Study of heat protection of external envelopes of a residential building in the cold period

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Abstract. In the study a full-scale thermovisional survey was carried out in the cold period of time of a multi-apartment residential building located in the Northern part of the Republic of Kazakhstan. The result of the survey showed the presence of significant problems on heat protection, where according to the analysis of thermograms of external wall envelopes it was revealed that almost all living rooms have envelopes with a negative value of heat protection, which does not meet existing standards. The analysis of thermograms of all rooms showed the existing problems on thermal stability of external wall envelopes, as the temperature difference between the inner surface of the external envelope and the internal air temperature ranged from 5.5 °C to 19.7 °C, where the difference reached 49 times in some places, depending on the living room. Analysis of thermograms of window openings also showed a lot of deviations. Thus, thermograms of window apertures showed deviations from sanitary-hygienic norms on dew point value from 12°C to 26.2°C depending on the living room. The revealed deviations on thermal protection of external envelopes are the main sources of heat energy loss and indicate the presence of problems on thermal stability of external envelopes in the cold period, which require special attention. In this regard, the obtained results of this study will be further taken into account in the development of new and optimization of existing wall envelope structures, taking into account the climatic features of the Republic of Kazakhstan.

1 Introduction

The problems of energy saving and energy efficient buildings are relevant for the residential sector in many countries. Residential structures should meet a number of requirements, such as, for instance, the shape and orientation of the building, the efficiency of solid envelopes, the efficiency of translucent envelopes, heating/cooling mechanisms in appropriate climatic conditions, etc. [1-3]. [1-3]. Internationally, to address this problem, various strategies have been developed in many countries of the European Union to modernize residential buildings in order to improve their energy efficiency [4-6]. Many

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studies are devoted to solving this problem, the results of which are used in the development of various programs at both local and state levels [7-10]. To achieve this goal, it was necessary to establish optimal energy efficiency requirements for new and modernization of existing buildings [11,12], the solution of which has demonstrated high performance in the modernization of residential buildings [13-17], where the correct selection of the design of the external envelope contributes to a significant reduction in thermal energy consumption [18-24]. The use of various kinds of thermal insulation, heat-accumulating and heat-reflecting materials is also a very popular way to save energy costs for heating and cooling [25-29]. In building envelopes, windows are one of the main ways of heat loss in heated buildings [30-32]. To increase the thermal protection of windows, designs with increasing glazing layers, with double-glazed windows and heat-reflecting or heat-absorbing glass in different bindings are used [33]. 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 [34].

In order to achieve the issue of heat protection of exterior building envelopes various methods of control are used, where the main method that has gained popularity at present is the method of nondestructive testing, which is carried out through the use of modern devices for thermovisional inspection [35-38].

The obtained results of this study further contribute to the development of new energy-efficient designs of exterior envelopes, as well as to the optimization of existing ones.

2 Methods and materials

The study of heat loss of external wall envelopes of a residential building was carried out by the method of thermal imaging survey [39]. The following devices were used in the study: testo thermal camera [40,41], Xiaomi thermohygrometer [42], pyrometer [43], rangefinder [44], tape measure [45], high quality digital camera [46]. All the instruments were compliant [47] and were verified in a timely manner.

The object of the study is located in the Northern part of the Republic of Kazakhstan in Astana, where a 3-room apartment on the fourth floor (Figure 1) of the residential complex Nexpo Union was chosen as the study room. Figure 2.

Fig. 1. Plan of a 3-room apartment: 1 - hall; 2 - children's room; 3 - kitchen; 4 - hallway; 5 - pantry; 6 - shower room; 7 - anteroom; 8 - bedroom; 9 - bathroom.

