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Problems of a Thermal Insulation of Multystoried Cast-in-Place Concrete Frame Buildings in the Conditions of Extreme North

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Abstract. In recent years in Yakutsk began to build residential buildings 12-16 floors high with a reinforced concrete framework. Thermovision examinations of these buildings are conducted and the analysis of thermograms of a surface of the protecting designs is made. Sites of violation of thermal protection of buildings are established and calculations of the main clusters of the external protecting designs with application of programs of a three-dimensional temperature profile are carried out. The comparative analysis of calculation datas with natural data on thermovision inspection is made. The main reasons for violation of thermal protection of the protecting structures of multystoried buildings are established. In a basement storey of buildings low temperature on an internal surface of designs is bound to existence of thermal bypass in places of an adjunction of a laying of external and internal walls to basement floor slabs, reinforced concrete columns to basement floor slabs with a foundation framework. During the winter period at especially low temperature of fresh air penetration of cold air in multystoried buildings is promoted by the increased air infiltration.

1. Introduction

According to the Federal Law No. 261 of November 23, 2009. "About energy saving and about increase in energy efficiency about introduction of amendments to separate acts of the Russian Federation" the energy consumption of GDP of Russia has to be reduced by 40% by 2020 and by 2,5 - 3 times by 2030 concerning the level of 2007. The housing sector in Russia takes the second place after manufacturing industry in size of final consumption of energy: 25% of the current volume of energy consumption in general and 45% of consumption of heat energy. Therefore, increase in energy efficiency of buildings is important strategic task in Russia.

Results of numerous researches show that losses of heat energy through the outside protecting designs are the main and are more than 50% in structure of costs of heat energy of the building of heating during the heating period [1,2]. Taking into account it, requirements to thermal shielding of the protecting designs have significantly been increased, since 80th years, in the European countries, and in Russia since 2000. In the set of rules 50.13330.2012 Revised edition office Construction Norms and Regulations 23-02-2003 "Thermal shielding of buildings" real toughening of step-by-step requirements consist in rationing of the specified resistance to heat transfer of the protecting designs reflecting influence of flat, linear and pointed heat-conducting inclusions. As the annex the modernized method of calculation of the specified resistance to heat transfer of the protecting designs is provided much. At the same time rated heat conductivity of all construction materials applied in the protecting designs is accepted taking into account their operational humidity [3]. Heat-conducting inclusions considerably reduce heat-shielding of buildings and demand application of different constructive actions at design of buildings. It should be noted that in the European countries heat-conducting inclusions are normalized separately and in most cases accounting of their influence at design of the protecting designs is made not fully [4]. For accurate accounting of heat-conducting inclusions different method of calculation of the specified resistance to heat transfer of the protecting designs are offered [5-6].

In foreign experience at research of buildings on the defects worsening thermal efficiency of the building any thermovision devices in the time-lapse mode at which all subtleties of change of temperature condition of the building after change of temperature of the outside environment are noticeable [7-8] are used. In work [9] ways and methods of integration of power-intensive materials in building constructions are described. The fact of use of such materials has the good potential for buildings at energy consumption reduction, but demands some investments into construction time. Investment and costs of increase in thermal efficiency of the building are favorable on ecological and almost by all economic criteria [10]. In this case costs of consumption of 1 kWh in the building at which at the building with weak thermal shielding costs of consumption of energy resources raise are described. In the European countries any buildings with the increased energy efficiency and the lowered energy consumption directed to the Zero Energy Building level [11] are developed.

