ARCHIVES OF TRANSPORT
Volume 76, Issue 4, 2025

ISSN (print): *0866-9546*
e-ISSN (online): *2300-8830*
DOI: *10.61089/aot2025.8hs1vf40*

THERMAL IMAGING DIAGNOSTICS IN INNOVATIVE RAILROAD SWITCH HEATING SYSTEMS

Andrzej TORUŃ[1], Jakub MŁYŃCZAK[2], Jacek KUKULSKI[3], Krzysztof STYPUŁKOWSKI[4]

[1] *Railway Research Institute, Warsaw, Poland*

[2] *Faculty of Transport and Aviation Engineering, Silesian University of Technology, Katowice, Poland*

[3, 4] *Faculty of Transport, Warsaw University of Technology, Warsaw, Poland*

Abstract:

The article presents research problems related to the operation of classical switch heating solutions and systems. This is due, among other things, to the excessive use of electricity and the strive to optimize these solutions. An overview of research related to various electric switch heating (ESH) systems is presented extensively in Chapter 2. This article presents selected results of thermal imaging measurements of ESH electric switch heating components used to heat railroad switches under the BRIK2/0036/2022 project. The study was carried out for different types of ordinary railroad switches most commonly used on the PKP PLK network. The studies included various positions of the switches in the normal position (straight track) and the non-normal position (switch track). The tests were conducted on real objects and under conditions allowing for the snowing of critical elements of the switch. The use of thermal imaging cameras and classic thermoelectric sensors with a recorder allowed for the assessment of the effectiveness of existing switch heating systems as well as proposed modifications. The results of the study made it possible to observe the temperature distribution for different switch design solutions and switch heating systems, and to interpret the results. Based on the obtained results, it can be concluded that the new solution in the area of electric switch heating with dedicated radiation overlays is more efficient compared to the classic solution. The use of thermal imaging cameras in research has enabled the execution and recording of heating sequences of the switch and imaging in the visible spectrum of the electromagnetic spectrum for snow melting in critical areas, such as the switch zones. Further work will focus on preparing a diagnostic manual for services responsible for the maintenance of railway switches, including the use of thermal imaging diagnostics. Subsequently, the authors will prepare the assumptions and criteria for the development of an application to assist in the interpretation of thermograms, which can be a tool supporting the diagnostics of electric switch heating (ESH) devices. The creation of a simple diagnostic tool that allows for the assessment and facilitates the interpretation of the obtained thermogram may enable maintenance services to make appropriate decisions regarding the operation of ESH systems.

Keywords: *railway infrastructure, thermal imaging studies, electric switch heating (ESH)*

To cite this article:

Toruń, A., Młyńczak, J., Kukulski, J., & Stypułkowski, K. (2025). Thermal imaging diagnostics in innovative railroad switch heating systems. Archives of Transport, 76(4), 75-92. https://doi.org/10.61089/aot2025.8hs1vf40

Contact:
1) atoruń@ikolej.pl [https://orcid.org/0000-0002-7333-2079]; 2) jakub.mlynczak@polsl.pl [https://orcid.org/0000-0003-2947-7980]; 3) jacek.kukulski@pw.edu.pl [https://orcid.org/0000-0002-9449-7614] – corresponding author; krzysztof.stypulkowski@pw.edu.pl [https://orcid.org/0000-0002-9374-7933]

1. Introduction

The transport tasks currently imposed on rail transport necessitate continuous development and improvement of the design and diagnostics of elements of railway infrastructure and systems. This is mainly due to changing operating conditions, including the need to increase maximum train speeds, permissible axle loads, and to increase the capacity of track systems. Ensuring the passability of the switch head at the station, especially during winter periods, requires the implementation of solutions that allow for the full functionality of the railway switch.. The electric switch heating (ESH) system, used for several decades, is one of the most effective solutions for ensuring the passability of the switch head by trains, especially in winter conditions and during snowfall. The solutions for switch heating systems have evolved over the years in terms of design solutions, from the most common resistive heating to inductive heating. An increasingly important role in these solutions is played by the issue of controlling the heating system in terms of power control and energy distribution to optimize electricity consumption.

An essential element during operation is the proper ongoing maintenance and diagnostics regarding the prediction of potential damages and failures of both switch elements and devices used for heating switches.. Conducting diagnostics of these elements and devices allows for avoiding emergency situations that hinder normal operation, ensuring full functionality and passability of the switch head.

Diagnostic tests using thermography are becoming more commonly used as a preventive diagnostic tool that does not interfere with the structure of the switch without the need for specialized measuring equipment mounted in the ESH switch elements. Such equipment was installed and utilized by the authors of the paper during the measurements, and its purpose was to verify and calibrate the obtained thermographic results.

The operation of the electric heating system for the switch requires planning a significant amount of power supply energy, which the Manager must order and later incur costs for its purchase. In this aspect, to reduce electricity consumption, innovative heating control systems for switches can be implemented and applied, allowing for the optimization of the heating intensity of the railway switch zones.

One of the goals of the article is to present the results of work related to the construction and verification of proposed solutions within the framework of a new, proposed control system for the electric heating of switches (ESAR type ESH with dedicated radiation overlays) that reduces the demand for electricity used for heating switches. These activities are carried out as part of the BRIK2/0036/2022 project. The use of thermographic diagnostics can be utilized for continuous and ad-hoc monitoring of the technical condition of the applied ESH solutions by maintenance services. This would require the preparation of a special manual regarding image diagnostics using thermographic cameras for railway switch heating systems. The structure of this article consists of several chapters and includes a review of the state of knowledge, the latest literature related to the research issues defined in the article, as well as the research methodologyand the obtained research results along with their interpretation and analysis. The article concludes with a synthetic assessment of the obtained results, the solutions studied, and a summary.

2. Research problem – literature review

2.1. Thermal imaging diagnostics

The paper (Mehdi Koohmishi et al., 2024) investigated the application of infrared thermography (IRT) technology for non-destructive assessment of ballast contamination in railway tracks, focusing on the influence of host rock types and contaminating materials. Using thermal imaging, it was determined how changes in ballast condition affect surface temperature, which serves as an indicator of structural integrity. The results showed that the level and type of contamination significantly affect the thermal signatures captured by the passive camera. The study highlights the usefulness of passive IRT cameras in routine maintenance and condition monitoring of railway infrastructure. A similar research work was carried out by (Clark et al., 2002) in which the authors investigated the application of IRT to monitoring the condition of railway ballast, in particular to identify different levels of contamination. The research involved the use of a thermal imaging camera equipped with an infrared detector, which proved effective in distinguishing between temperature changes associated with different levels of contamination.

The aspects of diagnostic testing using a thermal imaging camera can be seen in the work (Ye et al., 2023). The authors used IRT together with an edge detection algorithm to identify surface cracks on ballastless tracks. This method enabled precise defect detection by analyzing thermal images of the plate surfaces, demonstrating the ability of IRT to determine structural vulnerabilities. Active infrared thermography has been found to be useful in determining the structural condition of various railway track structures (Bilawal et al., 2021). This study was based on the detection of artificial surface defects on the track in service. Transverse and longitudinal defects of various dimensions were machined on the rough and smooth rail surface. Then, the track surface was subjected to thermal stimulation to a temperature equivalent to practical conditions. A similar approach to rail diagnostics is presented in (Ramzan et al., 2021). For crack detection, an infrared camera was used to record the infrared radiation that was emitted as a result of the applied thermal stimulus on the track surface. As the surface temperature increased above the ambient conditions, rail defects became visible.

In turn, the work (Liang et al., 2023) undertakes research on comprehensive contamination detection of crushed stone. Their work concerned detailed analysis of surface temperatures and included mixing crushed stone with typical contamination materials such as gravel and sand at different contamination levels. In addition, the work (Koohmishi et al., 2024) recognized the potential of integrating thermal imaging measurements with other NDT methods such as ground-penetrating radar and synthetic aperture interferometric radar. Such integrations increase the comprehensiveness and accuracy of subsurface diagnostics, supporting large-scale, multi-physics approach to infrastructure analysis.

