Peculiarities Research of Buildings and Structures Energy Efficiency

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Abstract. The constant buildings growth inevitably increases volume and work cost on their technical diagnosis. This defines the relevance of introducing non-destructive testing modern methods, which accelerate diagnosis, obtain a reliable assessment of technical condition and residual resource reasonable prognostication in safe operation field. Priority are control methods that do not require facility decommissioning, which provides a significant time and money reduction. Currently, infra-red thermal imaging using interest has significantly increased. This is due to the adoption of Russian Federation regulatory documents on improving energy efficiency and energy-saving technologies introduction in the construction and buildings reconstruction. Sweden, Canada and the United States developed a significant number of standards and guidelines for practical examinations of buildings and structures using thermal imaging quality control methods of building constructions thermal insulation at the end of the last century.

On the other hand, relatively inexpensive matrix detectors of infrared radiation have been developed and put into widespread use, as a result of measurement models have become available.

In the Bashkortostan Republic based on the analysis of thermal imaging studies of housing, civil and industrial construction projects, energy-efficient building construction have been developed and proposed.

1. Introduction

At present, Russia has large reserves of both already discovered and potential energy resources. In the world's explored supplies, Russian Federation resources share is: oil - 13%, natural gas - 36%, coal - 12%. Russia has the longest coastline, which provides it with huge areas of the continental shelf (3.9 million km), highly efficient in detecting oil and gas supplies. Despite such a country’s wealth, the situation is almost every second ton of burned fuel is spent irrationally. As evidence, you can refer statistics from the International Energy Agency and the American Council ACEEE. According to statistics from the International Energy Agency, Russian Federation has only twenty-eighth level in energy consumption [1, 2]. When researches of energy consumption by American Council for an Energy-Efficient Economy had been studied, it was noted that Russia occupies last level in rational energy consumption. They took into account 12 largest economies in the world: Australia, Brazil, Canada, China, France, Germany, Italy, Japan, Russia, Great Britain, the USA and the Euro Union. Leading positions in this rating were taken by Great Britain, Germany, Italy.
2. Theoretical part
Comparing Russia with other countries, we can conclude that harsh climatic conditions have a huge impact on energy consumption, which is 6-8 times higher than other countries [3]. One of the reasons is the large number of residential buildings that were built in 1917-1984. During this period, panel buildings construction was dominating. Residential buildings were built so quickly that they did not pay attention to thermal insulation, so it was necessary to solve problems of thermal insulation using traditional methods (gluing joints on windows, insulating walls, replacing windows and doors). Old type houses heat loss is high and can reach 80%. This problem leads to an increase in utility bills. Such buildings need renovation, which includes a set of measures, for example - facades insulation.

Since the 1970s many countries have implemented policies and energy efficiency programs. Today, the industrial sector accounts almost 40% of the annual global consumption of primary energy resources and global carbon dioxide emissions share. The international standard ISO 50001 has been adopted, which regulates energy efficiency too.

In Russia one of the important problem which connects with energy efficiency is the building materials quality [4, 5]. Currently primary housing of a multi-storey building is an expensive pleasure, however, people acquire this type of housing without suspecting it is quality. During the construction, low-quality materials are often used, which leads to “empty space” in walls (such defects reveal at diagnosing with a thermal imager), and low room temperature. Then residents of such apartments have to insulate walls, change windows and doors, and deal with energy conservation by their own expense, wherein that many young families buy apartments on a mortgage (for 20-30 years).

In developed countries, about half of all energy is spent on buildings construction and operation, in developing countries - about a third. This is due to large number of household appliances in developed countries. In Russia, household needs account for about 40–45% of all generated energy. In our country heating costs within residential buildings are 350–380 kW/m² per year (5–7 times higher than in EU countries), and some buildings expend 680 kW/m² per year. Heating systems distances and deterioration lead to losses 40–50% of all generated energy allocated for heating buildings. As a result of solving these breakdowns, there is an active buildings construction with effective heat insulation and location around the world, such buildings have low energy consumption and also use solar energy for heating. All of such points can affect the volume of purchased energy resources [6, 7]. And Russia having main income from the supply of energy resources to foreign countries, will not only reduce export volumes, but will also lose huge part of its income.