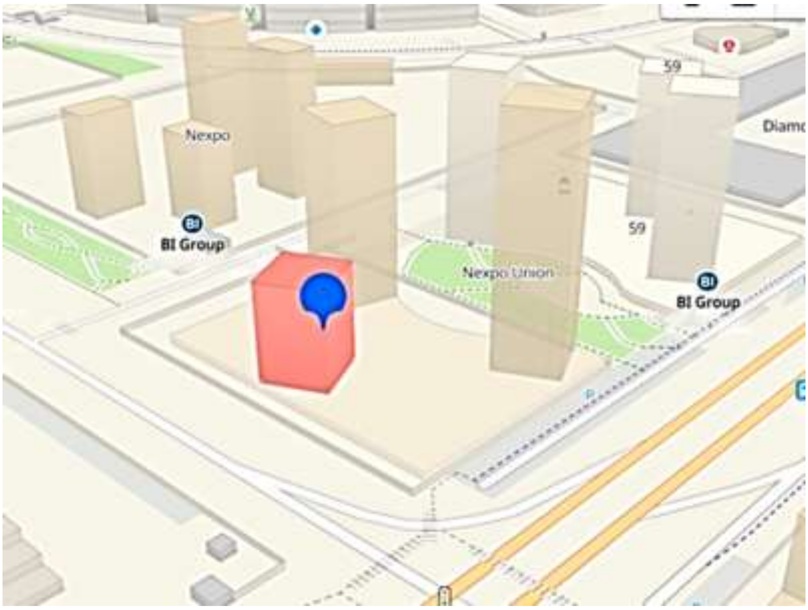

Fig. 2. Location of the object of study.

The structure of the external wall envelope is a ventilated façade, the main parameters of which are presented in Table 1.

Table 1. Parameters of the external wall envelope structure.

Layer	Material	Thickness, mm	Thermal conductivity coefficient of the layer, λ, (W/(m·°C)	Material	Thickness, mm
1	Cladding layer of composite panels	5	–	–	–
2	Air layer	100	–	–	–
3	Insulation from mineral wool board with density of *150 kg/m³*	100	0.038	0.69	0.30
4	Foam block masonry with density of *800 kg/m³*	300	0.215	4.91	0.15
5	Complex mortar with a density of 1800 *kg/m³*	10	0.76	9.6	0.09

As a design of translucent window opening was surveyed window size 1800×1800mm with a double-glazed window in a single pane of ordinary glass with a glass spacing of 12mm with a hard-selective coating.

The survey was conducted in the cold period of the winter period [48], that is, December 10, 2023, in the morning (9:00 a.m.), where the main climatic conditions of outdoor air are presented in Table 2 [49], and the main microclimate of the surveyed premises is presented in Table 3.

Table 2. Climatic conditions of outdoor air

Survey time, h	Air temperature, ºC	Humidity of outdoor air, %	Pressure, mmHg	Wind speed, m/s
9:00	-24	71	745	0.4

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

Survey time, h	Indoor air temperature, ºC	Humidity of internal air, %	Dew point temperature, ºC	Heating battery temperature, ºC
9:00	19.3	48.1	8.1	49.3

It should be noted that the heat protection of wall and window envelopes at the design stage is taken, according to the indicator, degree-day heating period and correspond to the norms [50, 51].

3 Results and discussions

3.1 Thermovisional inspection of solid exterioir wall envelopes

Thermovisional survey of thermal protection properties was carried out for two types of exterior envelopes. The first one is a solid wall envelope, the second one is window openings. Below is the analysis of thermograms in section by two types in two stages.

At the first stage the survey of thermal protection properties of solid wall exterior envelopes was carried out, where Figures 3-6 present thermograms and analysis of heat protection properties of the exterior wall envelope of residential premises.

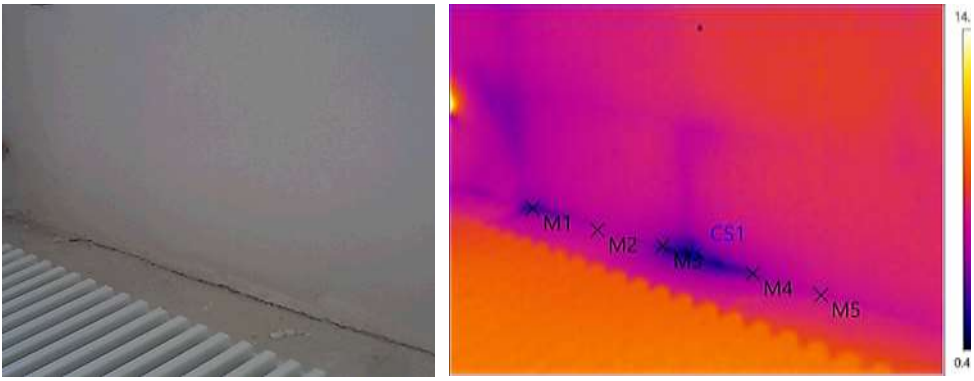

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Fig. 3. Thermogram of the wall exterior envelope of room No.1: a – full-scale photo of the wall; b - thermogram of the wall (M1=2.2°C, M2=5.1°C, M3=2.9°C, M4=3.4°C,M5=5.5°C, CS1=0.4°C).

