface temperature ranged from 0.2ºC to 8.0ºC (Figure 7d), which also does not meet the norm [38], and the total area not meeting the norm of the specified fragment was 5.9% (Figure 7c). Inspection of the fragment of the left upper part of the exterior translucent envelope of the kitchen room showed (Figure 8a) that the surface temperature in the area adjacent to the opaque part did not correspond to the dew point (Figure 8b). The minimum temperature on the surface was from - 5.6ºC to 1.4ºC (Figure 8d), which does not correspond to the dew point temperature up to 1.7 times [40]. At the same time, the whole surface of the specified fragment does not correspond to the norm, as it is below the dew point temperature (Figure 8c). Examination of the fragment of the right upper part of the external translucent envelope of the kitchen room showed similar results (Figure 9a,b), where the surface temperature in the adjacency zone was from -4.7ºC to 2.5ºC (Figure 9d), and the temperature of the entire surface of the fragment (Figure 9c) relative to the dew point does not correspond to 1.58 times [40].

4 Conclusions

As a result of the study, it was found that:
- the internal temperature of residential premises has a deviation of 3.5% from the optimal norm on the parameters of microclimate of premises, which leads to violation of the norm and overconsumption of thermal energy for heating in general due to inadequate heat protection of translucent external envelopes;
- at humidity of 48.1% and internal room temperature of 19.3 ºC it was found that the dew point amounted to 8.1 ºC. In this case, the value of the temperature of the wall surface, including the zone of adjoining to opaque elements of the structures under consideration showed a deviation from -16.3 ºC to 8.0 ºC, which exceeds the dew point temperature in some cases by 3 times;
- the total area not corresponding to the norm of the examined fragments of translucent external envelopes amounted to more than 5.9% depending on the room.

The value of the non-destructive method of assessment of thermophysical characteristics of translucent PVC structures at their joint operation with wall enclosing structures has been revealed.

Vulnerable areas of the thermal field of heterogeneous envelope structures of the façade system of the building are predicted, which allows to consider in the construction of external envelopes of the building as a whole.

It is noted that the above deviations in the research on heat protection of buildings can lead to the appearance of mold, comb and other extremely tenacious organisms on the inner surfaces of the walls of the nearby areas of light apertures, as well as in general on the interior surfaces of the premises.

Obtained as a result of thermophysical studies of qualitative and quantitative indicators is the basis for the design of translucent parts of the exterior envelope when they work together with the blind wall part of façade systems and in the future will be taken into account by designers in the development of new energy-saving exterior envelope structures, which are planned to be implemented throughout the Republic of Kazakhstan, considering the climatic features.

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