For many years, European countries have been using energy-saving technologies in buildings construction and reconstruction. In these countries legislative norms have been developed by taking into account economic interests of homeowners and investors. Improvement buildings energy efficiency is achieved by the use of effective thermal insulation [8], heat pumps installation, modern window and door blocks that prevent heat loss, boilers using with high efficiency and apartment temperature control devices.

The building thermal imaging diagnostics is an important heat engineering element part of the energy inspection [9, 10], consigned to measure and study the actual temperature field of radiation surface, which includes external building constructions, internal heat sources, etc. Measurements made by thermal imaging devices form a building thermal picture (several temperature values are recorded simultaneously).

3. Literature review
Thermal imagers (refer with Fig. 1) are devices consigned to observe heated objects by their own thermal radiation. They transform infrared radiation that invisible to human eye into electrical signals. These signals after amplification and automatic processing are again converted into a visible object image. Temperature changes of the object radiation surface suit to visually observed picture details, therefore images created by thermal imager mainly suit to ideas about the shape and size of objects and it’s individual sections.
The first attempt to create a thermal imager can be called an evaporograph, which means "registration of evaporation" (refer with Fig. 2). An oil membrane was used as a converter. The temperature difference between the observed object and the environment was fixed and transformed into membrane thickness. During heating uneven liquid evaporation occurred and object was displayed. In the 19th century the basis of its creation was the experiments of D. Herschel, who used filter paper soaked in alcohol and smoked from the observed object side. At the beginning of the 20th century there were attempts to improve the device and certain successes were achieved in America, Germany and the Soviet Union. However, all devices belonged to the class of non-scanning devices and did not receive widespread use because of the low resolution and reproduction speed.

In 1945-1950 many countries began development of a scanning device, the idea of which was proposed by the Soviet scientist F. E. Temnikov. The proposed method was based on deployment transformation. The main attention was dedicated to the optical-mechanical scanning system, since at that time transmitting television tubes have not been sensitive enough to infrared radiation and the main indicator was image transmission time. According to this principle, they were classified as low speed, medium speed and high speed. The first high-speed thermal imagers appeared in the 60s of the 20th century. From this moment industry development have begun.

Previous generations experience and rapid science development and technology served as an incentive for solid-state matrices development and it was proved using silicon is possible to convert optical to electrical signals. Using shift registers, individual matrix elements, which had located at the periphery, were scanned in two perpendicular directions. In the 70s registers analogs appeared, that served as signal keepers and then decrypted and broadcast in the images form by special devices. Currently, the most widely used are hypersensitive uncooled bolometers. Russia mastered this technology production in 2007.

Depending on the model, thermal imagers differ in measurement temperature step size. Modern technologies make it possible to distinguish objects temperature with an accuracy of (0.05-0.1) K. Due to the excellent filters locking, temperature measurements can be located beside the building’s area for all other processing lasers operating in range from 800 nm to 2.6 μm.

For correct object temperature measurement, it is necessary be completely into a pixel. Physically, object image is projected on detector and farther imager is from object more image is blurry. Therefore, more pixels there are in detector, clearer image we will receive. Sometimes the standard field of view can be changed. For such thing a telephoto lens is used. Such lenses have view angle less than standard and they “bring object closer to thermal imager”. Some thermal imaging lenses use a special lens structure that provides wider field of view. These lenses are called wide-angle and find applying when long distance movement to cover measurement object is impossible.