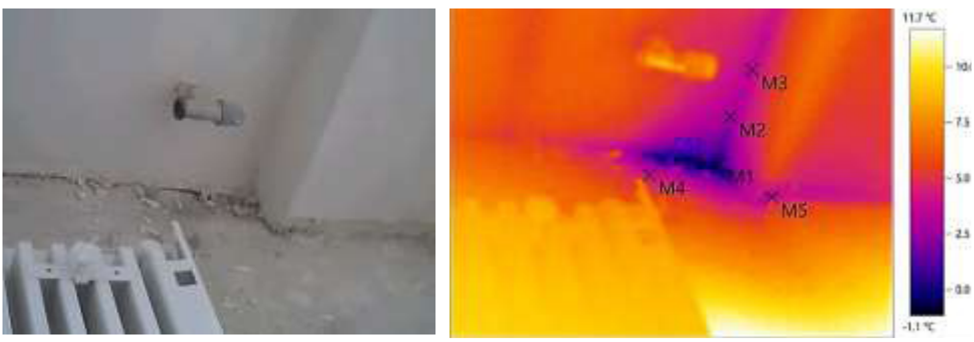

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Fig. 4. Thermogram of wall exterior envelope of room No.2: a - full-scale photo of the wall; b - thermogram of the wall (M1=0.8°C, M2=3.0°C, M3=3.5°C, M4=4.0°C,M5=3.6°C, CS1= -1.1°C).

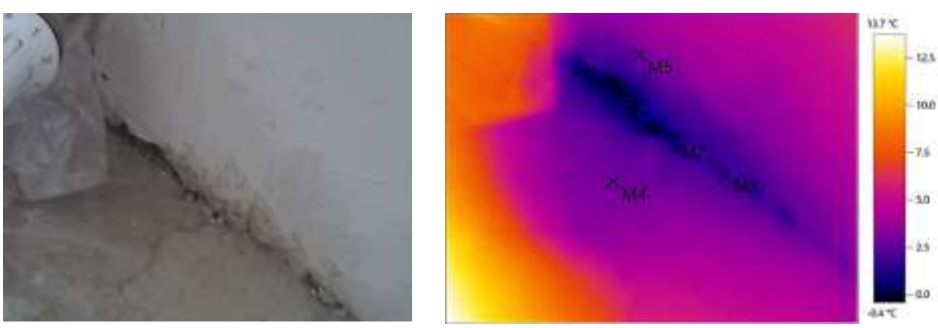

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Fig. 5. Thermogram of the exterior wall envelope of room No. 8: a - full-scale photo of the wall; b - thermogram of the wall (M1=0.4°C, M2=0.8°C, M3=1.7°C, M4=2.7°C,M5=2.7°C, CS1=-0.4°C).

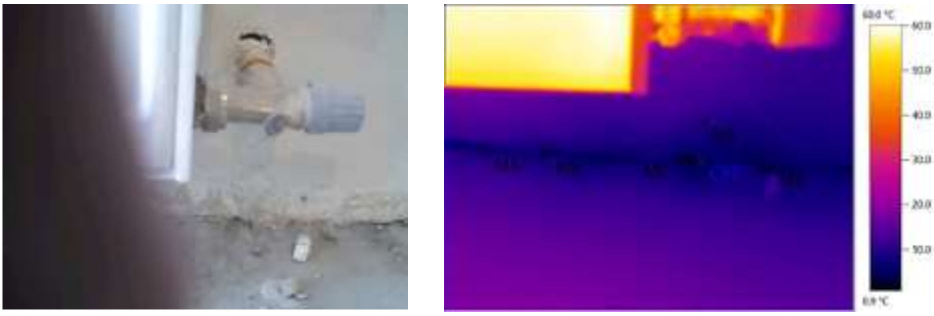

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Fig. 6. Thermogram of wall exterior envelope of room No. 3: a - full-scale photo of the wall; b - thermogram of the wall (M1=4.6°C, M2=5.7°C, M3=5.3°C, M4=8.2°C,M5=9.6°C, CS1=0.9°C).

