Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Utilization of thermovision systems for detecting problem areas in building renovation with regard to the use of renewable energy sources

***Maroš BEGÁNI*[1], *Lucia BEDNÁROVÁ*[2]* and *Ružena KRÁLIKOVÁ*[3]**

Authors' affiliations and addresses:
[1] Technical University of Košice, Faculty of Mining, Ecology, Process Control and Geotechnologies, Park Komenského 19, 042 00 Košice, Slovak Republic,
e-mail: maros.begani@tuke.sk

[2] Technical University of Košice, Faculty of Mining, Ecology, Process Control and Geotechnologies, Park Komenského 19, 042 00 Košice, Slovak Republic
e-mail: lucia.bednarova@tuke.sk

[3] Technical University of Košice, Faculty of Mechanical engineering, Letná 9, 042 00 Košice, Slovak Republic
e-mail: ružena.kralikova@tuke.sk

***Correspondence:**
Maroš Begáni, Technical University of Košice, Faculty of Mining, Ecology, Process Control and Geotechnologies, Park Komenského 19, 042 00 Košice, Slovak Republic
tel.: 0556022945
e-mail: maros.begani@tuke.sk

Funding information:
This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-21-0099. This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-21-0188.

Acknowledgement:
This paper was created in connection with the projects APVV-20-007: Waste and Construction - modeling the effectiveness of alternative cooperation options of administrative authorities.
This contribution/publication is the result of the project „Research of alternative energy sources' implementation impact on industries of energy management processes" supported by Operational Program Integrated Infrastructure (ITMS: 3131011T564).

How to cite this article:
Begáni, M., Bednárová, L. and Králiková, R. (2025), Utilization of thermovision systems for detecting problem areas in building renovation with regard to the use of renewable energy sources, *Acta Monstanistica Slovaca,* Volume 30 (1), 31-46

DOI:
https://doi.org/10.46544/AMS.v30i1.03

Abstract
This document presents an in-depth analysis of thermal imaging technology, elucidating its operational principles, evolutionary journey, and multifaceted applications in various sectors. It delves into the ability of thermal imaging to visualize heat variations, thereby facilitating detection in visually obscured conditions. The text underscores the significance of this technology in enhancing industrial maintenance, construction efficiency, medical diagnostics accuracy, military operations, and environmental preservation. Additionally, it explores potential future advancements, including sensor technology improvements, miniaturization, and integration with augmented and virtual reality, suggesting broader applications. Experimental case studies within the document illustrate thermal imaging's effectiveness in practical scenarios, such as leak detection and heating system evaluations, highlighting its utility in addressing real-world challenges.

Keywords
Thermovision, Thermography, Thermal imaging cameras, Thermal imaging.

Introduction

This document provides a comprehensive overview of thermal imaging technology, detailing its principles, historical evolution, and diverse applications across various sectors. The integration of renewable energy sources in building renovation is a growing trend aimed at enhancing energy efficiency and reducing environmental impact. One critical aspect of this process is identifying and addressing problem areas within existing structures that could hinder the effective use of renewable energy sources. Thermovision systems, also known as thermal imaging technology, have emerged as a powerful tool in this context.Thermal imaging, also known as infrared imaging, is highlighted for its capability to visualize heat emitted by objects, enabling detection in conditions where traditional visual cues are absent. The text outlines the technology's significant contributions to fields such as industrial maintenance, construction, medical diagnostics, military operations, and environmental monitoring. Furthermore, it explores the future potential of thermal imaging, emphasizing advancements in sensor technology, miniaturization, and integration with augmented and virtual reality, which could broaden its applications (Begáni et al., 2023). The document also includes experimental case studies demonstrating practical applications of thermal imaging in detecting water leaks and evaluating heating systems, showcasing the technology's practical benefits in diagnosing and solving real-world problems. Given the detailed exploration of thermal imaging technology in the document, including its operational principles, historical development, and broad range of applications, the introduction could encapsulate the essence of thermal imaging as a pivotal innovation in sensing technology. It should highlight how this technology transcends the limitations of human vision by capturing the infrared spectrum, offering critical insights across numerous fields. From enhancing diagnostic processes in healthcare to improving operational safety in industrial settings, and from supporting environmental conservation efforts to augmenting military and security operations, thermal imaging stands as a testament to human ingenuity in harnessing electromagnetic spectrum for the betterment of society. The introduction could also touch upon the document's discussion on future trends, suggesting the potential for even more innovative applications and technological advancements in thermal imaging.

Characteristics and principle of thermal imaging

Thermal vision, also known as infrared vision, is a technology that enables the visualization of heat emitted from objects in the form of infrared radiation, which is invisible to the human eye. This ability allows the detection of objects, people, or animals in complete darkness, fog, or other visually limiting conditions, thanks to the temperature differences between the object and its surroundings. The basic idea of thermal imaging is to convert infrared radiation into a visible image, which allows it to be used in various applications, from military operations to security systems to medical diagnostics and condition monitoring of buildings or machines (Begáni, 2021).

The infrared radiation that thermal imaging systems detect is a form of energy emitted from any object whose temperature is above absolute zero. This energy is directly proportional to the temperature of the object; the warmer the object, the more infrared radiation it emits. Thermal imaging cameras capture these radiations using a special sensor called a microbolometer, which can detect very small differences in temperature. This sensor converts infrared radiation into an electrical signal, which is then processed into a visible image showing the temperature differences of the scene. Color palettes are often used to highlight these differences, where different colors represent different temperatures, allowing the user to more easily identify and interpret the temperature properties of objects on the screen (SCPC, 2021).

Thermovision is a method of thermal scanning of objects radiating heat from digital display and grading of its temperature fields. Thermovision (thermography) offers one of the most effective ways of identifying heat leakage and thermal differences on the observed surface by a method that scans the emitted infrared radiation from the object's surface. The key to thermal imaging - thermography is the illustration of surface temperature distribution by measuring the intensity of infrared radiation from the surface. The result of the thermal imaging measurement is an infrared image (thermograph), where it is possible to accurately identify problem areas with a disturbed temperature field (Silva et al., 2019).