An advanced system based on a thermal imaging camera for detecting objects on railway tracks was described in the work (Pavlović et al., 2018). The aim of this system was to detect objects on and next to railway tracks and estimate the distance between the camera position and detected objects. A method based on homography was used to estimate the distance between the camera position and detected objects. Validation of estimated distances was performed with reference to the actual measured distances from the camera position to the objects participating in the experiment. Distances are estimated with a maximum error of 2%. The system can provide reliable object detection, and artificial intelligence tools can be used to improve robustness and adaptability. The work (Kisilowski et al., 2021) presents the possibilities of using a vision system, which, in combination with image processing analysis tools, allows for the detection of wear and distances between key elements of a railway turnout. The main idea of the proposed solution of the online diagnostic system is to use the analysis of the received images using a vision system. Algorithms responsible for generating wear areas from high-resolution images were developed. The algorithms created in the work were implemented and tested in the MATLAB software environment.

Visual inspection, thermographic measurements in the operation of electrical or energy devices, and monitoring or controlling 'hot axles' are becoming standard practices. In relation to rail vehicles, thermography can be used in the diagnosis of axle bearing arrangements or brake discs, and railway wheels in terms of thermal loads. Among others, the following publications can be mentioned, which included thermographic measurements in the study of rail vehicles or their components (Sawczuk et al., 2020, 2022) as well as in papers (Kampczyk et al., 2022) and (Kukulski et al., 2023). Another approach to the diagnostics of the running gear components of rail vehicles is presented in the work (Zhang et al., 2023), in which the authors confirm that infrared thermography examination can identify surface and near-surface cracks. Automatic visual testing can detect white etching layer, surface cracks, chips and dents. In the work (Miao et al., 2023), a new method based on deep learning is presented to predict personal thermal comfort in a vehicle using a facial thermal image. Thermal comfort data was collected from an experiment involving 22 people. The results indicate that the non-invasive method proposed in this study can accurately predict personal thermal comfort in the vehicle environment.

The work (Karabacak et al., 2020) proposes the application of a deep learning method, convolutional neural network (CNN), in the field of thermal imaging, which were collected from a test device operating at different loads and speeds. Deep learning approaches demonstrate the ability to leverage erroneous information from large data sets and make intelligent diagnostic decisions.

2.2. Simulation studies

Simulation studies in scientific research are the most commonly used solution for testing and verifying scientific assumptions. They are applied in all scientific fields, including the topic of this article. Conducting experimental studies of ESH systems on a real object, such as railway switches, requires significant financial investment, as well as adherence to all safety rules while on railway tracks.

Simulation studies involving a comparative analysis of energy losses during the heating of railway switches using two different methods are described in papers (Wołoszyn et al., 2016). The analysis of switch heating was carried out in the ANSYS program, where the structural solutions of the ESH system were modeled, both resistive and inductive. The comparative analysis of energy losses during the heating of two models of railway switches showed a significant energy intensity of traditional heating methods for railway switches. Another paper that utilized a simulation tool is the article (Flis 2019, 2020). The author conducted simulation calculations and analyzed the energy efficiency of heating railway switches with melting snow using both conventional and contactless methods. This is one of the works where thermal imaging measurements were used to assess the melted snow from the area of the installed ESH heater.

Another approach to studying switch heating using an induction system is presented in paper (Hyeong-Seok Oh et al., 2019). The authors introduced a Multi-Physics analysis for the induction heating system as part of the simulation studies to perform an analysis of the electrical circuit, electromagnetic field, and heat emission. Additionally, a 250 kHz – 200W induction system was compared with the existing heating system. Another work that addressed the research on induction heating of switches was paper (Uferev et al., 2021). The authors developed and created an experimental model of a direct induction heating system for the technological point of the switch's saddle. The results of calculations and studies of devices operating in resonance mode at increased frequency for induction heating were presented.

2.3. Experimental studies

Diagnostic studies are an integral part of maintaining the technical infrastructure of rail transport (Celiński et al., 2022). The application of vibration signals from rail vehicles and the creation of a specialized identification application for traffic and dynamics may enable the assessment of the technical condition of the railway track as well as its diagnostics.

In the case of railway switches, diagnostics in modern types of switches mainly concern the diagnostics of the switch drive itself, including the position of the blades or the force required to set the switch in the correct position. In the case of existing switch heating systems, there is no such extensive diagnostics; the operator only knows whether the system has been turned on or off. Research on electric switch heating solutions has been conducted by many scientific centers both domestically and abroad. These included both simulation and experimental studies, work related to new design solutions, and systems for controlling electric switch heating. One of the experimental works is paper (Brodowski et al., 2022), which presents an experimental verification of a new concept of electric switch heating in the form of a radiation overlay. The new methodology uses contactless heaters instead of classical ones and is based on an innovative method of heat distribution.

In papers (Żelazny et al., 2021) and (Szychta et al., 2020), the authors conducted a comparative analysis of the efficiency of resistive and inductive heating systems for railway switches. Laboratory experimental studies were conducted on a specially constructed test stand for switch heating. In the studies, sections of rails (stock rail and blade) constituting a part of the switch were used. The tests were conducted in a climate chamber, and temperature measurements were taken using thermoelectric sensors located at specific points of the installed heaters of the ESH system, both for the resistive and inductive systems. A detailed comparative analysis of the heating efficiency of the switch was carried out. Another paper that utilized a climate chamber to conduct an experiment on a rail section with ESH is paper (Lotfi, et al., 2024). Additionally, an analytical model was built in Matlab to simulate heat exchange.

Thermal imaging cameras play an increasingly important role in diagnostics, as they allow certain inspections to be carried out in a thermal aspect without the need to interfere with the device in question. Such tools can also be used to diagnose rail faults or faults in switch heating systems. Thermal imaging cameras are devices that capture infrared radiation emitted by objects at temperatures above absolute zero. One of the articles that utilized thermal imaging inspection is the publication (Stypułkowski et al., 2021). The article discusses the ESH device, its components and technical parameters, as well as the requirements for inspection and maintenance of railway switches. The method of using thermographic imaging to detect failures and faults in ESH is also presented through a practical example, as well as the concept of utilizing machine learning mechanisms for automatic analysis of thermograms.

An interesting approach to using thermal cameras for detecting abnormalities in rails can be found in paper (Oswald-Tranta, 2018), where an experiment was conducted on real objects. In article (Usamentiaga et al., 2018), a method for detecting the phenomenon of 'rolling' was sought, which cannot be detected by profile control or visual inspection. The author demonstrates that the use of thermography allows for the detection of this phenomenon, despite the fact that the only known method for detecting such defects so far involves complex inspection systems based on eddy currents.

Thermography-related technologies enable safe, non-contact, direct temperature measurement on the surface of the examined object for the operator. The result of this measurement, when correctly interpreted, allows one to determine whether the device or component is functional, operational, or requires replacement/repair. The interpretation of the technical condition should be objective; this objectivity is ensured by properly designed and properly utilized IT tools. The thermogram analyzed by the operator is burdened with their subjective assessment resulting from their knowledge of the device being tested, their understanding of the processes occurring in the device being tested, as well as their skills in operating the device at the stage of taking measurements and interpreting the result of that measurement. It is important to use appropriate tools defined and implemented in the thermal imaging camera and software at the stage of analysis and interpretation of the result during measurement.

The need for conducting diagnostics of railway switches, with particular emphasis on the issue of image diagnostics, was highlighted in paper (Kędra 2015), which discussed the principles of properly taking photographs of the tested element of the track.

As previously indicated, a railway switch equipped with an ESH system, due to its structural features, has varying thermal energy requirements. Due to the different amounts of snow and ice to be melted in the various zones of the switch and varying atmospheric conditions. Thermal imaging measurements were used as a tool for verifying and assessing the energy demand for individual zones of the railway switch and heat distribution. Another area where thermal processes mapped by thermograms were recorded resulted from the problem of unsatisfactory heating of skid plates. The some new types of plates, where there is no contact between the radiator and the bottom surface of the plate, resulting in insufficient snow melting, which can block the switch in harsh winter conditions.

Based on the literature review, it is evident that despite numerous research works related to electric heating of switches, thermal imaging diagnostics is used sporadically in studies. It is used as a tool to support measurements and to assess the structural properties of ESH solutions, rather than for diagnostic purposes in ongoing operation. The novelty presented in this article is the fact that research was conducted on real objects for various types of railway switches, rather than just for a single sample and in a laboratory scale. The research was carried out for the entire process of heating and tempering the switch, which was not located in the literature review. All components of the switches were taken into account, including different types of switches for both the 60E1 and 49E1 rails.