Based on the method of nondestructive testing with the help of thermovision camera was carried out inspection of continuous sections of the exterior wall envelope of rooms (1,2,3,8), Figures 3-6, where according to Figure 1 (room number 1) it was revealed that despite the correctness of the design solutions quality of the envelope does not meet the norm [50], as the temperature difference between the inner surface of the envelope and the internal temperature of the room should not exceed 4 ° C, which should be equal to 15.3 ° C. The actual difference is, in the case of the minimum value of the point (CS1) to 18.9 ° C, which is almost 47.2 times lower, and in the case of the point (M5) with a maximum temperature of 5.5 ° C the difference is 13.8 ° C, which is almost 1.5 times lower than the norm (Fig. 3b) [50]. Figure 4 shows the thermograms of the solid external envelope of room No. 2, where a similar situation on thermal protection is observed. Thus, according to the point (CS1) the minimum surface temperature is -1.1°C, and the maximum point (M4) is 4.0°C, which are lower than the internal air temperature by 20.4°C (17.5 times) and 15.3°C (4.8 times) respectively (Fig. 4b). According to the thermograms of room No. 8 of the fragment of Figure 5, it was also found that the temperature difference between the minimum and maximum points amounted to 19.7°C and 16.6°C, which is also 49 and 7.3 times below the norm, Figure 5b [50]. The thermogram of room No. 3 (Fig. 6) showed that the minimum temperature of the point (CS1) on the fragment is equal to 0.9°C, and the maximum temperature of the point M5 is equal to 9.6°C, which also revealed a non-compliance with the norm for thermal protection, which is lower by 21.4 and 2.1 times, respectively, Figure 6b.

At the second stage, the heat protection properties of exterior envelopes in the form of window openings were examined, where Figures 7-13 present thermograms and analysis of the heat protection properties of these structural elements.

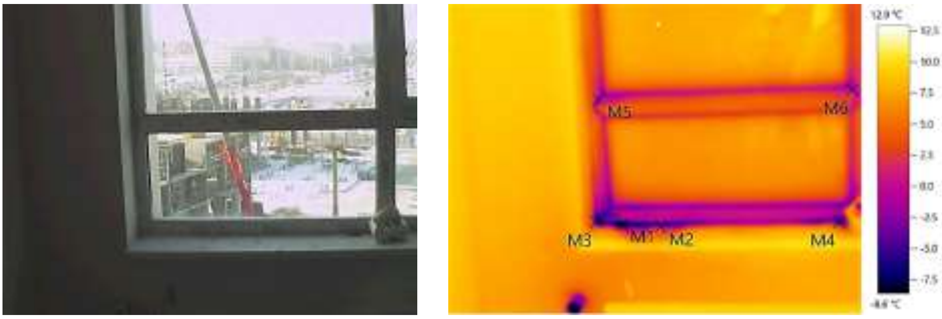

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Fig. 7. Thermogram of the window opening of room No. 9: a - full-scale photo of the window opening; b - thermogram of the window opening (M1=-8.6°C, M2=-0.8°C, M3=-4.4°C, M4=-5.0°C,M5=-1.7°C, M6=-0.6°C).

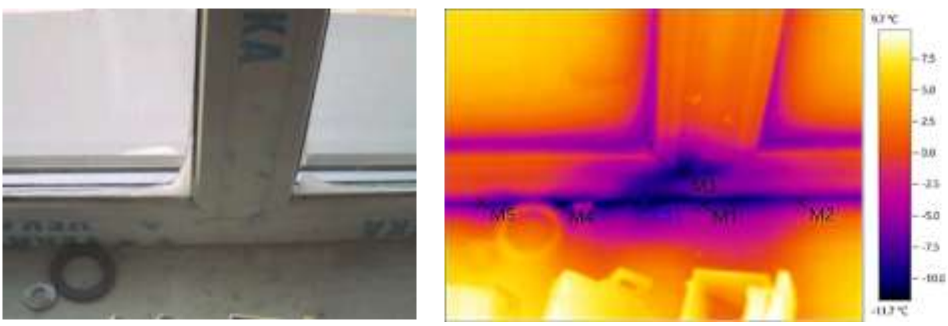

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Fig. 8. Thermogram of the window opening of room No. 3: a - full-scale photo of the window opening; b - thermogram of the window opening (M1=-8.4°C, M2=-6.9°C, M3=-9.9°C, M4=-9.9°C,M5=-6.9°C, M6=-11.7°C).