In modern construction by the most widespread frame housing construction using monolithic reinforced concrete constructions is. In many respects it is connected with development of construction technologies, possibility of construction of buildings of the increased number of storeys with different architectural expressiveness and flexible design. In outside wall designs of such structures the laying from blocks with outside heat insulation, the ventilated or "wet" facade is used. Accounting of heat-conducting inclusions and the ventilated layer, longitudinal filtering of air when calculating resistance to wall heat transfer with hinged front system is considered in work [12-14]. Considerable decrease in heat-protective properties of external wall with the ventilated facade on the site of interwindow piers is shown at application of thermal insulation materials with high air permeability due to longitudinal filtering of air, availability of errors of mounting of heat-insulating plates: leaky adjunction of plates to wall or not bringing to the window block it is shown in works [13,14]. Complex heatphysical researches for the purpose of assessment of heat-protective properties of node of interface of balcony slab to external wall are conducted in NIISPh [15-17]. As a result of pilot researches values of coefficients of heat exchange and their distribution to surfaces of balcony slab are received, comparison of heattechnical characteristics in the presence of perforation with heat-insulating inserts and installation is carried out to node of the bearing heat-insulating Schöck Isokorb® element [18]. For warming of external multilayer wall in exit points of end face of inserted floors outside heat insulation with protective device is offered [19].

Now with development of construction technologies there was opportunity to build buildings with the number of 12-16 floors using monolithic reinforced concrete constructions in the conditions of permafrost soil. At the same time, the heat-shielding of multi-storey buildings in northern climatic zone is complicated by number of the factors connected with severe operating conditions. It first of all, long winter period, especially low outside temperature -45° C and below within 50-60 days, availability of the aired underground at the pile bases, the increased air infiltration. One of shortcomings of frame and monolithic buildings are availability of different constructive bridges of cold, especially in socle part of buildings [20-22]. Main objective of work is identification of basic reasons of violation of thermal shielding of multi-storey buildings with concrete formwork in extreme conditions of the North.

2. Methods

Object of research are multi-storey frame and monolithic buildings in extreme conditions of the North. For identification of basic reasons of violation of thermal shielding of multi-storey buildings with concrete formwork in extreme conditions of the North on-site thermovision investigations of multi-storey buildings in Yakutsk are conducted and the numerical analysis of temperature fields of nodes of the outside protecting designs is made. As example 16 floor building in Yakutsk are considered. The building has in the plan rectangular shape of 16,7*61,4 m in size at the level of the second floor and the acting part of 3,5 m from the main facade of the first floor. The building is located in the open area on the bank of the lake. Load-carrying structures of the building represent concrete formwork with flat slab floors. Columns have the section of 600*400 mm with 1st on the 4th floors, with 5th on the 16th floors - 400*400 mm.

Constructive decisions of outside barriers for the considered building are made traditional, as well as in other frame and monolithic buildings designed for Yakutsk. External wall represents sandwich construction from laying using small concrete blocks between columns, outside heat insulation from mineral wool boards with a density of 125 kg/m^3 200 mm thick, ventilated facades. Polystyrene foam plates with a density of 35 kg/m^3 are applied to heat insulation of socle overlapping 300 mm thick. Resistance to heat transfer of external wall and socle overlapping on smooth surface is according to 5,27 and 7,45 (m^2 ºC) / W.

In December-January outside temperature in Yakutsk is -36 …-45°C without special differences. Therefore, on-site investigations of the considered multifamily residential building were conducted in December, 2017 at outside temperature of -39,4°C. Thermovision inspection of the building was made according to requirements of GOST P 54852-2011 "Buildings and constructions. Method of thermovision quality control of heat insulation of the protecting designs". In this case thermovision examination was conducted from the inside of the building that is dictated by weather patterns and availability of the ventilated facade. For carrying out thermovision shooting the SAT G-90 thermal imager, for temperature measurement of internal air in rooms - the Testo 435-4 device is used. At the beginning of natural works survey shootings of the protecting designs, and then comprehensive survey of separate fragments of designs where violations of thermal shielding of the building have been established were carried out.