In the further perspective, a diagnostic tool and instruction manual for maintenance services utilizing thermal imaging measurements will be developed.

3. Experimental studies of the ESH system

3.1. The research objectives

The research objective presented in this article is to verify the theoretical assumptions for reducing electricity consumption for heating railway turnouts by implementing an innovative solution using radiant overlays mounted on existing EOR system heaters.

The design and heating power control implemented allowed for more efficient snow melting in buried areas of the turnout.

The use of thermal imaging in the research aimed to compare both solutions during operation and obtain temperature distribution in areas most critical to the turnout's passability.

The thermal imaging camera diagnostic tool allows for a thorough assessment of the technical condition of railway turnout heating elements.
The test results obtained can be used to develop a diagnostic procedure for turnout heating systems by EOR system maintenance services.

3.2. Research procedure

Experimental studies using thermal imaging techniques were conducted according to the established procedural algorithm, taking into account safe movement in the area of real railway objects, which are elements of track infrastructure:

1. notification and obtaining formal approvals in accordance with procedures used in railway areas,
2. before and during the measurements, securing the area, the area where measurements are carried out – notifying, among others, the Station Duty Officer at the station where measurements are being made and securing direct communication, appropriate signage, and attire.
3. setting parameters of the thermal imaging camera before starting the measurements, such as:
   a. emission levels,
   b. distance from the object being tested,
   c. consideration of climatic conditions, ambient temperature, and humidity,
   d. temperature range;
   e. selection of color palette;
   f. selection and positioning of chosen measuring tools of the camera, e.g., a marker in the form of a line on the surface of the radiators; additionally, several measurement points can be defined and added in characteristic locations to monitor and capture specific temperatures on the surface of the radiator,
   g. selection of the camera's mode of operation, preferred operation in automatic mode providing automatic tuning of the image and temperature spread.
4. Positioning, locating the camera in the track, in the area of the object under study when taking measurements:
   a. set up the camera so as to ensure an appropriate image composition covering the monitored area of the switch, or a fragment thereof;
   b. set up the camera at a distance to ensure the appropriate image composition, e.g. 1, 3, 5, 10 m from the study area, the characteristic element of the switch, e.g. the end of the blade, in the track axis. When evaluating the distance, the average distance between the axes of the sleepers of 0.60-0.80 cm should be taken;
   c. pay attention to how the stock rail heaters were installed, so that the relevant sections of them are visible on the thermogram;
   d. set up on a stand the thermal imaging camera at a height of 1.4-1.6 m from the ground (the surface of the sleeper); this height corresponds to the height of the bridge, the eyes of an anthropometric man; this will allow convenient operation of the camera to set the focus, image composition and depict the assumed monitored area with radiators integrated in the turnout.
5. Performing measurements in cold state, before switching on the heating (making thermograms including visible areas, sections of the switch, which must be free of snow and ice.
6. Performing measurements in the heating state for successive degrees of heating of the switch after snow filling the switch section, for the adopted time intervals of 0, 0.5 h, 1 h, 2 h, 3 h.
7. Performing measurements in the basic and non-basic state for the position of the switch blade.
8. Preparing, selecting appropriate thermograms (rejection of out-of-focus ones and those with incorrect image composition) and collation of these thermographic images. Use of camera-dedicated software to facilitate analysis and interpretation of the thermogram.
9. Analysis and evaluation of measurement results in subjective aspect based on visual assessment of temperature distribution on test surfaces as well as for defined indicators, e.g. energy efficiency.
10. Formulation of conclusions and recommendations after measurements and testing.

3.3. Research objects

Thermographic studies of heat distribution in railroad switches equipped with ESH devices were carried out at various locations on the PKP PLK S.A.

network. The thermographic tests were conducted on ordinary switches with 60E1 rails and those with 49E1 rails. In order to obtain as much data and information as possible on the performance of ESH systems, the following types of switches were studied: Rz-49E1-190-1:9; Rz-49E1-300-1:9; Rz-60E1-190-1:9; Rz-60E1-300-1:9; Rz-60E1-500-1:12 and Rz-60E1-1200-1:18,5. The tests were performed for the switch in a cold state (without ESH engaged), as well as during engaged heating. The studies included aspects of switch construction such as:

– the position of the switch blade (half-switch with the blade retracted or extended),
– varying distances of the blade from the stock rail for the half-switch with the blade retracted,
– varying stroke of the blade along its length,
– varying cross-section and mass of the blade along its length.

Additionally, the heating time as well as the process of preheating the switch elements were taken into account. Figure 1 shows the heating working area of the stock rails considered during the conducted studies.

Experimental studies using thermal imaging measurements were conducted depending on:

– the position of the switch in the +/- position,
– the distance of the blade from the stock rail in the individual zones of the half-switch,
– the stroke of the blade,
– the direction of heat towards the working area (radiation overlays).

As part of the thermal imaging measurements, an inventory and classification of the electric switch heating devices was carried out from a thermal imaging perspective. Initially, thermal imaging studies were conducted on the basic structures of the selected types of switches in the design with regard to heating.

Thermographic studies were conducted at three research polygons. These were the railway stations Ciechanów, Gdańsk Osowa, and Międzylesie near Kłodzko. The thermographic studies included both existing solutions, i.e., with flat heaters in contact with the stock rail, as well as with NR type contactless radiation overlays, which are part of the modified ESAR ESH control system. All measurement sessions conducted during this period covered switches and their types as presented below:

– ***Rz – 60E1-1:9-300;***
– *Rz – 60E1-1:9-190;*
– *Rz – 49E1-1:9-300;*
– *Rz – 49E1-1:9-190;*
– *Rz – 60E1-1:12-500;*
– *Rz – 60E1-1:18,5-1200.*

The location of the research polygons was determined, among other things, by the presence of the required types of switches at the stations as well as appropriate weather conditions, mainly low air temperatures and the presence of snow. An important element in the selection of research polygons was also the same climatic zone of the selected railway stations. Figures 2 and 3 show photographs of the two studied switches at the Międzylesie station. This is a standard switch No. 38 and No. 39 (Rz – 60E1-1:9-300), with switch No. 39 serving as the reference switch for comparison with switch 38 equipped with NR type radiation overlays.

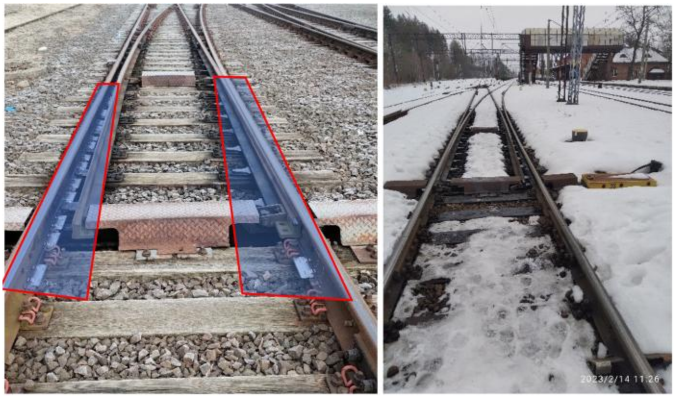


Fig. 1. Heating working area of the stock rails for the right and left half-switch

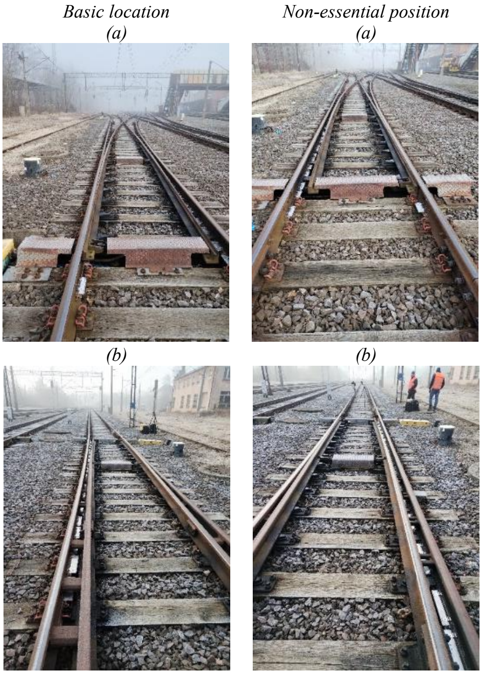


Fig. 2. View of the examined switch No. 38 from the beginning (a) and the end of the switch (b)