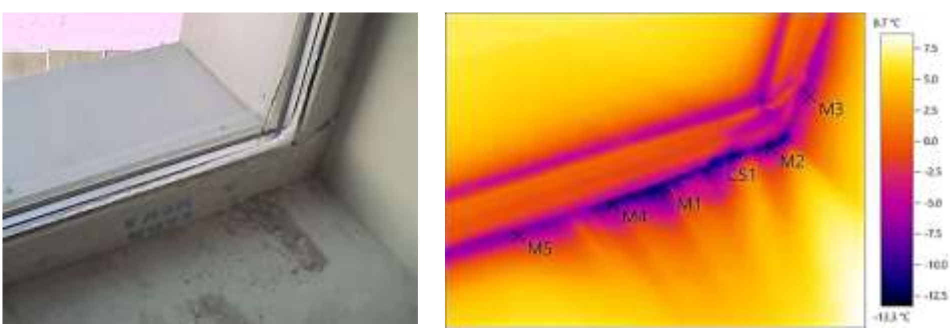

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Fig. 9. Thermogram of the window opening of room No. 3: a - full-scale photo of the window opening; b - thermogram of the window opening (M1=-8.2°C, M2=-8.3°C, M3=-4.6°C, M4=-9.9°C,M5=-6.5°C, M6=-13.3°C).

a b

Fig. 10. Thermogram of the window opening of room No. 3: a - full-scale photo of the window opening; b - thermogram of the window opening (M1=-9.0°C, M2=-11.8°C, M3=-5.7°C, M4=-4.6°C,M5=-2.3°C, M6=-15.9°C).

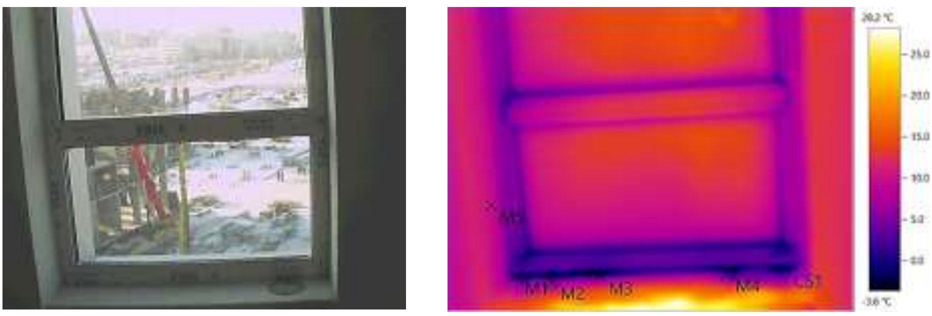

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Fig. 11. Thermogram of window opening of room No. 2: a - full-scale photo of window opening; b - thermogram of window opening (M1=0.0°C, M2=4.7°C, M3=1.6°C, M4=3.1°C, M5=9.6°C, M6=-3.9°C).

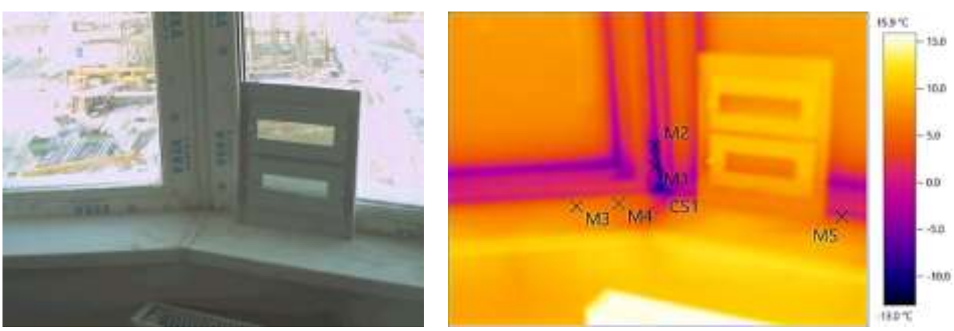

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Fig. 12. Thermogram of the window opening of room No.1: a - full-scale photo of the window opening; b - thermogram of the window opening (M1=-4.8°C, M2=-7.7°C, M3=6.4°C, M4=5.4°C, M5=1.8°C, M6=-13.0°C).