History of infrared thermography

Infrared thermography was first used for purposes other than civil construction. The principle of infrared thermography was discovered by accident, scientist William Herschel was trying to solve an astronomical problem in 1800. Over the years, this technique has been perfected and started to be used in several industries. In 1830, the Italian investigator Melloni discovered that NaCl in natural crystal reaches a sufficient size to be transformed into lenses and prisms. And so they became the main infrared radiation until 1930, the time of the emergence of synthetic crystals. The first thermographic detector was developed between 1870 and 1920 by Karl Planck based on the interaction between radiations, which increased accuracy and significantly reduced response time. During the Second World War, thermography was greatly improved, which was mainly demonstrated by its use at night. The spread of infrared images in the construction sector did not occur until 2000, with the use of barium and strontium titanate and a microbolometer. In recent years, the use of thermography has increased dramatically, especially in restoration, construction and survey work. In addition, it is important to note that this technique has improved over the years, which is related to the reduction in equipment size, cost reduction and resolution improvement. The use has increased significantly over the last 15 years, mainly for civil engineering and the restoration of historic buildings, thus facilitating the spread of European legislation not only for energy efficiency, but also for the energy audit of buildings. The development of infrared thermography and its applications in construction and the restoration of historic buildings are significant examples of how technological advances can bring significant benefits to traditional industries. With the expansion of the use of infrared thermography in civil buildings, new possibilities have opened up for the diagnosis, maintenance and protection of infrastructure and cultural heritage. The technology makes it possible to identify problems that are not visible to the human eye, such as hidden water leaks, missing or insufficient insulation, and a number of other problems that can affect the structural integrity and energy efficiency of buildings. Thanks to the ability of thermography to display temperature differences on the surface of objects, it has become an irreplaceable tool in energy audits and evaluations (Begáni, 2021). Energy efficiency is a key component of European building legislation, and thermography provides an accurate and non-invasive way to identify areas where improvements are possible. This not only helps reduce energy costs, but also contributes to environmental protection by reducing greenhouse gas emissions. In the restoration of historic buildings, thermography allows experts to examine the condition of materials and reveal hidden structural damage without the need for invasive intervention, which is especially valuable when it is necessary to preserve the original substance and appearance of the object. This technique has become invaluable in planning restoration and conservation work, as it provides a detailed view of issues that require attention and allows for more efficient use of resources. Likewise, in engineering structures such as bridges, tunnels, and other critical infrastructures, thermography helps in the early detection of material damage or wear, which enables preventive maintenance work and extends the life of these important structures. This approach not only reduces repair costs but also increases user safety. The development and refinement of infrared thermography continues, with the scientific community and technology companies constantly seeking new applications and methods to improve its accuracy, resolution and availability. With the combination of advanced software solutions and the decrease in the price of thermal imaging cameras, the use of this technology is expected to continue to grow, bringing innovations and improvements in many areas of human activity (Silva et al., 2019).

Origin and development of thermal imaging

In 1900, the German physicist Max Karl Ernst Ludwig Planck discovered the relationship between the temperature of an object and the amount of infrared radiation it emits. This discovery laid the foundations for the development of infrared thermography, a scientific field focused on non-contact analysis of temperature distribution on the surface of objects. Infrared thermography works with infrared energy emitted by bodies that have a temperature higher than absolute zero. This energy is converted into a temperature image - a thermogram, using emissivity, which is an indicator of how effectively the object emits infrared radiation compared to a black body at the same temperature (SCPC, 2021).

Thermal imaging technologies allow the visualization of temperature differences, thus clarifying the presence of people, animals, vehicles, or temperature leaks from buildings. These images can be obtained even in complete darkness, fog or during rain, which is why Planck's work enabled the development of thermal imaging cameras. These cameras capture infrared radiation from objects and focus it on a semiconductor detector that transforms the radiation into an electrical signal. Detectors in thermal imaging cameras are most sensitive in the range of 3.5-5.6 μm and work in the temperature range from -20 °C to +850 °C, while this range can be extended with the use of special filters (Proszak-Miąsik, 2019).

The displayed thermal information on the monitor can have different degrees of gray or color, which correspond to the intensity of infrared radiation and thus to the temperature of the scanned object. The accuracy of modern thermal imaging systems is extremely high, reaching a sensitivity of up to 0.02 °C, which enables the detection of minimal temperature differences.

Today, thermal imaging is used in a wide range of applications, from the diagnosis of problems with thermal insulation, through the identification of weak points in pipe systems and electrical installations, to the detection of hidden leaks. This technology enables quick and effective identification of problem areas, thereby contributing to the prevention of possible accidents and optimization of operating costs (Pyrosales, 2018).

In addition to its practical applications, thermal imaging also contributes to scientific knowledge and research, enabling the study of thermal processes in various materials and systems. With the gradual reduction of the cost of thermal imaging technologies and the improvement of their availability and resolution, their use in the commercial sphere, scientific research, as well as in environmental protection is constantly growing. For example, in the field of environmental monitoring, thermal imaging helps in the detection and analysis of forest fires, the monitoring of wild animals, or the assessment of the impact of climate change on various ecosystems.

In the restoration and maintenance of historic buildings, thermographic scanning provides irreplaceable information about the condition of structures without the need for physical damage. In this way, thermal imaging can contribute to the preservation of cultural heritage for future generations. Thanks to its ability to provide detailed temperature maps, thermal imaging enables a better understanding and management of energy flows in buildings, thus contributing to higher energy efficiency and sustainability (Begáni, 2021).

Thermography and Thermovision

Thermography is the conversion of an infrared image into a radiometric image that allows temperatures to be read. Because infrared radiation has more energy than visible radiation, it can be detected from a greater distance than visible radiation. This is done using the installed infrared detector array in cooperation with the image retrieval system. The microbolometer detector used, which is intended for temperature detection by reaching the thermal radiation of the camera, creates a certain type of electrical signal based on readings from the matrix of the pixel sensor, which in the next stage is converted into a digital form that is displayed on the camera display. The resulting image is called a thermogram or thermal image. The temperature distribution on the studied objects is presented in the form of colored zones, where one color corresponds to points of the same temperature.

However, it should not be forgotten that the radiation detected by the lens of the thermal camera is the sum of radiations: proper radiation (sent by the investigated object), scattered and reflected radiation from the surface of the investigated object. Any thermal radiation is also attenuated to some extent by the atmosphere/environment between the camera and the object being scanned (Proszak-Miąsik, 2019). The measurement results are also affected by: solar radiation that is absorbed and reflected by the observed surface; interfering factors coming from the environment (clouds, sky, high humidity) and other objects with a higher temperature that are in the environment (furnaces, electronics, heaters, etc.). In order for the thermal imaging device to determine the correct temperature of the object, the camera operator must enter the following data:

- emission factor, which determines the amount of energy emitted by a given object, which should be emitted by a so-called black body (which is the emission standard).
- the distance between the camera and the object in order to determine transmission through the air
- air temperature
- humidity
- ambient radiation temperature reflected from the object (in most cases it is assumed to be equal to the air temperature)

The main errors in measurement are incorrectly set camera and input of incorrect environmental parameters (Hudeczek and Sopuch, 2015).

The principle of thermal imaging

Thermal imaging is based on the science of infrared energy (otherwise known as "heat") that is emitted from all objects. This energy from the object is also called a "thermal signature" and the amount of radiation emitted tends to be proportional to the total heat of the object. Thermal imaging, also known as thermography, is a technique that visualizes and measures infrared energy emitted by objects. Each material or object has its own unique thermal signature, which is determined by its properties and temperature. The thermal signature enables the identification of objects even in complete darkness or in environments with limited visibility, since infrared radiation is not dependent on lighting conditions as it is with visible light. When thermal energy radiates from an object, the thermal camera captures it and converts it into an electrical signal, which is then processed and displayed as an image (Więcek and De Mey, 2011). This image represents the temperature differences between the object and its surroundings. Color palettes are often used to better visualize these differences - cold areas can be shown in blue or green, while warmer areas can be in red or yellow tones.

In Figure 1 (Pyrosales, 2018), we see that infrared radiation is located between the visible and microwave parts of the electromagnetic spectrum. Infrared radiation is electromagnetic radiation with a wavelength longer than visible light and shorter than microwave radiation. Infrared radiation occupies 3 decades in the spectrum and has a wavelength between 760 nanometers and 1 mm. Visible radiation, i.e. radiation visible to the human eye, has a wavelength from 380 nanometers to 780 nanometers.