For carrying out the numerical analysis and comparison with actual data payment of temperature fields of nodes of the protecting designs and their heattechnical characteristics under the certified Shaddan 3D ST program is executed at outside temperature of t_{out} = -39,4°C, temperature corresponding to value in day of carrying out natural measurements. This program allows to define space temperature fields of the structures of any difficult configuration adjoining with environments on different parameters. The problem is solved by method of grids by means of the differential scheme of the second order of accuracy on space variables on uneven rectangular grid. Testing of the program is carried out using earlier developed programs of calculation of two-dimensional and three-dimensional temperature fields [23,24 18, 19]. When carrying out heattechnical calculations of nodes of the building of the characteristic of materials are accepted by the following: reinforced concrete slabs of overlapping - coefficient of thermal conductivity λ = 1,92 W / (m ºC); expanded polystyrene of PSB-S 35 – λ = 0,042 W / (m ºC); cement and sand tie – λ = 0,76 W / (m ºC); steel concrete column – λ = 1,92 W / (m ºC); laying from wall stone on cement and sand solution – λ = 0,64 W / (m ºC); mineral wool boards – λ = 0,042 W / (m ºC).

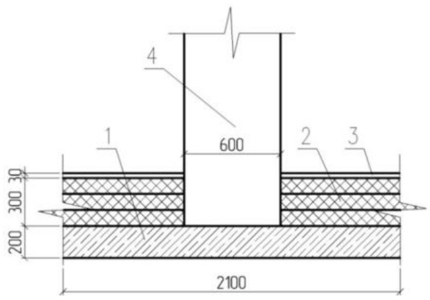
3. Results

In this article five constructive nodes of the building in which characteristic low-temperature sites are observed are considered and allocated and normative values of thermal shielding of buildings are not provided. Experience of construction and operation of multi-storey frame and monolithic buildings in Yakutsk shows that the most problem sites are nodes of interface of structural components of the first floor to socle steel concrete overlapping. These nodes in the made design decisions are characterized by availability of several heat-conducting inclusions. Besides, in the conditions of especially low outside temperature and the aired underground at application of the pile bases considerable influence on heat-shielding of first floors of buildings is rendered by air infiltration. During the coldest months (t_{out} = -40°C …-55° C) on the first floor of 9 floor buildings pressure difference between outside and internal air makes 80-100 Pas, and for 16 floor - 180-200 Pas. In such conditions any defect in the outside protecting designs leads to penetration of cold air in the building and respectively to heat loss.

As a result of the analysis of materials of thermovision inspections of buildings heat loss, characteristic of all buildings, through nodes of adjunction of columns to socle steel concrete overlapping are established. On these sites it is impossible by constructive methods to exclude "cold bridges": steel concrete columns of the first floor - socle steel concrete overlapping - grillages of pile groups. On the given example from fig. 1 influence of the specified heat-conducting inclusions is well visible. On perimeter of columns zones with temperatures on surface of designs which on value below of the normalized parameters are revealed. For example, on the R1 line minimum temperature is t_{min} = +6,9ºC, on the R2 line - t_{min} = +2,8ºC (fig. 1, b).

By results of calculation of temperature fields of design of node of socle floor slab with steel concrete column minimum temperature on inside face of designs of t_{min}= +6,9ºC is established, the specified resistance to heat transfer was R_{red} = 4,05 (m^2 ºC) / W. Temperature isolines in fig. 1, with visually reflect negative influence of the bridge of cold. Discrepancy of calculated values of temperature on inside face with data of natural measurements can be explained with poor quality of mounting of heat-insulating plates of socle overlapping. In places of leaky adhering of end faces of polystyrene foam plates to side face of columns because of the increased infiltration of air cold air gets into the winter period and temperature condition of the building is broken. During installation works gaps between column and heat-insulating plates, as a rule, try to fill with polyurethane foam or tow. During initial stage of operation this method gives some effect, however over time appear gap in the considered site because of shrinkage of polystyrene foam plates and temperature deformations of elements of designs.

a.