Thermal imagers have found applying in many industries. On the one hand, this has become possible because of infrared radiation that surrounds us constantly and carries a lot of information for detecting objects and diagnosing them. On the other hand, thermal imagers catholicity is associated with their main advantages: remote measurement at sufficient distances, mobility, and real-time operation.
The main thermal imager disadvantage is high price - 90% of device cost is made up of its elements: matrix and lens. Matrices are very difficult to manufacture and expensive. Lenses cannot be made of glass, because this material does not transmit infrared radiation. For this reason, rare and expensive materials are used to create lenses.

Any work, including thermal imaging inspection, should be carried out in accordance with regulatory documents regulating a particular activity area [11, 12]. For thermal imaging inspection, first of all, a list of state standards, federal laws and joint ventures that are decisive for this type of work. Before describing the regulatory framework that defines thermal imaging research rules, it is necessary to mention building thermal control theory and electrical structures has been developed for a long time, and modern thermal diagnostics version is a “re-carnation” of a proven and well-proven construction diagnostics technique. This means that any thermographic analysis is made not for ordinary measurements, but in order to detect deviations from the approved quantitative and qualitative ratios in the building’s construction or electrical equipment.

Specially, checking the heat-insulating building structures fencing, they are guided by the standards set out in the following documents:
- SP 50.13330.2012 with amendment No. 1 “Thermal buildings protection”;
- MGSN 2.01-99 “Energy Saving in Buildings”.
- In addition, these documents give requirements for thermal balance between internal atmosphere and walls temperature, and these standards became a basis for filling out claims against builders.
- The basic decrees of non-destructive testing methods are set out in following rules and standards:
  - GOST R 54853-2011 “Buildings and structures. Method of determination of thermal resistance and thermal coefficient of enclosing structures with assistance heat flow meter”;
  - GOST 26629-85 “Buildings and structures. Method of thermovision control of enclosing structures of thermal insulation quality” (it considered special heat-insulating coatings control features);
  - GOST R 25380-2014 “Buildings and structures. Method of measuring density of heat flows passing through enclosing structures” (it set out methodological guidelines for organizing thermographic measurements);
  - RD-13-04-2006 "Guidelines on the procedure for conducting thermal control of technical devices and structures used and operated at hazardous production facilities" (it included conducting thermal imaging control procedure at high-risk facilities).

There is a more modern standard of basic concepts, numerical ratios and guidelines for thermographic inspections are formulated: GOST R 54852-2011 “Buildings and structures. Method of thermovision control of enclosing structures thermal insulation quality”

If the electrotechnical laboratory plans to provide heating networks energy audit services, recommendations will set out RD 153.34.0-20.364-00 “Method for infrared diagnostics of thermomechanical equipment” and should be taken into account. There is also a normative document for conducting a buildings thermal imaging survey and all kinds of facilities - Federal Law No. 261 “On energy saving and improvement of energy efficiency”.

The main requirements for conducting thermal buildings and their constructions imaging monitoring are licenses, certificates and approvals availability, all types equipment mandatory verification required for inspection, mandatory temperature difference during work compared to indoor room and air temperature, availability of heat measuring sensors and recorders in accordance with current regulatory documents. Also, at the work time, there should be no precipitation, and buildings thermal boundaries should be closed. Outside, structure should be measured at the same distance for each measurement. All surfaces of enclosing structures must be subject to thermal imaging.

During building constructions thermal imaging diagnostics, other non-destructive testing methods can also be used [13, 14].
4. Practical significance

In Ufa widespread thermal imaging survey of residential buildings facade systems, approved by the Ministry of Housing, Utilities and Road Construction of the Bashkortostan Republic [15, 16]. To analyze the objects energy losses level were carried out thermal imaging surveys in Ufa [17].

The one-storied building with sandwich panel lining is an industrial housing with dimensions of 33.0 x 13.8 m, 6.840-8.045 m high. Windows, exterior doors and stained-glass windows are made of PVC profile with two chamber double-glazed windows. Gate - sectional with a wicket.