Thermal cameras are sophisticated devices consisting of a sensitive thermal sensor with the ability to detect minute temperature differences. As they collect infrared radiation from objects in a particular environment, they can begin to map the image based on differences and temperature measurements.

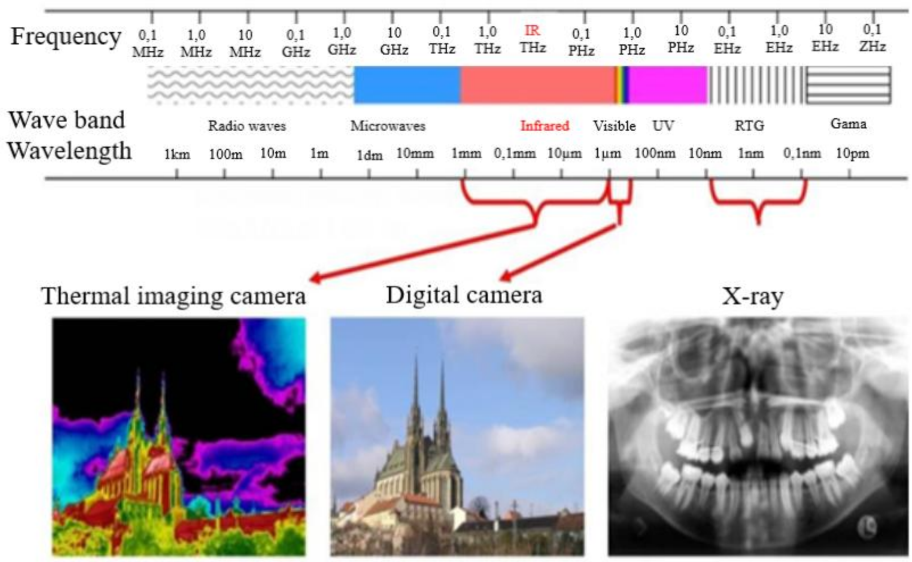

Fig.1 Infrared radiation – electromagnetic radiation in the range of wavelengths from 0.75 µm to 1 mm
Source: Pyrosales, 2018

Generally, thermal images are in grayscale: with white representing heat, black representing cooler areas, and various shades of gray indicating temperature gradients between the 3,two temperatures. However, newer models of thermal imaging cameras actually add color to the images they produce to help users better identify more obvious objects - using colors like orange, blue, yellow, red and purple (Pyrosales, 2018).

Thermovision systems detect infrared radiation emitted by objects, producing images that represent temperature variations on the surface of those objects. This technology is particularly valuable in building renovation for several reasons:

1. **Identifying Heat Loss**: Thermovision systems can detect areas where heat is escaping from a building, such as through poorly insulated walls, roofs, or windows. By pinpointing these areas, renovations can be targeted to improve insulation and reduce energy consumption, making the building more suitable for renewable energy sources integration.
2. **Locating Moisture Intrusion**: Moisture problems can compromise the structural integrity of a building and reduce the efficiency of insulation materials. Thermovision can reveal moisture-laden areas by showing cooler temperatures where evaporation is occurring, allowing for timely repairs.
3. **Detecting Air Leaks**: Air leaks around windows, doors, and other openings can lead to significant energy loss. Thermal imaging can identify these leaks, enabling precise sealing and weatherproofing measures.
4. **Assessing HVAC System Efficiency**: Thermovision can evaluate the performance of heating, ventilation, and air conditioning (HVAC) systems. It can identify uneven heating or cooling distribution, leaks in ductwork, and other inefficiencies that need addressing to ensure the building can effectively utilize renewable energy sources.

Emissivity

Emissivity is the rate at which a material emits infrared radiation compared to an ideal blackbody at the same temperature. A blackbody is an ideal, hypothetical object that perfectly absorbs all incoming electromagnetic radiation and at the same time efficiently emits energy in the form of infrared radiation. Emissivity ranges on a scale from 0 to 1, where 1 corresponds to a perfect black body, which has the maximum possible emissivity and completely radiates all received energy (Beryozkina et al., 2012).

In practice, no real materials reach an emissivity of 1. Each material has its own specific emissivity, which can be affected by many factors, such as its surface properties, temperature, humidity and even the angle of view of the thermal imaging camera. In thermal imaging, it is important to know the emissivity of the material because it affects the accuracy of the temperature measurements. If the emissivity of the object is known, thermal imaging equipment can use it to correct and provide a more accurate temperature measurement.

Selecting the correct emissivity is critical when interpreting thermographic data, as an incorrect value can lead to erroneous temperature readings. In case the emissivity of the measured material is not known, it may be necessary to perform additional tests or use reference materials with known emissivities to calibrate the thermal imaging device before making accurate measurements.

The basic quantity in thermographic measurement is emissivity. It is related to the material of the measured object. With its help, we can determine the emission of thermal radiation of any object, with respect to the radiation

of an absolutely black body. It is denoted by the letter ε. It is the ratio of the energy radiated from the surface of the object to the radiated energy of a blackbody with the same temperature as the object in the same spectral interval. Emissivity is a very important parameter when measuring with the thermographic method. An illustrative explanation of emissivity is shown in Fig. 2. In order to be able to make the measurement using an infrared thermographic camera correctly, it is important to set this emissivity appropriately according to the environment and the material of the object being measured. The table of materials with prescribed emissivity can be used to determine the emissivity value (see Table 1). These values are only informative and we often determine the emissivity in two ways:
• Using contact temperature measurement. The temperature of the measured object depends on the emissivity.
• Using a comparison with a reference surface where we know the emissivity.

The emissivity value of real bodies depends on:
• on the structure of the material,
• on the temperature of the surface of the material,
• on the wavelength,
• on direction conditions,
• on the material of the measured object (Hudeczek and Sopuch, 2015).

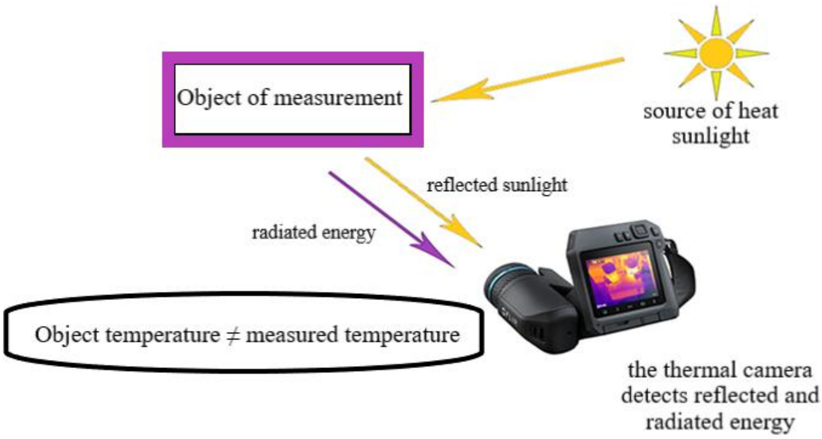

Fig.2 Visual explanation of emissivity
Source: FLIR, 2019

Tab. 1 Emissivity values for different materials

Material	Emissivity
asphalt	0.90 – 0.98
wood	0.98
asbestos	0.96
aluminum foil	0.04
skin - human skin	0.98
glass	0.92
brick	0.93

Source: Begáni, 2021

Infrared radiation and emissivity

Emissivity refers to the ability of an object to emit radiation. Infrared cameras generate images based on the amount of heat scattered on a surface by infrared radiation. This technology represents a sophisticated way of receiving electromagnetic radiation and converting it into electrical signals. These signals are eventually displayed in grayscale or color, representing temperature values. Human thermal energy is transferred to the environment through four mechanisms:

1. Conduction: transfer of thermal energy through a layer of tissue by contact between two bodies with different temperatures;
2. Convection: heat exchange between the skin and the environment;
3. Radiation: heat transfer that does not require a medium. Energy is transferred between two separate objects at different temperatures via electromagnetic waves (photons).