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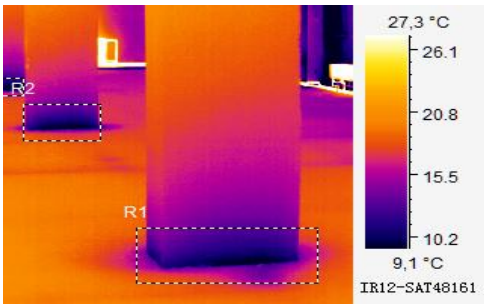

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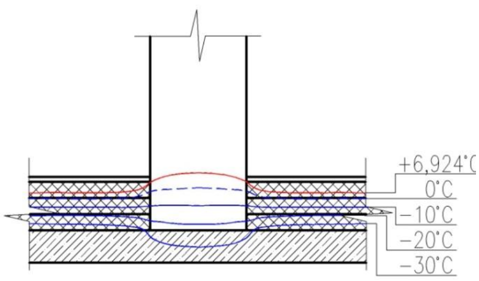

Figure 1. Node of socle floor slab with steel concrete column: a - node design; b - thermogram; c - isolines of distribution of temperature
1 - socle floor slab 2 - expanded polystyrene of PSB-S 35; 3 - cement and sand tie; 4 - steel concrete column

In the considered building the first floor on the one hand acts concerning the second floor. On this site in corner of the building there is cold bridge: reinforced concrete slab of overlapping - laying from wall stone (fig. 2, a). By results of calculation of temperature fields of this node minimum temperature on inside face of the protecting designs was t_{min} = +8,07ºC, the specified resistance to heat transfer was R_{red} = 2,44 (m^2 ºC) / W (fig. 2, c). In fact, actual temperature was much lower than

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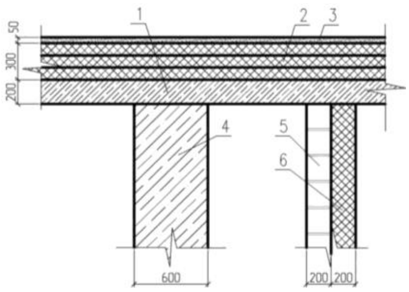
calculated values. For example, on the allocated R2 area in fig. 2, b minimum temperature in corner from the inside of the outside protecting designs in day of carrying out inspection was all t_{min} = -2,1°C. This fact is explained by availability of cavities or slots in solution seam between the upper edge of laying from small concrete blocks and lower face of inserted floor. In actual practice construction site, it is rather difficult to fill with cement and sand solution gap on this site. Besides, mineral-cotton plates not always densely adjoin to laying surface because of availability of roughness's of laying or flows of solution that also in the conditions of the increased infiltration of air during the winter period leads to heat loss.

On this site heat leakage is also observed on site laying joint with column. For example, on the allocated R1 area in fig. 2, b minimum temperature is t_{min} = -1,6°C that is much lower than value of temperature of loss of condensate. One of basic reasons of such state is availability of cavities or slots in solution seam between end face of laying and surface of column that depends on quality of construction jobs on blockwork from small blocks. Besides, in the period of upkeep of buildings there are vertical cracks between laying and column owing to temperature deformations.

a.



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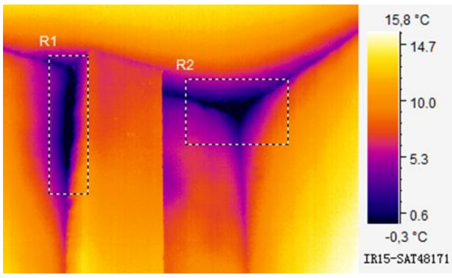

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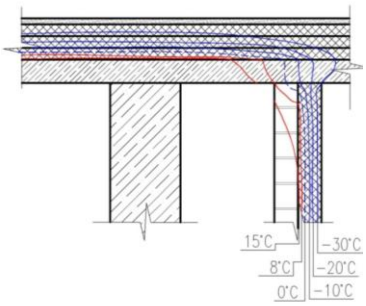
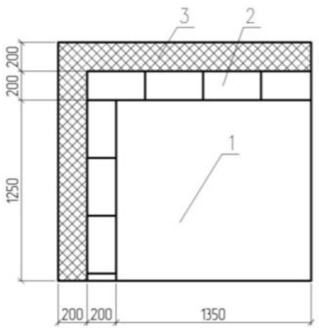