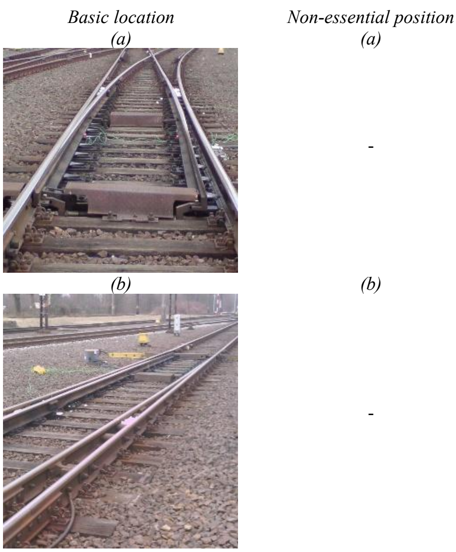


Fig. 3. View of the examined switch No. 39 from the beginning (a) and the end of the switch (b)

3.4. Measurement devices used

Thermographic studies were conducted using a Flir SC660 thermal imaging camera and a Flir 1020. Measurements were carried out according to the procedure described in section 3.1 of the article.

Simultaneously with recording the distribution of apparent temperature using the thermal imaging camera, the temperature was measured at selected points of the switch using an HD32.8.16 Guenther data logger with thermoelectric temperature sensors. The location of the measuring sensors in various places of the switch is shown in Figures 4 and 5.

Fig. 4. View of the location of thermoelectric sensors installed on the studied switches No. 38 (a) and reference switch No. 39 (b) in the area covered with snow

One of the goals of this solution was to obtain information and data on the heating temperature values of selected switch components associated with the ESH heater system (Figure 4). Calibration (comparison) of thermal images and measurements using thermoelectric temperature sensors was also carried out to verify the correctness of the accepted emissivity coefficient.

3.5. Selected research results

The article presents selected results of thermal imaging measurements of ESH elements used for heating railway switches as part of the

BRIK2/0036/2022 project. The studies were conducted for different types of railway switches (standard). The obtained measurement results show the temperature distribution for various structural solutions of the switches. Figures 6 and 7 present selected thermograms for the tested switch No. 38 and the reference switch No. 39. The presented thermograms were recorded during the heating phase of the switch in both the main and non-main positions. Thermographic tests were conducted using thermal imaging cameras.

Figure 7 shows thermograms that recorded the temperature distribution for the entire area of the monitored switch section in a heated state, supplemented with photos of the monitored area.

a) b)

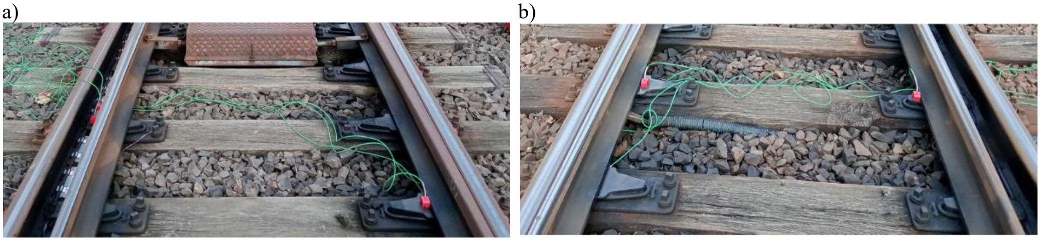
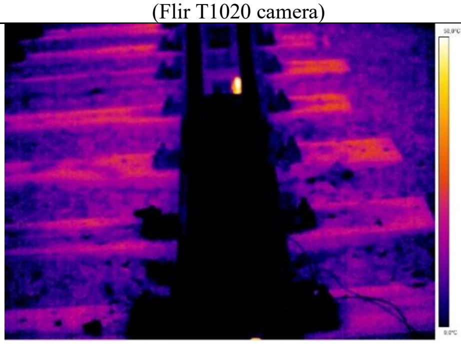
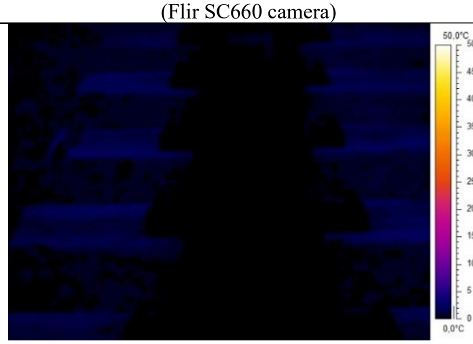
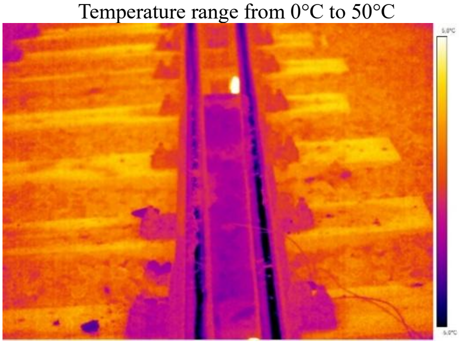
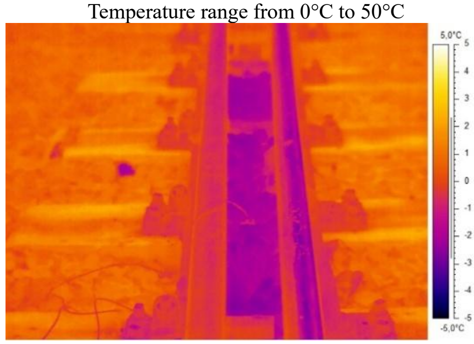
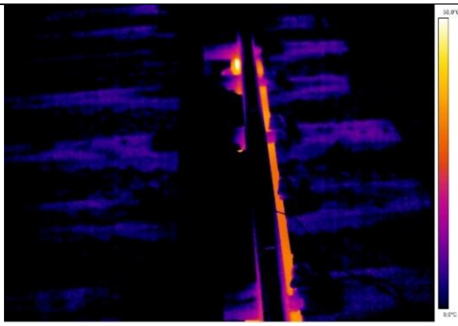


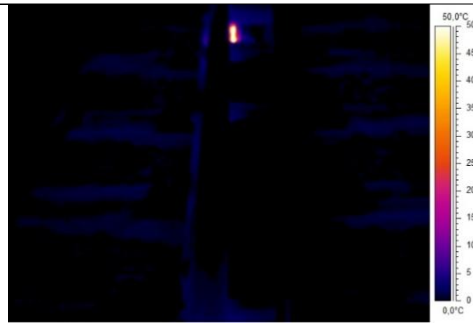
Fig. 5. View of the location of thermoelectric sensors installed on the studied switches No. 38 (a) and reference switch No. 39 (b) near the switch drive

Recording time	Reference switch No. 39 (Flir T1020 camera)	Railway switch No. 38 with radiation overlays (Flir SC660 camera)
11:04	 Temperature range from 0°C to 50°C	 Temperature range from 0°C to 50°C
	 Temperature range from -5°C to 5°C	 Temperature range from -5°C to 5°C