4. Sweat evaporation: which is the main mechanism for heat dissipation during exercise? The conversion of liquid to vapor allows the body to regulate its temperature. The result of evaporation is a drop in surface temperature.

The generated thermogram provides a quantitative and qualitative temperature map of the surface temperature, which can be related to different pathological conditions and blood flow.
Unlike a single-detector thermal imager, focal-plane detectors generate high-resolution thermal images without a mechanical scanning mechanism. These cameras operate in the long-wave infrared region (8–15 μm) with the advantage that they are less affected by solar radiation compared to shorter waves (Maldague, X.P.V., 2001).

Temperature

Non-contact temperature measurement is based on sensing the electromagnetic radiation emitted by the monitored object. This includes radiation in the range of wavelengths from 0.4 μm to 25 μm, which is part of visible light and mainly the region of infrared radiation. The radiation is directed to the detector, then it is converted into an electrical signal, which is further processed and converted into an output format. This can be numerical data about a specific temperature value, or a thermogram - a picture of the temperature distribution on the surface of the monitored object.
Advantages of non-contact temperature measurement:
• the possibility of measuring moving objects
• temperature measurement from a distance (from the point of view of safety)
• the possibility of recording rapid changes
• the possibility to measure and then digitally process surface temperatures.

Disadvantages associated with non-contact temperature measurement include not knowing the exact emissivity, reflected radiation from the surroundings and the necessary knowledge of the permeability of the environment (Hildebrandt et al., 2010).

Elektromagnetic spectrum

Electromagnetic radiation is the transfer of energy in the form of electromagnetic waves. Electromagnetic wave is a locally created change in the electromagnetic field, a periodic event, during which there is a spatial and temporal change in the electric field intensity vector and at the same time the magnetic induction vector.

Electromagnetic radiation includes the electromagnetic spectrum: gamma radiation, X-rays, ultraviolet radiation, visible radiation, infrared radiation, microwave radiation, and radio radiation. The speed of propagation in a vacuum, or also the speed of light, is 299,792.458 km/s. Based on the theory of relativity, this speed is the greatest possible speed in the entire universe. The human eye is able to perceive only a narrow region of the spectrum from about 380 to 780 nm, called visible light (Brynda, 2010).

There are several imaging methods in the electromagnetic spectrum, which are defined as a range of frequencies of electromagnetic radiation. According to their physical principles, these different techniques provide diverse information. Planck's law describes the characteristics of infrared radiation emitted by an object in terms of spectral radiation emission (Hildebrandt et al., 2010).

Current approaches and possibilities of using thermal imaging

Thermal imaging, also known as infrared imaging technology, is now used in many fields due to its ability to record images based on temperature differences. This technology finds application in various sectors from industry to medicine to security services. Here are some current approaches and uses of thermal imaging:

Industrial Applications: Thermal imaging is used to monitor and diagnose machinery and electrical equipment. Using thermography, engineers and technicians can identify overheating components or potential failures before they can cause serious damage (Pyrosales, 2018).

- Construction and energy: In the field of construction, thermal imaging is used to detect heat losses in buildings, which helps to identify places with insufficient insulation. In the energy industry, it is used to monitor solar panels and wind turbines.
- Medicine: In medicine, thermographic cameras are used to diagnose and monitor various health conditions, such as vascular problems, inflammation, and even early detection of breast cancer.
- Military and Security Applications: In the field of defense and security, thermal imaging is used for night vision, tracking and targeting. Thermal imaging cameras can detect persons or objects even in total darkness or in adverse weather conditions.

- Automotive: Some vehicles are equipped with thermal imaging cameras to help drivers identify pedestrians or animals on the road at night or in low light conditions.
- Agriculture: Thermal imaging is also used in agriculture to monitor and analyze vegetation, detect plant stress or identify the need for irrigation.
- Research and development: In the R&D sector, thermal imaging is used for experimental purposes, such as the analysis of thermal processes, the investigation of materials and the testing of prototypes.
- Rescue and fire services: Rescue teams and firefighters use thermal imaging cameras to find people more quickly in smoke or dark environments and to identify hot spots in fires.

Each of these uses demonstrates how thermal imaging is an important and versatile technology that has the potential to improve safety, efficiency and effectiveness in many areas of human activity (Steidl and Krause, 2009).

The role of thermal imaging in diverse sectors aligns with the growing emphasis on technological advancements in modern industries, including healthcare. In the context of healthcare, technologies like thermal imaging are being integrated to improve diagnostic accuracy and patient care. For example, studies by (Gavurova et al., 2024) explore how digital tools, including thermographic technologies, can enhance healthcare outcomes by supporting trust and improving communication between healthcare professionals and patients. Similarly, (Smolanka et al., 2024) emphasize the integration of information technologies to optimize management and operational systems within healthcare institutions, which could benefit from the use of such imaging technologies in diagnostics and monitoring.

The future of thermal imaging

The future of thermal imaging appears to be very promising, with expectations pointing to the development of new technologies, the improvement of existing applications, and the expansion of the use of this technology in various fields. This development could be driven by advances in sensor technology, improvements in image processing, miniaturization and integration with other technologies. Let's take a look at some expected trends and potential uses of thermal imaging in the future:

- Improved accuracy and resolution: As sensors continue to evolve and image processing algorithms improve, thermal imaging cameras are expected to provide even more accurate and detailed images. This could enable more accurate diagnostics in medicine, more effective quality control in the manufacturing industry, and better environmental monitoring.
- Miniaturization and wearable technologies: With the miniaturization trend, we can expect thermal imaging devices to become smaller, lighter, and more energy efficient, enabling their integration into wearable devices such as smart watches, glasses, or even clothing. This could have a significant impact on personal safety, healthcare and even consumer electronics.
- Augmented Reality (AR) and Virtual Reality (VR): The integration of thermal imaging with AR and VR technologies could open new possibilities for education, simulations and training, allowing users to see and interact with temperature-based images in real time.
- Automation and autonomous systems: Thermal imaging could play a key role in the development of autonomous vehicles and robots by giving them the ability to see at night or in bad weather conditions, increasing their safety and efficiency.
- Disaster prediction and prevention: The use of thermal imaging in monitoring climate change and the environment could help predict natural disasters, such as forest fires and volcanic eruptions, and enable faster responses to prevent damage.
- Smart Homes and Cities: Thermal imaging could be integrated into smart homes and city infrastructures to improve energy efficiency, safety and comfort for residents.
- Personalized medicine and healthcare: The development of thermography could enable more accurate and personalized diagnostic procedures, the delivery of targeted therapy and the monitoring of treatment progress in real time.