During thermal imaging survey, minor heat losses were detected of building outer walls (defect should be eliminated after a natural walls humidity decrease during subsequent heating periods), windows, exterior doors, gates and corners are natural areas of heat loss (Figure 3).

It was revealed that on a significant surface filler structures part temperature field is steady. On the facade, no temperature anomalies and defects that could be caused by poor-quality wall insulation were found. The heat flux from ordinary walls surface is steady.

![Figure 3. One-story building fragment thermogram with sandwich panel lining.](image)

A multi-storey residential building with brick walls and mineral wool insulation. The fifteen-story building with a wall thickness of 380-510 mm, a insulation of 100 mm mineral wool, dimensions of 53.81x15.22 meters. Partitions are made of ceramic bricks 65, 120 and 250 mm thick, 80 mm and concrete slab-ridge slabs blocks 200 mm thick.

A temperature field of filler structure surface is steady. On the facade, no temperature anomalies and defects were found that could be caused by poor-quality wall insulation. The heat flux from ordinary walls surface is steady (refer with: Fig. 4). Significant heat loss is occurs only in outer rooms corners.

As a result of thermal imaging survey, areas that did not meet heat engineering requirements were identified. The wall insulation joint to the building corner has bad-quality. According to paragraph 5.2 of table 5 (SP 50.13330.2012 "Thermal buildings protection") "... standardized temperature difference for residential buildings outer walls is 4.0°C ...". According to thermal imaging survey results, the actual temperature difference varies from 3.2°C to 16.1°C, which does not meet standards.

According to work results with using visual-measuring control and design and executive documentation analysis, it was found work on thermal insulation of external walls was carried out in accordance with the project. However, the insulation adjunction to walls’ ends is poor-quality, and this is the result heat losses occur in rooms corners.

![Figure 4. Multi-story residential building thermogram with brickwork walls and mineral wool insulation.](image)
Three-storey shopping and service building with external brick walls and mineral wool insulation. The building is three-story, with a wall thickness of 380, 510 mm, with a basement, a rectangular shape with overall dimensions of 34.725x14.61 m, with a first-floor height 4.2 m, second 3.7 m, third 3.1 m, basement height 3.2 m. The shopping and service building facades are made of three-color ceramic-granite slabs combination. The plinth lining is made of tiles using Besser technology. Windows, exterior doors and stained-glass windows are made of PVC profile with double-glazed windows (refer with: Fig. 5).

Slight heat loss was detected in the end of building rooms (the defect should be eliminated after a natural walls humidity decrease during subsequent heating periods), corners are natural heat loss areas. It was revealed that on a significant filler structure surface part temperature field is steady. No temperature anomalies and defects were found on facade. The heat flow from the ordinary walls surface is steady.

![Three-story shopping and service building thermogram with brickwork walls and mineral wool insulation](image)

**Figure 5.** Three-story shopping and service building thermogram with brickwork walls and mineral wool insulation.

### 5. Conclusion

The thermal imaging survey analysis results show reasons heat efficiency indicators decreasing – project miscalculations, poor-quality materials selection, work poor-quality and improper operation [18, 19].

Based on conducted thermal imaging surveys, the economic efficiency of different insulation methods was determined. Then filler structure optimal options for the device were selected, depending on building purpose.

### 6. References

[1] Bedov A I, Gaisin A M, Gabitov A I, Galeev R G, Salov A S and Shibirkina M S 2015 Determination of heat losses of a window frame to the wall joint when replacing the outdated constructions of window blocks with modern ones *Bulletin of MSUCE* 11 pp 46-57

[2] Gagarin V G 2010 Macroeconomic reasons for applying energy saving measures under increasing of heat insulation in building enclosing structures *Construction materials* 3 pp 8-16

[3] Gabitov A I, Gaisin A M, Udalova E A, Salov A S, Yamilova V V, Gainanova E S 2019 Historical aspects of the development of energy efficient technologies in construction *Ecological systems and devices* 4 pp 44-50