Figure 2. Node of covering of the first floor from the outside protecting design and steel concrete column: a - node design; b - thermogram; c - isolines of distribution of temperature
1 - slab roof of 1 floor; 2 - expanded polystyrene of PSB-S 35; 3 - cement and sand tie; 4 - steel concrete column; 5 - laying from wall stone on cement and sand solution; 6 - mineral wool boards

One of problem sites in frame and monolithic buildings is the angle of socle overlapping with the outside protecting design. In design decisions taking into account arrangement of non-residential premises on the first floor thickness of heat-insulation layer of socle overlapping of buildings in weather conditions of Yakutsk is accepted usually by 300 mm. At the same time, according to heattechnical calculation temperature on inside face of node of socle overlapping with external wall does not meet the normative requirements and values of temperature of loss of condensate are lower. For the considered building by results of calculation of temperature fields of constructive node at outside temperature of -39,4°C minimum temperature on surface of the protecting designs, equal t_{min}= +4,9ºC is received (fig. 3, b). Results of thermovision shootings confirm low temperature on inside face of angular part of node of the protecting design. For example, on the allocated Pol1 area of the site of the protecting designs minimum temperature is all t_{min}= +3,5°C. On other similar nodes have been established even negative temperature. From the point of view of heat-shielding this node is the most vulnerable as the cold zone is located from three parties and there is cold bridge: socle reinforced concrete slab - laying from small concrete blocks. Besides, availability of gaps between end faces of polystyrene foam plates and laying owing to low-quality carrying out heat-insulating works and shrinkage of plates is cause of infringement of temperature condition over time. All this in the conditions of the increased infiltration of air at low outside temperature of $t_{out} \leq$ -35°C leads to intensive penetration of cold air and heat loss.

In the presence of column on the considered site of socle overlapping the situation becomes more adverse from the point of view of heat-shielding. In this case there is additional bridge of cold: steel concrete column - grillage of pile groups. Besides, at work on heat insulation of socle overlapping the angular zone leads to complication of these works. Emergence of additional bridges of cold leads to change of temperature condition in the adverse part and respectively temperature condition changes for the worse. The actual minimum temperature on the allocated R1 area in fig. 4, b was -0,1°C in day of carrying out thermovision inspection. As a result of heattechnical calculation of this node very low temperature on inside face of the protecting designs is established. Minimum temperature on surface is equal to -1.7°C and the specified resistance to heat transfer of the considered site of the outside protecting designs has very low R_{red} = 2,22 (m^2 ºC) / W. Violation of thermal shielding of this site is explained by the above-stated reasons for similar node only without column.

a.



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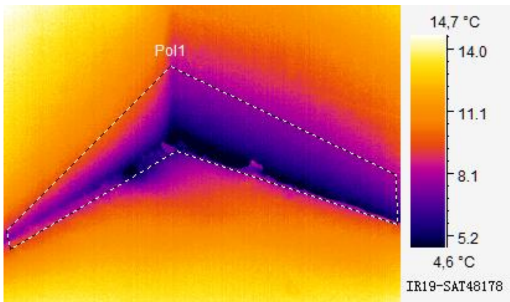

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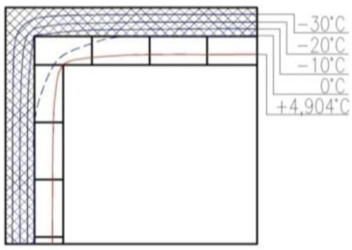
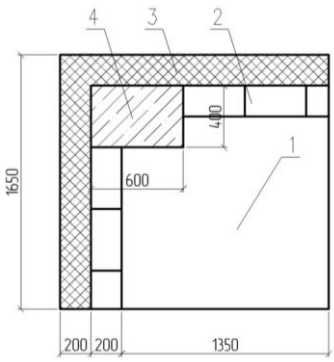


Figure 3. Node of angle of socle overlapping from the outside protecting design: a - node design; b - thermogram; c - isolines of distribution of temperature
1 - socle floor slab; 2 - laying from wall stone on cement and sand solution; 3 - mineral wool boards