These developments show that thermal imaging could significantly contribute to innovation in many industries and sectors, improving quality of life, increasing safety and promoting sustainable development (Red Current, 2021).

The research by (Moravec et al., 2025) on digital literacy and algorithmic personalization, along with studies by (Skare et al., 2023; Gavurova et al., 2024), suggests that the integration of advanced technologies like thermal imaging will be influenced by broader trends in digital transformation, decision-making, and the need to address societal challenges in a more connected and informed manner.

Ecology and environmental science

Ecology is another area where thermal imaging has recently been widely used. People are more and more interested in the environment and ecology, this causes an increased demand for greener equipment, vehicles and buildings. The topic of the environment and ecology has been topical especially in recent years. With the help of thermal imaging, we can obtain, e.g., information about the temperature of water in water reservoirs and thus reveal places with increased temperature that arise as a result of insufficient water flow. Thanks to aerial thermal imaging images, we can gain knowledge about microclimates in inhabited areas and, based on the images, we can find out the amount of heat energy accumulated and transmitted by various objects. Subsequently, this condition can be modified by appropriate means, such as planting trees (Holubčík et al., 2016). Thermal imaging is also used to monitor the atmosphere (storms, hurricanes, etc.). Concern for our environment has led the EPA (Environmental Protection Agency) and other American companies to identify and prosecute environmental polluters. Emissions such as oils, chemicals and pollutants radiate different heat than the soil or water around them. As a result, the investigator can trace these substances to their source thanks to thermal imaging (Icela, 2008).

Fig. 3 Thermal image of an oil rig and oil spill into the ocean (FLIR 2019)

Fig. 4 Discharge of waste substances into the air - thermal image (FLIR 2019)

Benefits for Renewable Energy Integration

Utilizing thermovision systems in building renovations offers several advantages when incorporating renewable energy sources:

- **Enhanced Energy Efficiency**: By addressing thermal inefficiencies, buildings can achieve higher energy efficiency, reducing the load on renewable energy systems and making them more effective.
- **Optimized Renewable Energy Utilization**: With improved insulation and airtightness, buildings can better maintain desired temperatures, allowing renewable energy systems like solar panels and heat pumps to operate more efficiently.
- **Cost Savings**: Detecting and addressing problem areas early can prevent costly repairs and reduce energy bills, making the investment in thermovision technology and renewable energy systems more economically viable.
- **Environmental Impact**: Enhancing energy efficiency and optimizing the use of renewable energy sources contribute to reducing greenhouse gas emissions and the overall environmental footprint of buildings.

Thermal imaging in the mining industry

Thermal imaging and thermal imaging cameras are extremely useful tools in the mining industry. They can be used to effectively monitor and analyze temperature differences in mines, which is crucial for preventing dangerous situations such as fires or methane explosions. These cameras can identify "hot spots" where coal could spontaneously combust. In addition to security applications, thermal imaging cameras are also used to optimize the operation of mining equipment. By checking the temperature of machines and equipment, it is possible to prevent malfunctions and extend their service life. Thus, thermal imaging represents an irreplaceable tool in the modern mining industry, which increases its efficiency and at the same time reduces the risks associated with work in difficult conditions. Thermal imaging cameras in the mining industry have become an invaluable tool not only in terms of safety, but also the efficiency and sustainability of operations. The detection of excessive underground heat allows mining engineers to quickly identify and address problems associated with ventilation and cooling in deep mine shafts. These cameras are capable of working in extreme conditions such as dust, humidity and low visibility, which are typical characteristics of mining operations (Proszak-Miąsik, 2019).

In addition to monitoring the temperature of equipment and infrastructure, thermal imaging cameras contribute to monitoring the condition of electrical installations, which is critical in terms of preventing electrical failures that can lead to serious incidents. The system integration of thermal imaging cameras with other security and monitoring systems creates a complex security network that increases overall security in the conditions of mining operations.

As a result of advances in thermal imaging technology, these cameras are becoming increasingly available and their applications are expanding into areas such as geological surveying and environmental monitoring. By using thermal imaging technology to scan the surface of mining areas, geologists can identify potential mineral reserves, allowing for more accurate planning and more efficient mining. In this way, thermal imaging not only increases safety and efficiency but also contributes to environmental protection by minimizing the necessary interventions in nature associated with mining activities (Jin, 2012).

Experiment 1

This part of the work describes the measurements of several objects with the FLUKE Ti32 thermal imaging camera, which were available and selected as suitable for testing the camera as well as from the point of view of availability at the time of measurement.

Measurement with thermal imaging camera FLUKE Ti32 - No. 1

I took measurement number 1 in a family home where there was a water leak from the bathroom one floor above. Based on the thermal imaging measurement, I was able to determine the exact place from where the water is leaking and thus prevent further spread and subsequent damage, see Fig. 5. Thermal imaging of the damaged area and subsequent determination of the leak prevented unnecessary opening of the walls and thus reduced repair costs for the owners of the family house (FLUKE, 2021).

Fig.5 The part of the ceiling and cabinets where water seeps in
Source: Begáni, 2021

The basic temperatures measured on the evaluated object (bathroom) correspond to Fig. 5 and are listed in Tab. 2.

Tab. 2 Determination of basic temperatures from figure no. 3

Title	Temperature	Emissivity
The middle point	20.7°C	0.90
Warm surface	22.6°C	0.90
Cold surface	19.80°C	0.90

Source: Begáni, 2021

Not every damp wall is caused by a broken pipe. An increase in humidity or water seepage is usually caused by faulty drainage of rainwater or waste water, which can cause the walls to become wet. Damage caused by moisture can also be caused by blocked drains or imperfect insulation of the building. With the help of a thermal imaging camera, I discovered the causes of the increase in humidity and water seepage, which can cause extensive damage (Begáni, 2021).

Measurement with thermal imaging camera FLUKE Ti32 - no. 2

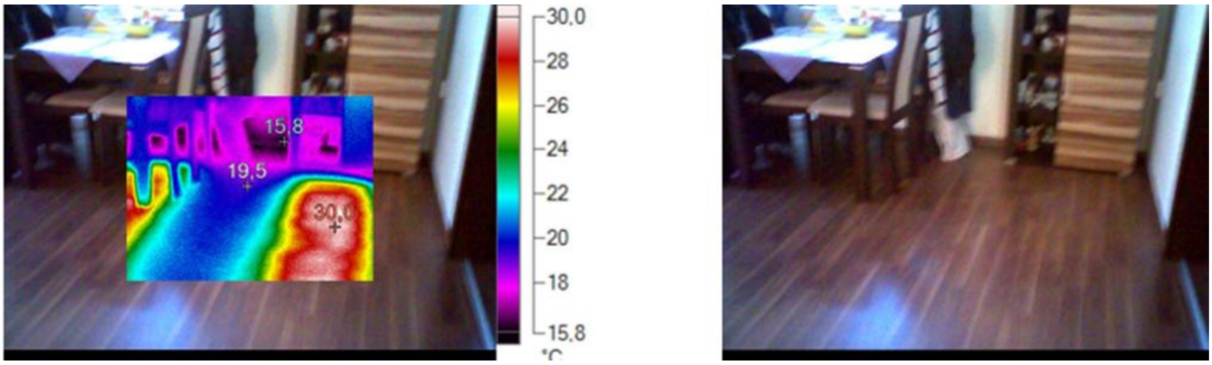

Fig.6Thermal imaging measurement of floor heating in a family house, dining room.
Source: Begáni, 2021

Thanks to the simple operation of thermal imaging cameras, it is possible to quickly and reliably test heating and air conditioning / ventilation systems. At first glance, you can use a thermal imaging camera to find a place with uneven temperature distribution. Deposits and blocked radiators, underfloor heating can be reliably found.