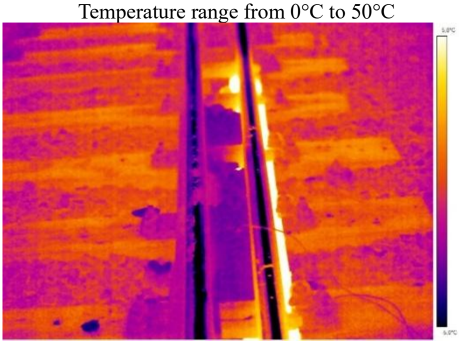
11:34



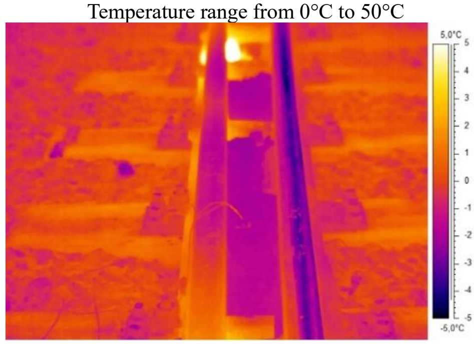
Temperature range from 0°C to 50°C



Temperature range from 0°C to 50°C

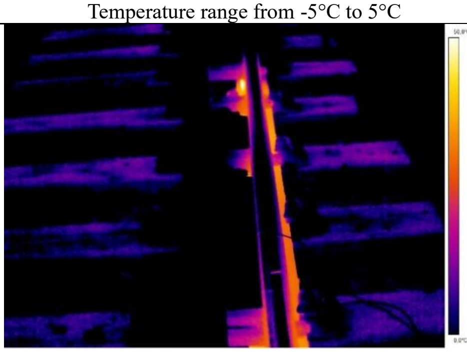


Temperature range from -5°C to 5°C

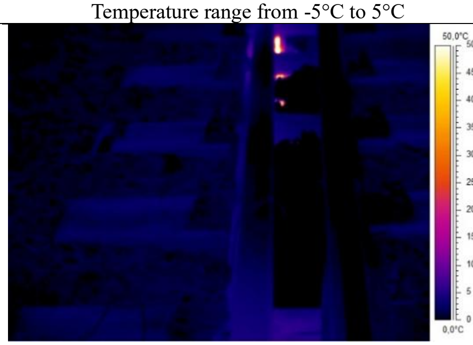


Temperature range from -5°C to 5°C

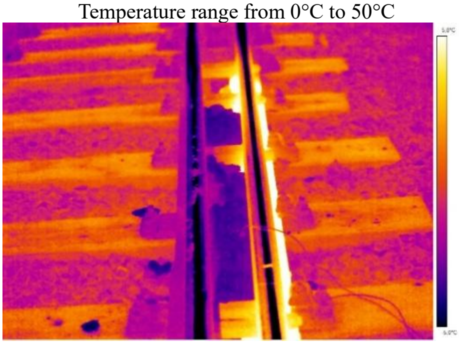
12:07



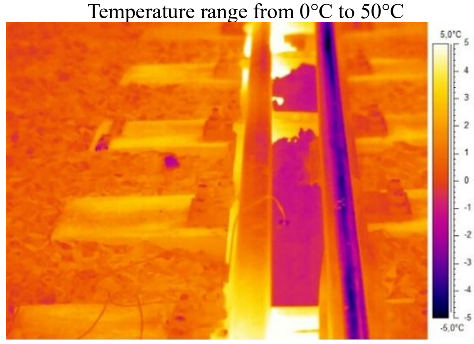
Temperature range from 0°C to 50°C



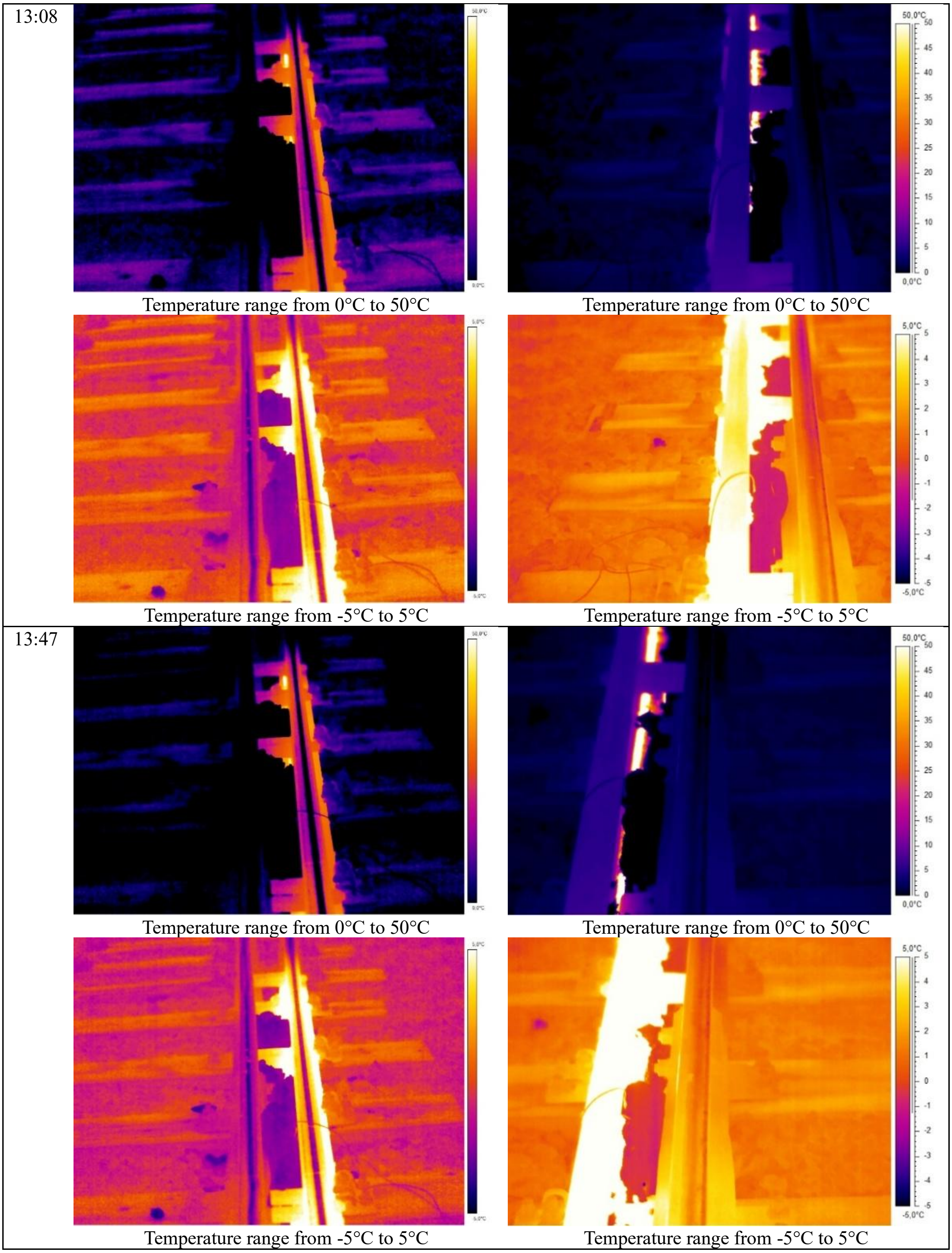
Temperature range from 0°C to 50°C

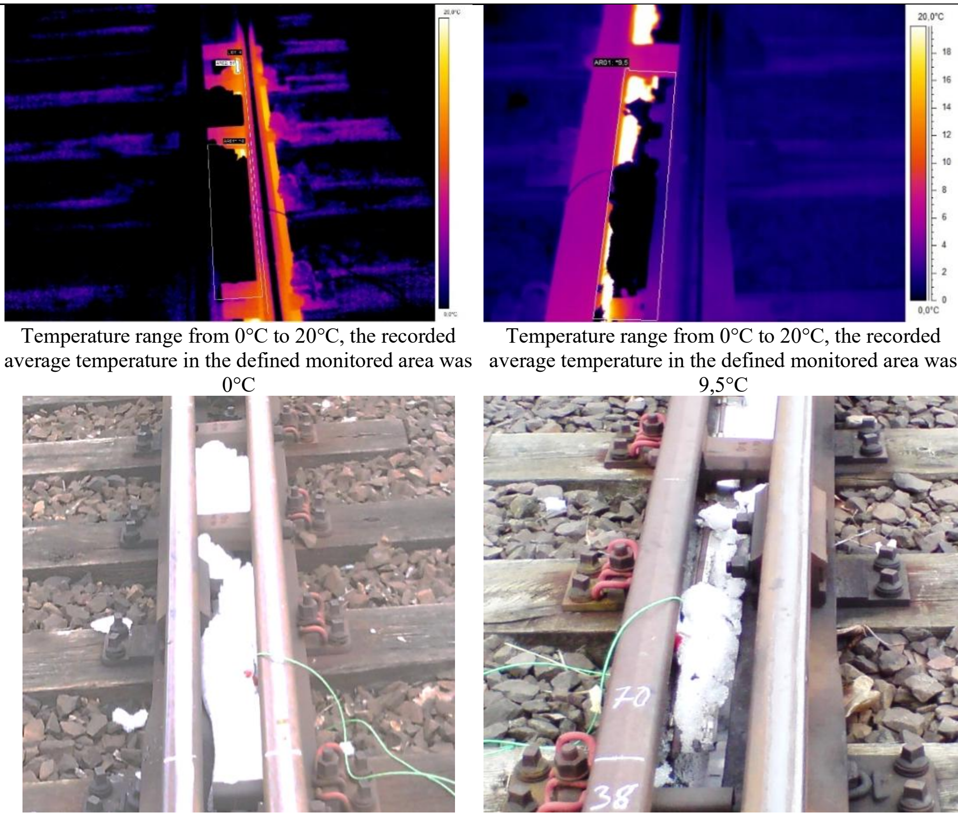


Temperature range from -5°C to 5°C



Temperature range from -5°C to 5°C


13:08
Temperature range from 0°C to 50°C
Temperature range from 0°C to 50°C
Temperature range from -5°C to 5°C
Temperature range from -5°C to 5°C
13:47
Temperature range from 0°C to 50°C
Temperature range from 0°C to 50°C
Temperature range from -5°C to 5°C
Temperature range from -5°C to 5°C