At design and construction of frame and monolithic buildings in the conditions of Yakutsk movement joints in socle overlapping are located with step, not exceeding 15 m. This structural component is especially important for northern areas with big temperature drop of outside air during the winter and summer periods. Quite often because of errors of design and construction there are cracks in grillages of piles because of temperature deformations. Movement joints have to be filled with elastic thermal insulation material and from outer side to be pressurized by weatherproof sealants. In practice seams in socle overlapping are in most cases closed up by tow and polyurethane foam or polystyrine plates. In the considered building the first approach is applied. The constructive solution of the site of socle overlapping with pair columns and expansion seam is provided on fig. 5. By results of calculation of temperature fields minimum temperature on inside face of the protecting designs is t_{min} = -2,89ºC. The specified rated resistance to heat transfer of this node is R_{red} = 1,126 (m^2 ºC) / W. Results of thermovision shooting have shown low temperature on inside face of the protecting designs with the minimum value t_{min} = -8,4°C. On this site explicit impact is exerted by penetration of cold air through movement joint because of their insufficient seal. It should be noted that the above-stated methods of seal of movement joints accepted in construction practice are ineffective and eventually lose the functions.

a.



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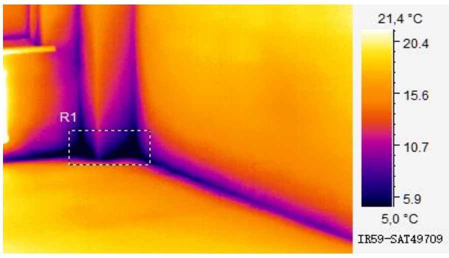

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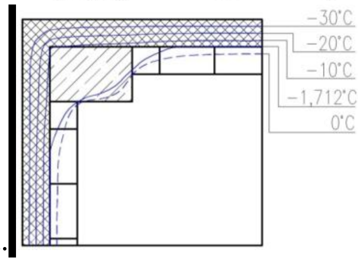
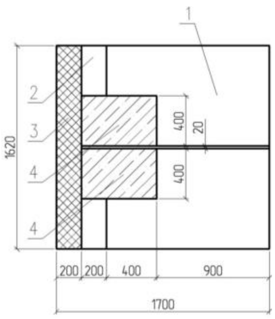


Figure 4. Node of angle of socle overlapping from the outside protecting design in the presence of column: a - node design; b - thermogram; c - isolines of distribution of temperature
1 - socle floor slab; 2 - laying from wall stone on cement and sand solution; 3 - mineral wool boards; 4 - column

a.



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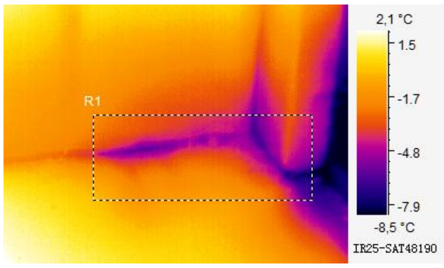

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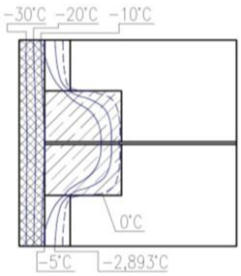

Figure 5. Node of socle floor slab with columns on movement joint of the building: a - node design; b - thermogram; c - isolines of distribution of temperature
1 - socle floor slab; 2 - laying from wall stone on cement and sand solution; 3 - mineral wool boards; 4 - steel concrete column; 5 - movement joint

During conducting on-site investigations violations of thermal shielding of the outside protecting designs and on upper floors are established. In fig. 6 the node of angle joint of the protecting design with constructional column is given in the 6th floor of the building. By results of calculation of temperature fields minimum temperature on inside face of the protecting design is t_{min}= +11,8ºC, the specified rated resistance to heat transfer of this node - R_{red} = 4,28 (m^2 ºC) / W. On this site there is no direct access of cold air to heat-conducting inclusions: to column and laying. Nevertheless, from

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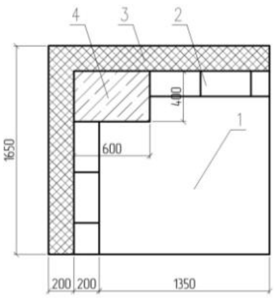
picture of isolines of distribution of temperature it is visible that at outside air temperature of t_{out} = -39,4°C the most part of column section is in zone with negative temperature.