Floor heating is provided in the entire family house with the help of electric mats, which are placed unevenly and in different sizes (Fig. 6). In my opinion, they do not fulfill the basic task of underfloor heating, which is to keep the floor covering evenly warm.

In this arrangement, with the mats on, the thermal difference is on average 10°C, which does not contribute to thermal comfort.

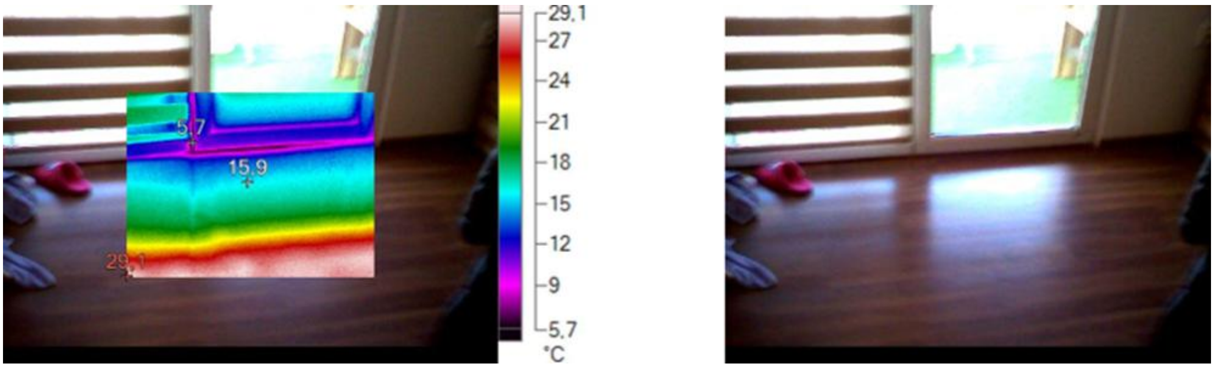

Fig.7 Thermal imaging measurement of floor heating in a family house, living room and transition to the garden
Source: Begáni, 2021

By measuring the floor heating also in the other rooms of the family house (Fig.7), the previous statement about the floor heating, which is uneven across the surface and in different sizes, was only confirmed. In addition, when measuring in the living room, which has a transitional balcony door to the garden, I found insufficient heating and poor insulation of the area between the balcony door and the floor. In picture no. a dark purple band is visible, which indicates that there is a temperature difference of up to 20°C in this place (Begáni, 2021).

Measurement with thermal imaging camera FLIR T440 - No. 1

During thermal imaging measurement with a FLIR T440 camera, the object of measurement was a 25-year-old family house (Fig. 8), on which I checked the insulation and heat leaks from the building. During the thermal imaging measurement of the building from the exterior, thermal bridges caused by insufficient thermal resistance of the structure are sought. In the case of uninsulated houses, typical structures with greater heat leakage include ceiling cornices, plinths, balcony and loggia beams, window and door lintels, etc. In the case of insulated houses, it is possible to check the correct placement of thermal insulation parts, the number and distribution of anchors and the execution of details around windows and doors. In the case of new or reconstructed single-skin roofs with a homogeneous waterproofing layer, it is possible to check the placement of the thermal insulation parts. There must be specific conditions for scanning such roofs. If the roof covering is equipped with, e.g., anti-reflective coating, measurement from the exterior is very problematic and sometimes practically impossible.

Fig.8 Family house, object of measurement
Source: Begáni, 2021

When measuring from the exterior, it is very difficult to detect thermal bridges in structures with a ventilated gap, such as double-skinned roofs, which include most pitched roofs above residential attics. In the case of double-skinned roofs, thermal defects are only manifested if they are really significant, e.g. a thermal insulation board is missing in the roof. If the defects are not thermally obvious, it is not possible to establish a 100% faultless condition. This is due to the fact that the roofing is cooled from both sides, from the face by the weather and from the reverse by air flowing in the ventilated layer.

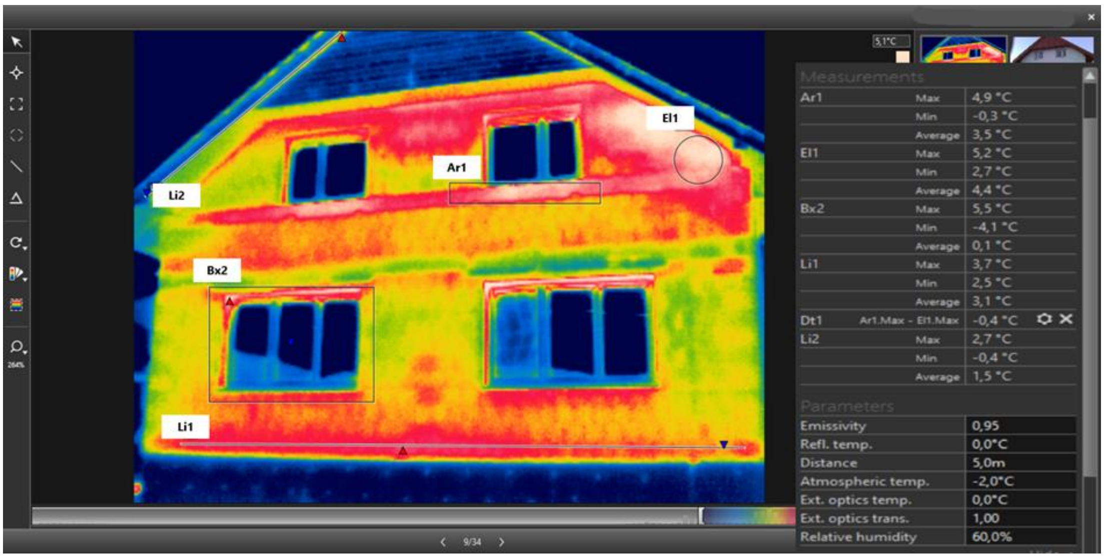

Fig.9 Thermal imaging measurement of the exterior of a family house
Source: Begáni, 2021

In picture no.9 is a photographed family house, and for a better representation of heat leaks and determining poor insulation, I chose the rainbow palette in the FLIR Tools program. I set the emissivity to 0.95 because the plastered wall has a value of 0.95 in the emissivity table. The measurement took place in the early hours of the morning so that the temperature difference between the interior and the exterior was as large as possible. The measured external temperature was -2°C and the internal temperature reached +23.5°C. Since the thermal imaging measurement of the building is suitable to be done under conditions when:

- the outside temperature is close to zero,
- it is approximately 20°C indoors,
- the object is heated.