Temperature range from 0°C to 20°C, the recorded average temperature in the defined monitored area was 0°C

Temperature range from 0°C to 20°C, the recorded average temperature in the defined monitored area was 9,5°C

Monitored area

Monitored area

Fig. 6. Thermographic test results for switch No. 38 and 39 in the snow-covered area

Field tests of heat distribution using thermal imaging cameras and thermoelectric sensors were conducted at the Międzylesie research polygon from February 11 to 13, 2025. Reference switch, reference switch No. 39 type Rz-60E1-1:9-300 with an installed power of 7.3 kW was compared to switch No. 38 of the same type, in which NR radiation overlays were installed. The same type and number of heaters were installed on both switches according to the ESH sheet. The difference was that switch No. 38 with NR radiation overlays was heated with a 30% reduced power. Heat distribution comparison was conducted, among other methods, thermographically. In Figure 7, the measurement results are compiled in the form of thermograms, for which the same temperature range was adopted for both switches from 0 to 20˚C, as well as from 0 to 50˚C. An isotherm tool was also used, which visually highlights the differences between both technical solutions. It is clearly visible that the switch equipped with NR radiation overlays has a significantly larger share of areas with higher temperatures in the defined temperature ranges, thus its heat distribution efficiency is higher than that of the reference switch. In this solution, thermal energy is distributed for snow melting rather than rail heating.

Heaters with increased heating surface are clearly visible on the thermograms due to the installation of dedicated radiators and radiation overlays. Without radiators, the average temperature in the defined monitored area is 10˚C. The use of radiators results in a noticeable increase in the area with a temperature above 10˚C, with the average temperature on the surface of the components in the defined area of the switch equipped with radiation overlays being 47˚C during the study.

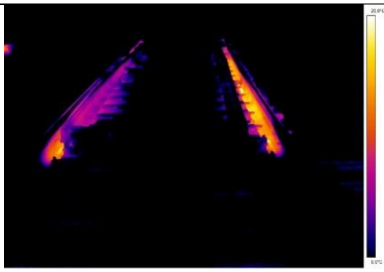
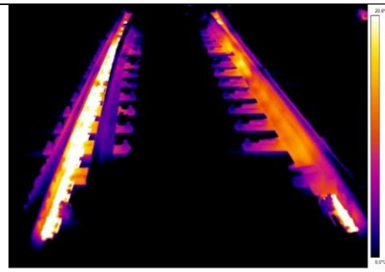
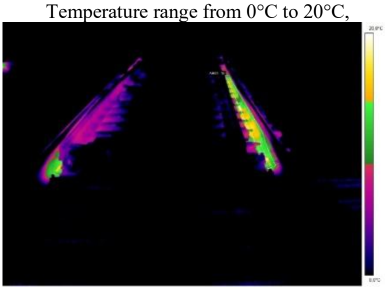
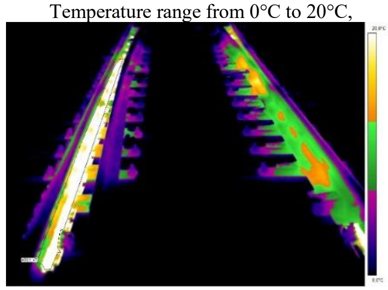
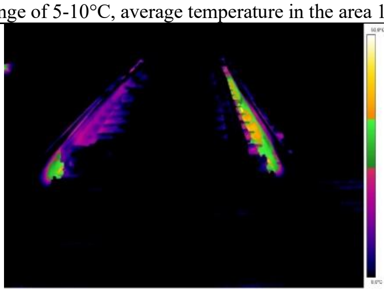
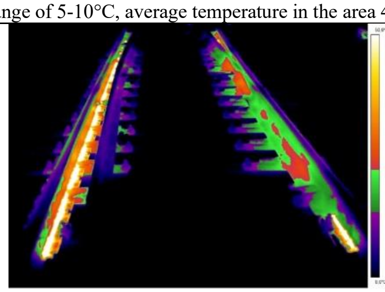
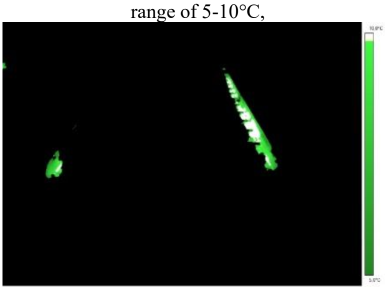
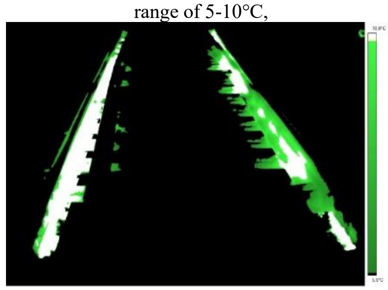
13:32 - 13:57	Reference switch No. 39 (Flir T1020 camera)	Railway switch No. 38 with radiation overlays (Flir SC660 camera)
	 Temperature range from 0°C to 20°C,	 Temperature range from 0°C to 20°C,
	 Temperature range from 0°C to 20°C, isotherm tool in the range of 5-10°C, average temperature in the area 10°C	 Temperature range from 0°C to 20°C, isotherm tool in the range of 5-10°C, average temperature in the area 47°C
	 Temperature range from 0°C to 50°C, isotherm tool in the range of 5-10°C,	 Temperature range from 0°C to 50°C, isotherm tool in the range of 5-10°C,
	 Isotherm for the temperature range from 5 to 10°C. The white areas refer to temperatures above 10°C, the black area on the thermogram indicates temperatures below 5°C.	 Isotherm in the range from 5 to 10°C. A significantly larger area of temperatures above 10°C is visible despite a 30% reduction in power.

Fig. 7. Thermographic test results for switch number 38 and 39 showing the temperature distribution for the entire area of the studied switches in a heated state

Additionally, to verify the thermographic studies and to adjust the emissivity settings of the thermographic camera, measurements were taken using thermoelectric sensors and a recorder. The placement of the sensors considers the most critical points from the perspective of safety and the passability of the railway switch.

The results presented in Figure 8 show a comparison of the obtained temperature values for the entire heating process of the classic solution of electric heating equipment for switch No. 38 and the switch equipped with additional NR type radiation overlays.

To illustrate the effectiveness of the proposed innovative heating system for switches, Figure 9 presents a comparison of the snow melting process in the most critical areas due to the operation of the switch, considering its usability in traffic, maintaining its switchability, and thus the passability of the track system.

In the final phases of heating the switch, it is evident how the innovative solution effectively melts the snow, despite a 30% reduction in the power of the heaters. This is visible in the recorded time intervals of 13:08 and 13:47.

4. Summary

This article presents selected results of thermographic studies conducted for one type of switch equipped with electric switch heating devices (ESH) operated on the PKP PLK S.A. network. The studies were carried out for the entire heating process of the railway switch equipped with the existing ESH system and the innovative ESAR (radiant shields) system solution, including the use of special radiation overlays. Comparative studies of both solutions using thermal imaging cameras and additionally thermoelectric sensors allowed for interesting results to be obtained. The innovative solution in the form of radiation overlays mounted on the existing ESH heating system showed a reduced demand for heating power compared to existing solutions. The expected effect of snow melting in designated areas was achieved much faster than in the reference switch equipped with the current solution. Lower energy consumption will result in a reduced demand for ordered heating power, and consequently lower costs for consumed electricity, which, on a scale of approximately 35,000 switches equipped with the ESH system, can represent significant savings.