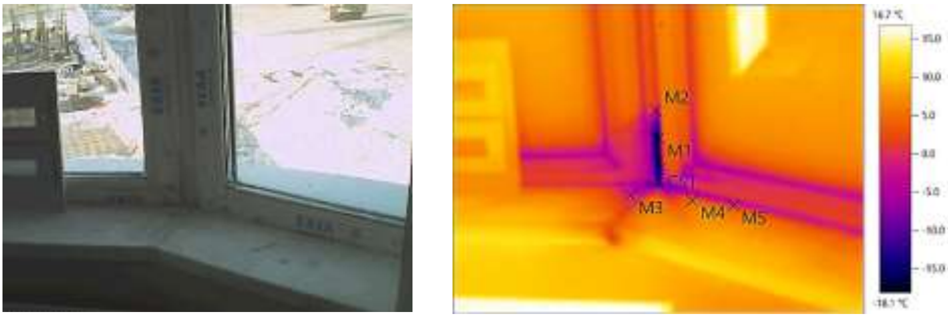

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Fig. 13. Thermogram of the window opening of room No.1: a - full-scale photo of the window opening; b - thermogram of the window opening (M1=-15.3°C, M2=-2.4°C, M3=-1.4°C, M4=3.7°C, M5=0.1°C, M6=-18.1°C).

A similar problem with vulnerabilities has also been identified in the structural part of the exterior envelope in the form of window openings. Thus, according to the norm [52], if the construction of the window opening includes: the window opening itself, window unit, lining details of the jambs, sill board, etc., then the analysis of the impact of temperature differences was made taking into account these elements. As a criterion for assessing the heat protection properties were taken sanitary and hygienic requirements, according to which the temperature on the surface of the window opening structure with the incoming structural elements should not be lower than the dew point [52]. Thus, when analyzing the thermogram of the window opening in Figure 7 it was revealed that the deviation relative to the dew point (Table 3) is observed almost at all points of Figure 7b, which does not correspond to the norm [52], where the deviation is from 8.9 ° C to 16.7 ° C. The analysis of thermograms of room No. 3 according to Figures 8-10 shows also non-compliance with the norm according to sanitary-hygienic requirements, where in relation to the thermogram of Figure 8b the deviation was up to 19.8°C, the thermogram of Figure 9b showed a deviation up to 21.4°C, and in the thermogram of Figure 10b the deviation was up to 24°C. During the examination of room No. 2 (Figure 11) was found similar deviations in temperature difference on the coldest surface of 12 ° C, where it can also be noted room No. 1 (Figures 12 and 13) discrepancy relative to the value of the dew point, which reaches up to 26.2°C. Identified deviations in the heat protection of external envelopes are the main sources of thermal energy loss in the cold period, where such deviations in addition to excessive energy consumption can lead to poor health of residents, as well as to the deterioration of the state of the finishing of the premises in the form of mold, moisture, etc. on the surface.

Thus, the research results obtained by the authors in combination with the previously conducted works [37,38] on envelope inspection will be further considered in the development of new energy-efficient exterior wall envelope structures, as well as optimization of existing exterior wall envelope structures, the solution of which is supposed to be implemented considering the climatic features of the territory of the Republic of Kazakhstan [48].

4 Conclusions

According to the analysis of thermograms of external wall envelopes it was revealed that in almost all living rooms there are envelopes with a negative value of heat protection, which does not comply with existing norms. Thus, in room No. 1 the temperature difference between the internal surface of the envelope and the internal temperature of the room is equal to 15.3 °C, where the deviation is 47.2 times lower than the norm, the thermogram of room No. 2, showed a deviation of 20.4 ° C, which is almost 17.5 times lower than the norm. According to the thermogram of room No. 8, the temperature difference was up to 19.7°C, the deviation from the norm is up to 49. The thermogram of room No. 3 also showed the difference up to 9.6°C, which is 21.4 times lower than the norm.

Analysis of thermograms of window openings also showed a lot of deviations. Thus, thermogram of window opening of room No. 9 showed deviation to sanitary-hygienic norms by value below dew point up to 16.7°C. Analysis of thermograms of room No. 3 revealed similar deviations, the value of which reaches from 19.8°C to 24°C. The results of examination of room No. 2 showed that the temperature difference is 12°C, which is typical of room No. 1, which during the examination showed a temperature difference of up to 26.2°C.

Thus, the identified deviations in the thermal protection of exterior envelopes are the main sources of heat loss and indicate the presence of problems on the thermal stability of exterior envelopes in the cold period, which require special attention. In this regard, the obtained results of this study will be further considered in the development of new and optimization of existing wall envelope structures, considering the climatic peculiarities of the Republic of Kazakhstan.

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