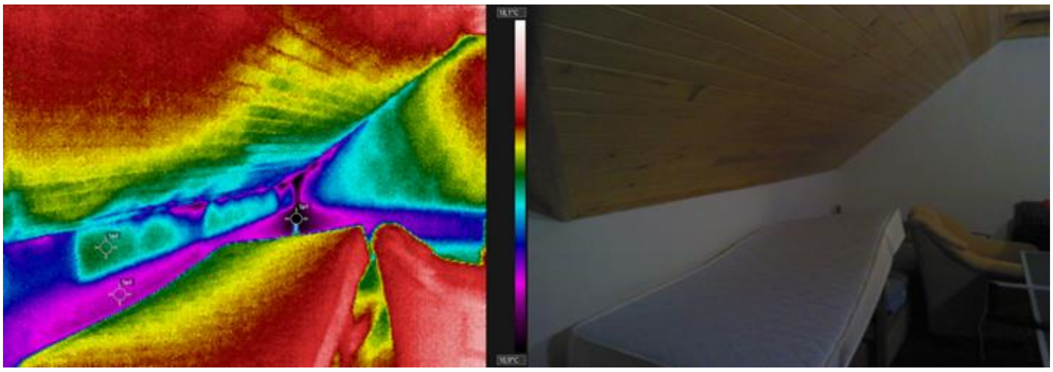

Fig.10 Attic of a family house
Source: Begáni, 2021

I have tried to ensure these basic conditions for thermal imaging measurement so that the measurement results and also the indicative value of this measurement are as accurate as possible. The family house was photographed from a distance of 5 m, which can also be seen in the attached picture. The FLIR T440 camera automatically measures the distance between the camera and the measured object.

I evaluated the images from the thermal imaging camera in the FLIR Tools program. In the attached picture, you can clearly see the strong red areas, which signal the biggest heat leaks from the building and point to a possible fault or fault in the insulation. In picture no.9, I have shown several points/surfaces through which the greatest heat escape occurs. The Li2 line runs from the end of the roof to its peak and shows the lowest and highest temperature on this line, and also on this line leaks were detected between the roof and the wall masonry. Zone El1 shows the area where the insulation is poorly done and this is how the greatest heat leakage from the family house is caused.

Measurement with thermal imaging camera FLIR T440 - No. 2

It is generally known that due to insufficient ventilation, the concentration of harmful substances increases and air humidity increases depending on the production of water vapor. One of the advantages of the thermal imaging camera FLIR T440 is the determination of dew point and water vapor condensation.

Dew point or dew point temperature is the temperature at which the air is maximally saturated with water vapor (relative air humidity reaches 100%). If the temperature drops below this point, condensation occurs. Air at a certain temperature can only contain a certain amount of water vapor. The higher the air temperature, the more moisture it can absorb. If the air starts to cool, the water vapor starts to condense.

When measuring no. 2, we focused on measuring the dew point and condensation of water vapor and the subsequent spread and formation of molds.

By measuring with a FLIR T440 thermal imaging camera, it is possible to determine the dew point and the place with condensation of water vapor in every room in a family house. I evaluated and processed the measurement results in the Flir Tools program. In picture no.11 is a table of measured values, and based on these values, the program calculated that the dew point and thus the place where water vapor condenses in the living room of a family house is 15.1°C. The program can also determine with great accuracy the location and area of the dew point or, in an advanced stage of humidity, it can determine the area of mold growth. Thanks to the thermal imaging camera, we can prevent the spread and growth of molds that could have a negative effect on the human body, but even with early diagnosis, we can significantly save money that would have to be invested in case of a larger extent of damage (Begáni, 2021).

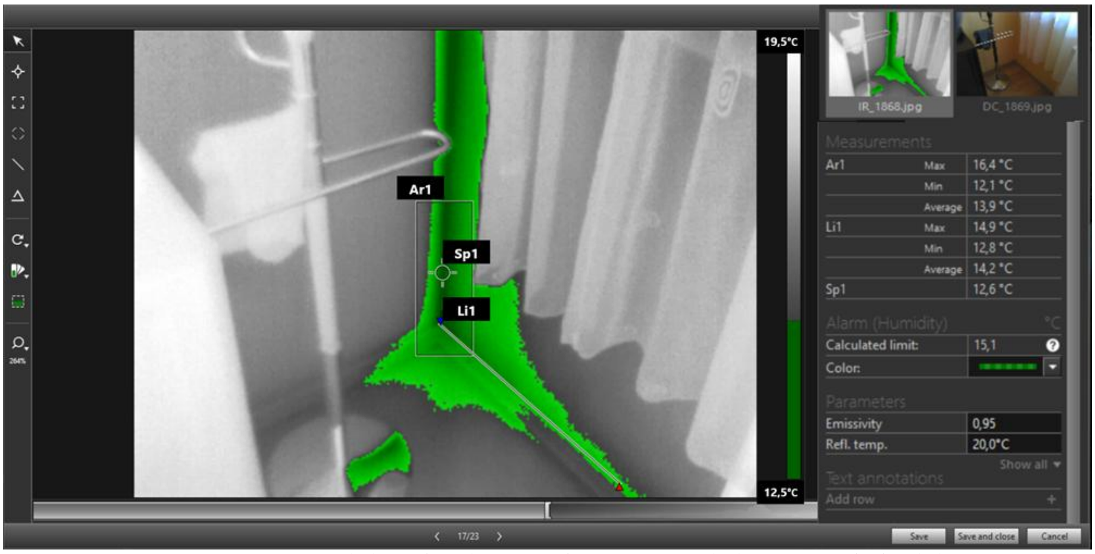

Fig.11 Dew point and place of condensation of water vapor in the living room of a family house
Source: Begáni, 2021

Evaluation of experiments

In the experimental part, the measurements were described in detail, which were carried out to familiarize yourself with working with a thermal imaging camera, learning to master the routine measurement setup of cameras, reading and determining the correct distance, position, and working with the FLUKE Connect.Ink and FLIR Tools.Ink program.

It can be concluded that the data obtained are relevant, reliable, readable, and clear from both cameras. Thermal imaging proved that it can detect e.g. humidity, uneven floor heating, bad insulation and so on. Working with a FLUKE thermal imaging camera is easier to set up than a FLIR camera. The programs are equally demanding, but they do not offer the same possibilities. The FLIR Tools. The ink program, which belongs to the FLIR camera, has many more functions and options for working with the measured object than the FLUKE Connect.Ink program. I also evaluate the FLIR T440 camera as better and more suitable for thermal imaging measurements, because the results were more accurate and the camera itself and its program have more functions and evaluation options.

Conclusion

Based on the detailed content and findings presented in the document, the conclusion highlights the indispensable role of thermal imaging technology across multiple applications and its potential for future advancements. The document thoroughly examined thermal imaging's principles, historical development, and its current applications in fields such as industrial maintenance, construction, medical diagnostics, and environmental monitoring. The experimental part, involving the use of FLUKE Ti32 and FLIR T440 thermal imaging cameras, underscored the practical benefits of this technology in real-world scenarios, such as detecting water leaks and evaluating heating systems' efficiency. The utilization of thermovision systems is a crucial step in modern building renovation, especially when aiming to integrate renewable energy sources. By accurately detecting problem areas such as heat loss, moisture intrusion, air leaks, and HVAC inefficiencies, thermovision technology facilitates targeted interventions that enhance energy efficiency and the effectiveness of renewable energy systems. This approach not only promotes sustainability but also offers significant cost savings and environmental benefits, making it an indispensable tool in the quest for greener, more energy-efficient buildings.