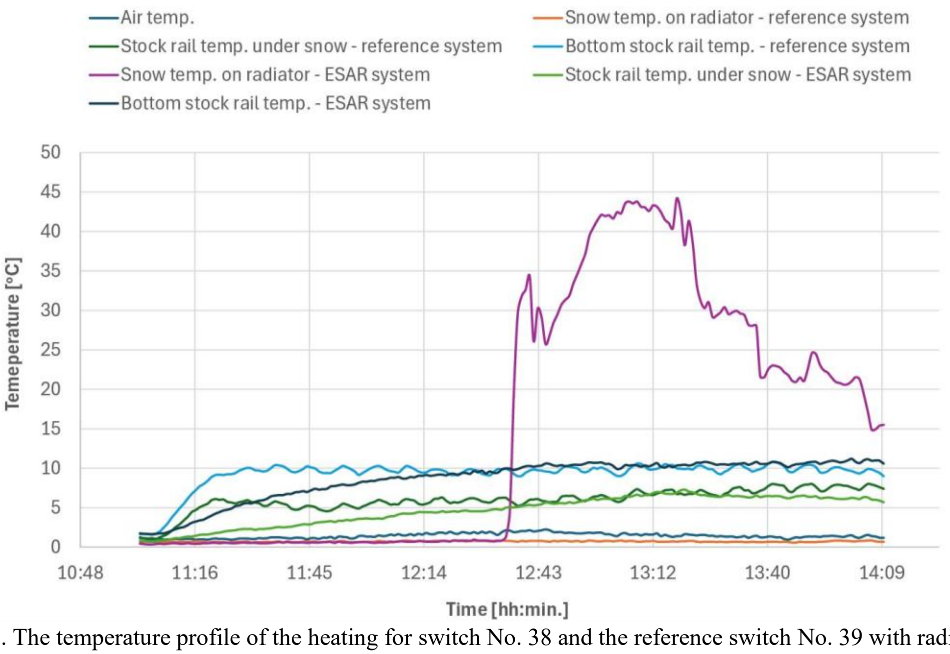


Fig. 8. The temperature profile of the heating for switch No. 38 and the reference switch No. 39 with radiation overlays

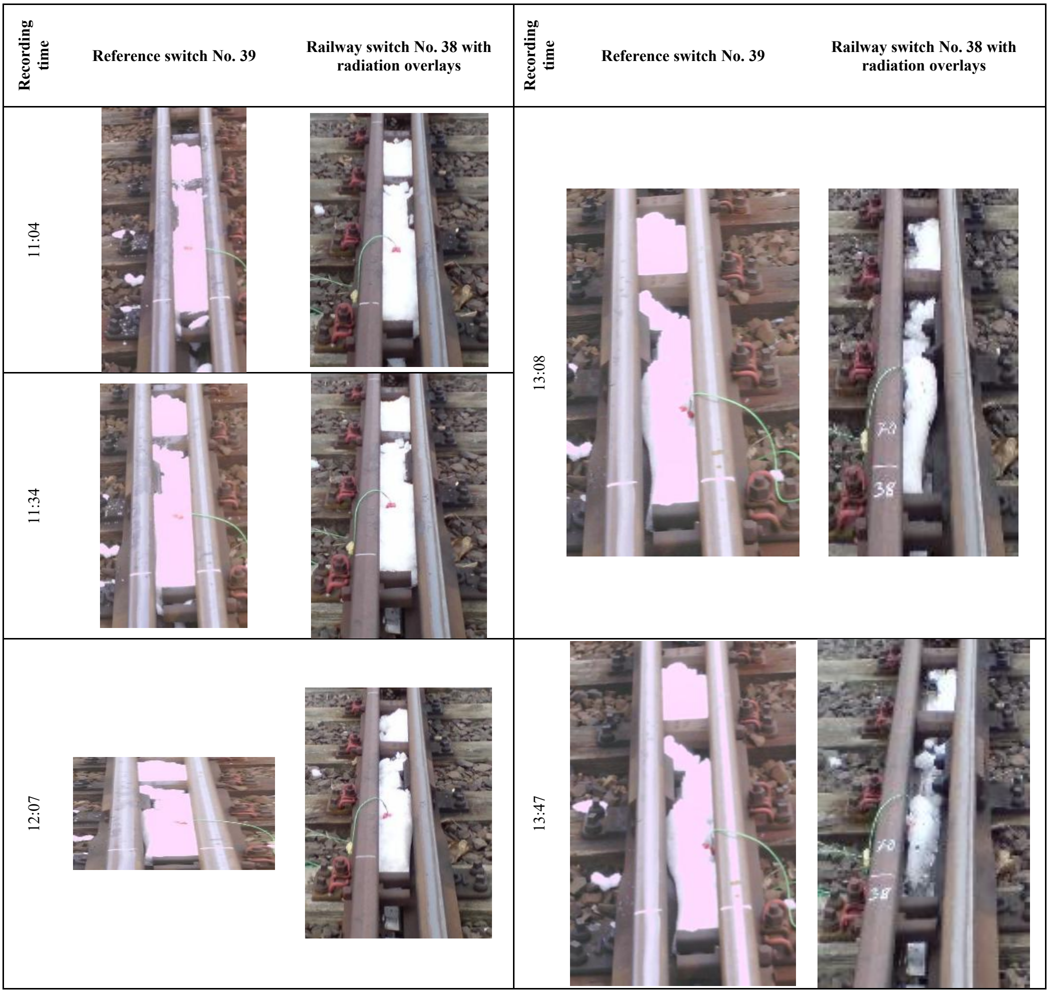


Fig. 9. Visualization of snow melting

The use of radiant overlays mounted on the heaters of the existing ESH system allowed for more efficient snow melting in a significantly shorter time than with existing solutions. The use of the overlays indicates effective heat distribution thanks to the radiant shields. The power reduction also resulted in lower average surface temperatures of the heaters and radiators, indicating effective heat distribution thanks to the radiant shields. Tests conducted with various variants of reducing heating power by up to 70% demonstrated its effectiveness compared to the reference system. This is visible in Figure 8 of the manuscript, showing the volume of accumulated snow in both cases. Reducing electricity consumption reduces the emission of harmful substances into the environment.

The use of a measuring tool that is thermography also brings tangible benefits, allowing for interesting measurement results for the entire area of the studied object. The obtained measurement results showed that areas near the rail heating system, where factors (snow, ice) were effectively eliminated, may influence the improper functioning of the switch. As a result of thermographic inspections of switches, areas were identified where the range of heat distribution and radiated energy from the rail heating system

to the environment was determined. Such intense heating of certain areas of the switch is not required and justified. This leads to excessive electricity consumption.
These observations are a reason to implement optimal management and control of the switch heating process, not only using radiation overlays but also a system for controlling the distribution of heating power, thereby actively reducing energy consumption.
Studies of this type exemplify that thermography can be a significant element of diagnostics, especially regarding thermal processes occurring in operated devices and systems..
In the longer term, there are plans to create a simple diagnostic tool for assessing and interpreting the obtained thermogram, which may enable maintenance services to make appropriate operational decisions. In the first stage, a measurement instruction for conducting thermographic inspections will be created, followed by a computer application utilizing, for example, artificial intelligence to interpret the obtained thermographic image.

Acknowledgements
This work was supported by project BRIK-II/0036/2022 - (Energy Efficient Electric Turnout Heating System with Adaptive Heating Power Distribution".). Joint Undertaking NCBIR-PLK S.A. consisting in supporting scientific research and development work in the area of railway infrastructure called Research and Development in Railway Infrastructure BRIK II.