As practice shows, in the conditions of the increased air infiltration the large role is played by quality of performance of laying from small concrete blocks and the laying adjunction density to column. From fig. 5, with it is visible that on the considered site there are cavities in seam between laying and column. Respectively actual temperature on inside face of the protecting design was t_{min}= +1,5ºC. Except the aforesaid, also leaky adjunction of mineral wool boards to laying is cause of infringement of temperature condition of the protecting design.

a.



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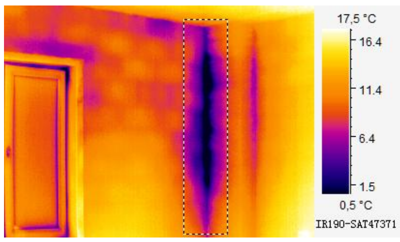

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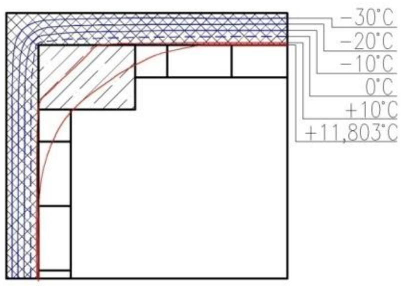

Figure 6. Node of corner of the outside protecting design in the presence of column on the 6th floor: a - node design; b - thermogram; c - isolines of distribution of temperature
1 - socle floor slab; 2 - laying from wall stone on cement and sand solution; 3 - mineral wool boards; 4 - column

Conclusion

1. As a result of the conducted on-site thermovision examinations multi-storey (12 and more floors) frame and monolithic buildings in Yakutsk characteristic sites of the outside protecting designs with the low temperature which is not meeting the normative requirements of thermal shielding of buildings are established. The most problem sites is nodes of socle overlapping with the outside protecting design. On these sites at outside temperature in day of carrying out inspections of t_{out} = -39,4°C minimum temperature on inside face of the protecting designs places was below, than dew point temperature of air. Such picture is especially characteristic of angular sites of socle overlapping of the 1st floor of buildings in the presence of column. During inspections infiltration of air is established through movement joints in socle overlapping of multi-storey buildings. On upper floors of buildings heat leakage by places is observed through blockwork joints with columns.

2. Are basic reasons of violation of temperature condition on the first floor of multi-storey buildings availability of bridges of cold: steel concrete socle overlapping - laying from small concrete blocks. On some sites in addition to them there is one more heat-conducting inclusion in the form of column with grillage of piles. The made design decisions of nodes of socle overlapping initially assume low temperature on inside face of designs. By heattechnical calculation it is established that at calculated temperature of outside air t_{out} = -52.0°C minimum temperature on inside face in ordinary connection of wall barrier with socle overlapping is t_{min} = 8,81°C, in T-joint of wall barrier with socle overlapping - t_{min} = 1,64°C, and in the presence of column in T-joint - t_{min} = -5,54°C.

3. In the conditions of especially low outside temperature (t_{out} =-40°C …-55°C) on temperature condition of the protecting structures of the first floor considerable impact is exerted by air infiltration. At pressure difference between outside and internal air of 180-200 Pas on the first floor of 16 floor houses any defect in the outside protecting designs leads to intensive penetration of cold air in the building. The main defects of nodes of the protecting designs are: in socle overlapping gaps between end faces of polystyrene foam plates and laying or colons owing to low-quality carrying out heat-insulating works and shrinkage of plates over time, leaky seal of movement joints; on upper floors availability of cavities in seams between laying and lower face of inserted floors, in seams between laying and columns, leaky adjunction of mineral wool boards to laying surface from small concrete blocks.

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