[4] Gaisin A M, Babkov V V 2016 Analysis of Bearing External Walls of Multistory Residential Buildings in the Republic of Bashkortostan from the Position of Specific Thermal Protection Characteristic *Construction materials* 10 pp 55-57

[5] Mamleev R F, Sagitov R Sh, Kolesnik G S, Babkov V V, Gareev R R, Gaisin A M, Moskalov A P, Korobeinikov Yu M, Razumova G F, Chikota A N, Fedortsev I V, Mavluyarov H D, Yarovenko A L, Kartashov V B, Sinitsyn D A 2003 Experience in applying new Russian standards for heat protection of building enclosing structures in the Republic of Bashkortostan *Construction materials* 10 pp 6-9

[6] Bedov A I, Gabitov A I, Gaisin A M, Salov A S, Chernova A R 2018 CAD in interdisciplinary integration as a tool to increase specialist training quality in “Construction” education VI International
Scientific Conference “Integration, Partnership and Innovation in Construction Science and Education” (IPICSE-2018) (Moscow, Russia) pp 1-7

[7] Babkov V V, Gaisin A M, Naftulovich I M, Sinitsyn D A, Kolesnik G S 2005 Operating experience of buildings with heat efficient exterior walls in the Republic of Bashkortostan Rostekhnadzor. Our region 5 pp 22

[8] Babkov V V, Kolesnik G S, Gaisin A M, Gareev R R, Chikota A N 1998 Bearing exterior three-layer walls of buildings with hyperinsulation Construction materials 6 pp 16-18

[9] Burkitbaev A K, Adilova Sh K 2013 Thermovision inspection as a way for technical diagnostics of heat loss in buildings and structures Bulletin of Almaty technological University 1 pp 77-79

[10] Logacheva Ye A, Zhdanov V G, Taranukha D S 2014 Thermovision inspection of buildings and structures Collection «Methods and technical means of improving efficiency in the use of electrical equipment in industry and agriculture. The 75th Scientific and practical conference» pp 102-106

[11] Smorodova O V 2016 Problems for assessing heat consumption under thermovision inspection Innovation science 4-3 pp 147-151

[12] Bedov A I, Gabitov A I, Gaisin A M, Salov A S, Chernova A R 2018 CAD analysis for stress and strain behaviour of masonries made of hollow ceramic blocks IOP Conference Series: Materials Science and Engineering: Volume 465 VII International Symposium Actual Problems of Computational Simulation in Civil Engineering 1–8 July 2018 (Novosibirsk, Russian Federation) pp 1-7

[13] Bedov A I, Gaisin A M, Gabitov A I 2017 Computer Modeling of Work under the Load of High-Loose Ceramic Wall Articles and Classics Based on Their Basis News of higher educational institutions. Textile industry technology 3(369) pp 231-236

[14] Salov A S, Gainanova E S 2019 Features of monitoring and inspection of the thermal state of building structures Bulletin of the eurasian science T 11 1 pp 54

[15] Samarlin O D 2014 Provisions for making internal conditions in buildings (M.: ASB Publishers) 208

[16] Nedoseko I V, Ishmatov F I, Aliyev R R 2011 Application of structural and heat insulating lightweight concrete in bearing and enclosing structures of civil engineering facilities Construction materials 7 pp 14-17

[17] Vavilov V P 2009 Infrared thermography and heat control (Moscow) Spectr Publ. 544

[18] Babkov V V, Khushnutdinov R F, Chuiken A E, Gaisin A M, Gareev R R 2011 Heat efficient exterior walls in modern practice of constructing residential houses and other buildings Ufa state petroleum technological university (Saint-Petersburg)

[19] Bedov A I, Gabitov A I, Salov A S, Biktasheva A R 2020 Increase of energy performance of residential buildings with enclosing structures made of masonries with application of ceramic blocks Journal of Physics: Conference Series 1425(1) 012042