Thermal imaging has proven to be a crucial tool for enhancing operational safety, energy efficiency, and preventive maintenance across various sectors. Its non-contact nature, ability to detect issues invisible to the naked eye, and application versatility were emphasized as key benefits. Moreover, the document discussed the technology's future, pointing towards miniaturization, integration with wearable devices, augmented and virtual reality, and broader application in autonomous systems and smart infrastructure.

The conclusion reaffirms thermal imaging's growing significance in advancing technological innovation, improving human safety, and promoting sustainable practices. It calls for ongoing research and development to explore new applications and improve the technology's accessibility and effectiveness, ensuring thermal imaging continues to be a valuable asset in addressing contemporary challenges and opportunities.

References

Bednárová, L., Pavolová, H., Šimková, Z., Bakalár, T. (2023). Economic efficiency of solar and rainwater systems—A case study. *Energies*, 16(1), 504. https://doi.org/10.3390/en16010504

Begáni, M. (2021). Aplikačné možnosti termovíznych systémov v praxi [Application possibilities of thermographic systems in practice, in Slovak]. Diploma thesis. Technical University of Košice.

Begáni, M., Bednárová, L., Swiss, A. (2023). Inovácie a technologické trendy v podpore cirkulárnej ekonomiky: vplyv na životné prostredie [Innovations and technological trends supporting the circular economy: impact on the environment, in Slovak]. In: *Proceedings* of the International Conference Strategies and Innovations in Raw Material Policy of the Slovak Republic and the EU – The Importance of Critical Raw Materials*, 7–12. Technical University of Košice.*

Beryozkina, S., Sauhats, A., Bargels, V., Vanzovichs, E. (2012). Detecting the Capacity Reserve in an Overhead Line. *International Journal of Electronics and Electrical Engineering*, 6(1), 30–35. Available at: https://www.idc-online.com/technical_references/pdfs/electrical_engineering/Detecting%20the%20Capacity.pdf [Accessed 21 Apr 2025].

Brynda, P. (2010). Úvod do teorie termovizního měření [Introduction to the theory of thermographic measurement, in Czech]. Prague: Czech Technical University. Available at: https://www.fd.cvut.cz/projects/k611x1s/doc/works/teorie_brynda.pdf [Accessed 21 Apr 2024*].*

FLIR® Systems. (2019). Thermal Camera Specs You Should Know Before Buying? Available at: https://www.flir.com/discover/professional-tools/thermal-camera-specs-you-should-know-before-buying/ [Accessed 9 Apr 2021]

Fluke. (2021). Fluke Ti32. Available at: https://www.fluke.com/cs-cz/search/fluke/?query=Fluke%20Ti32 [Accessed 18 Apr 2021].

Gavurova, B., Moravec, V., Hynek, N., Miovsky, M., Polishchuk, V., Gabrhelik, R., Bartak, M., Petruzelka, B., Stastna, L. (2024). The impact of digital disinformation on quality of life: a fuzzy model assessment. *Technological and Economic Development of Economy*, 30(4), 1120–1145. https://doi.org/10.3846/tede.2024.21577

Gavurova, B., Smolanka, V., Polishchuk, V. (2024). Intellectual model for analyzing and managing patient trust in medical staff of primary healthcare institutions. *Polish Journal of Management Studies*, 30(1), 98–115. https://doi.org/10.17512/pjms.2024.30.1.06

Hildebrandt. C., Raschner, C., Ammer, K. An Overview of Recent Application of Medical Infrared Thermography in Sports Medicine in Austria. In Sensors. 10(5), 4700–4715. 2010. https://doi.org/10.3390/s100504700

Holubčík, M., Holubčíková, L., Kantová, N. (2016**).** Termovízia v praxi [Thermography in Practice, in Slovak]. Žilina: CEIT.

Hudeczek, M., Sopuch, P. (2015). Rutinní využití termovize v elektrotechnické praxi [Routine Use of Thermography in Electrical Engineering Practice, in Czech]. Available at: https://matlab.fei.tuke.sk/prs/subory/literatura_7/Termovizia/Rutinni%C2%AD%20vyuziti%C2%AD%20termovize%20v%20praxi%20VN,%20NN-1.pdf [Accessed 23 Mar 2021].

Icela, J. (2008). Infrakamera a její využití v BT [Infrared Camera and Its Use in Biomedical Technology, in Czech]. Bachelor's thesis. Tomas Bata University in Zlín, Faculty of Applied Informatics. Available at: DigiLib [Accessed 21 Apr 2025].

Jin, X., Zhang, X., Cao, Y., Wang, G. (2012). Thermal performance evaluation of the wall using heat flux time lag and decrement factor. *Energy and Buildings*, 47, 369–374. https://doi.org/10.1016/j.enbuild.2011.12.010

Maldague, X.P.V. & Moore, P. O. (2001) Fundamentals of Infrared and Thermal Testing. In Nondestructive Handbook, Infrared and Thermal Testing. USA: ASNT Press, Columbus.

Moravec, V., Hynek, N., Skare, M., Gavurova, B., Polishchuk, V. (2025**).** Algorithmic personalization: a study of knowledge gaps and digital media literacy. Humanities and Social Sciences Communications, 12, Article 341. https://doi.org/10.1057/s41599-025-04593-6

Pacana, A., Siwiec, D., Bednárová, L., Petrovský, J. (2023). Improving the process of product design in a phas of life cycle assessment (LCA). *Processes*, 11(9), 2579. https://doi.org/10.3390/pr11092579

Proszak-Miąsik, D. (2019). **Use** of thermal imaging in construction. *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska*, 9(2), 12–15. https://doi.org/10.5604/01.3001.0013.2540

Pyrosales. (2018). Thermal imaging – where is it used? Available at: https://www.pyrosales.com.au/blog/thermal-imaging/thermal-imaging-where-is-it-used [Accessed 21 Apr 2024].

Red Current. (2021). The Future of Thermal Imaging Cameras Is Already Here. Available at: https://www.red-current.com/thermal-imaging-blog/100-the-future-of-thermal-imaging-cameras-is-already-here [Accessed 21 Apr 2024].

Silva, G. P., Batista, P. I. B., Povóas, Y. V. (2019). The usage of infrared thermography to study thermal performance of walls: a bibliographic review. *Revista ALCONPAT*, 9(2), 117–129. https://doi.org/10.21041/ra.v9i2.341
Silva, G. P., Batista, P. I. B., Povóas, Y. V. (2019). The usage of infrared thermography to study thermal performance of walls: a bibliographic review. *Revista ALCONPAT*, 9(2), 117–129. https://doi.org/10.21041/ra.v9i2.341
Smolanka, V., Gavurova, B., Polishchuk, V. (2024). Managing and evaluating the integration of information technologies in healthcare institutions. Polish Journal of Management Studies, 30(2), 297–313. https://doi.org/10.17512/pjms.2024.30.2.18

Steidl, T., Krause, P. (2009). Termowizja w ocenie jakości przegród budowlanych [Thermography in the assessment of building envelope quality, in Polish]. *Pomiary Automatyka Kontrola*, 55(11), 942–945.

Więcek, B., De Mey, G. (2011). Termowizja w podczerwieni: podstawy i zastosowania [Infrared Thermography: Fundamentals and Applications, in Polish]. Warszawa: Wydawnictwo PAK.