References
1. Bilawal, R.,Sohail, M., Martarelli, M., Hafiz T. Ali, Yusuf, M., S.M., Ahmad, (2021). Pixel frequency based railroad surface flaw detection using active infrared thermography for Structural Health Monitoring. *Case Studies in Thermal Engineering*, 27. https://doi.org/10.1016/j.csite.2021.101234.
2. Brodowski, D., Flis, M. (2022). Experimental Verification of Contactless Heating Method in Railway Turnouts Heating System. *Problemy kolejnictwa*, Zeszyt 194, 9-15. https://doi.org/10.36137/1941P
3. Celiński,I., Burdzik, R., Młyńczak, J., Kłaczyński M. (2022). Research on the applicability of vibration signals for real-time train and track condition monitoring. *Sensors*, 22(6), 1-19. https://doi.org/10.3390/s22062368
4. Clark M., McCann D.M., Forde M.C (2002). Infrared thermographic investigation of railway track balast. *NDT and E International,* 35(2), 83-94. https://doi.org/10.1016/S0963-8695(01)00032-9
5. Flis, M. (2020). Contactless turnouts' heating for energy consumption optimization. *Archives of Electrical Engineering*, 69(1), 133–145. https://journals.pan.pl/publication/131763/edition/115093/archives-of-electrical-engineering-2020-vol-69-no-1-contactless-turnouts-heating-for-energy-consumption-optimization-flis-mateusz?language=en
6. Flis, M. (2019). Energy efficiency analysis of railway turnout heating system with a melting snow model heated by classic and contactless heating method. *Archives of Electrical Engineering*, 68 (3), 511–520. https://journals.pan.pl/publication/129338/edition/112882/archives-of-electrical-engineering-2019-vol-68-no-3-energy-efficiency-analysis-of-railway-turnout-heating-system-with-a-melting-snow-model-heated-by-classic-and-contactless-heating-method-flis-mateusz?language=pl
7. Hyeong-Seok, Oh., Chan-Bae, P., Seung-Hwan, L., Jae-Bum, L., Tae-Hyung K., Hyung-Woo, L. (2019). A study on de-icing for railway turnouts using 250 kHz-200W-class induction heating system. *AIP Advances*. 9(12). 125229. https://doi.org/10.1063/1.5129857.
8. Karabacak, Y. E., Gürsel Özmen, N., Gümüşel, L. (2020). Worm gear condition monitoring and fault detection from thermal images via deep learning method. *Eksploatacja i Niezawodność – Maintenance and Reliability,* 22(3), 544-556. https://doi.org/10.17531/ein.2020.3.18
9. Kampczyk, A., Gamon, W., Gawlak, K. (2022). Implementation of Non-Contact Temperature Distribution Monitoring Solutions for Railway Vehicles in a Sustainability Development System Transport. *Sensors*. 22 (24), 9624. https://doi.org/10.3390/s22249624
10. Kędra, Z. (2011). Diagnostyka obrazowa rozjazdów kolejowych. *Logistyka*. 6, 1603–1610. https://mostwiedzy.pl/pl/publication/download/1/diagnostyka-obrazowa-rozjazdow-kolejowych_95297.pdf

11. Kisilowski, J., & Kowalik, R. (2021). Railroad Turnout Wear Diagnostics. *Sensors*, *21*(20), 6697. https://doi.org/10.3390/s21206697
12. Koohmishi, M., Kaewunruen, S., Guoqing, J., Yunlong, G. (2024). Thermal imaging analysis of ballast fouling: Investigating the effects of parent rock and fouling materials through IRT passive camera, *Transportation Geotechnics*, 48, 101313. https://doi.org/10.1016/j.trgeo.2024.101313
13. Koohmishi, M., Kaewunruen, S, Ling C., Yunlong, G. (2024). Advancing railway track health monitoring: Integrating GPR, InSAR and machine learning for enhanced asset management. *Automation in Construction*. 162. https://doi.org/10.1016/j.autcon.2024.105378
14. Kukulski, J.; Wolff, A.; Walczak, S. (2023). Selected Simulation and Experimental Studies of the Heat Transfer Process in the Railway Disc Brake in High-Speed Trains. *Energies.* 16, 4514. https://doi.org/10.3390/en16114514
15. Lotfi, A., Yousuf, A., & Virk, M. S. (2024). Study of Heat Distribution in Railway Switch Using Resistive Heater in Cold Climate Conditions. *Applied Sciences.* 14(18), 8151. https://doi.org/10.3390/app14188151
16. Oswald-Tranta, B. (2018). Induction Thermography for Surface Crack Detection and Depth Determination. *Applied Sciences*, 8(22), 257.https://doi.org/10.3390/app8020257
17. Pavlović M.G., Ćirić I.T., Ristić-Durrant D., Nikolić V.D., Simonović M.B., Ćirić M.V., Banić M.S. (2018). Advanced Thermal Camera Based System for Object Detection on Rail Tracks. *Thermal Science*. 22, 1551–1561. https://doi.org/10.2298/TSCI18S5551P
18. Ramzan B., Malik S., Ahmad S. M., Martarelli M. (2021). Railroads Surface Crack detection using Active Thermography, *21 International Bhurban Conference on Applied Sciences and Technologies (IBCAST),* Islamabad, Pakistan, 183-197, DOI: 10.1109/IBCAST51254.2021.9393210
19. Rilo Cañás, A-M., Sawczuk, W. (2020). Thermal imaging test of the disk brake of a diesel multiple unit in field conditions. *Rail Vehicles/Pojazdy Szynowe*. 3,28-36. https://doi.org/10.53502/RAIL-138554
20. Sawczuk W., Merkisz-Guranowska A., Ulbrich D., Kowalczyk J., Rilo Cañás A-M. (2022). Investigation and Modelling of the Weight Wear of Friction Pads of a Railway Disc Brake. *Materials.* 15, 6312. https://doi.org/10.3390/ma15186312
21. Stypułkowski K., Gołda P., Lewczuk K. [i in.]. (2021). Monitoring System for Railway Infrastructure Elements Based on Thermal Imaging Analysis. *Sensors.* 21, nr 11(11), 1-21.3819. https://doi.org/10.3390/s21113819
22. Szychta, E., Szychta, L. (2020). Comparative Analysis of Effectiveness of Resistance and Induction Turnout Heating. *Energies*. 13(20), 5262. https://doi.org/10.3390/en13205262
23. Uferev, L., Roshchin, O., Chepelev, Y., Ermolenko, D. (2021). Research of Induction Heating of a Turnout Rail at an Increased Frequency. *International Scientific Siberian Transport Forum*. 631-639. https://doi.org/10.1007/978-3-030-96383-5_70
24. Usamentiaga, R., Sfarra, S., Fleuret, J., Yousefi, B., García, D.F. (2018). Rail inspection using active thermography to detect rolled-in material. *In Proceedings of the 2018 International Conference on Quantitative InfraRed Thermography, Berlin, Germany*, 25–29 June 2018. https://doi.org/10.21611/qirt.2018.107
25. Wołoszyn, M., Jakubiuk, K., Flis, M. (2016). Analysis of resistive and inductive heating of railway turnouts. *Przegląd. Elektrotechniczny*. 4, 54–57. doi:10.15199/48.2016.04.14
26. Xiaolong. L., Xinyu N., Poquan L., Caihao L., Rongshan Y., Zhiqiang Z. (2023). Test on fouling detection of ballast based on infrared thermography, *NDT & E International*. 140. https://doi.org/10.1016/j.ndteint.2023.102956
27. Ye X.Y., Luo Y.Y., Li Z.W., Liu X.Z., A. (2023). Quantitative Detection Method for Surface Cracks on Slab Track Based on Infrared Thermography. *Applied Sciences*, 13(11), 6681. https://doi.org/10.3390/app13116681
28. Zhang, Y., Liu X., Xiong, L., Chen, Z., Wei J. (2023). A Review of NDT Methods for Wheel Burn Detection on Rails. *Sensors.* 23(11): 5240. doi: 10.3390/s23115240. PMID: 37299966; PMCID: PMC10256060.

29. Zhihong, M., Ran, T., Yan,g K., Guo, H., Li, K., Xuejin, Z. (2023). A novel method based on thermal image to predict the personal thermal comfort in the vehicle. *Case Studies in Thermal Engineering*. 45. https://doi.org/10.1016/j.csite.2023.102952
30. Żelazny, R., Jabłoński, P., Szczegielniak, T. (2021). Operation of the Prototype Device for Induction Heating of Railway Turnouts at Various Operating Frequencies. *Energies*. 14(2). 476. https://doi.org/10.3390/en14020476