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Dagmara KOTRYS-DZIAŁAK, Katarzyna STOKOWIEC

Kielce University of Technology
al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

Corresponding author: ddzialak@tu.kielce.pl

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TEMPERATURE DISTRIBUTION ANALYSIS ON THE SURFACE OF THE RADIATOR WITH AN INFRARED CAMERA AND THERMOCOUPLES

Abstract: *The aim of the work was to perform experimental tests for thermal analysis on the outer surface of the radiator. For this purpose, a localized test stand was used in one of the lecture rooms in Kielce University of Technology. The experiment concerned the isothermal character of a radiator during its operation. Temperature distribution was verified with two different methods: thermocouples and thermovision camera. The radiator was divided into 8 measuring fields and temperature was measured in each of them. The experiments were conducted for different supply flow rates of the medium. The results were presented by means of diagrams comparing both methods of temperature survey.*

Keywords: *radiator, thermal analysis, isothermal, thermovision, thermocouples*

Introduction

Most of us spend plenty of our every day time in the buildings interiors. We sleep, spend some of our free time and even often work inside different types of rooms. One of the most important factors during that time is our general sensation named as thermal comfort and defined by ASHRAE (ASHRAE, 2013) as: “the condition of mind in which satisfaction is expressed with the thermal environment”. In order to analyze the function between the surrounding environment and the person thermal comfort a proper balance was required and the predicted mean vote (PMV) index has been proposed by Fanger model. The scale ranges between -3 to +3 depending on the cold or hot conditions. The approach includes the heat transfer between the occupant and his environment (Stokowiec et al., 2022). The environmental parameters are: air temperature, mean radiant temperature, relative humidity and air velocity. As it can be concluded, the temperature inside the room (both air and radiant ones) strongly influences our sensations.

That is why in order to predict the personal thermal feelings, it is necessary to conduct experiments on the source of proper temperature level inside the room. When analyzing winter season, the heating season in particular, the heating system is of key importance. The elements that transfer the heat to the room interior are heaters. Depending on the heating media they can be water/steam/electric or gas ones. On the other hand, we can divide heaters to convection, that principle is the motion of heated air, or radiant ones, that heat the surfaces around. The materials used for their production are cast iron, aluminum or steel. They can be manufactured as plate, of tinned tubes or sectional radiators.

Many investigations have been conducted in order to observe the phenomena occurring in the area of the operating radiators that influence the personal comfort system in order to extend acceptable comfort zones. Results from the survey conducted in China revealed (Du et al., 2020) that the feet and lower body parts were the most preferred parts to be heated in winter and therefore local heating device was designed to supply warm air to subjects' feet and calves directly. For the experiments 20 subjects (10 males and 10 females) were randomly recruited.

Radiant heating was also compared to other systems such as all-air systems (Karmann et al., 2017) and in that case they provide equal or even better thermal comfort. In case of convective and radiant heating systems, there was no significant thermal comfort difference observed (Lin et al., 2016). Radiant electric heaters that are situated overhead provide localized heat in case of historic buildings (churches) without affecting painted walls or works of art that are displayed (Samek et al., 2007). Radiant heaters are most commonly used in case of any large-cubage building. However, they can be also gas-fired with the possibility of additional heat energy recovery from the flue gases of gas radiant heaters (Dudkiewicz and Szałański, 2019).

The temperature stratification was much higher during research of convective heaters compared to floor heating system, but still not significant enough to change the thermal comfort vote. The reduction of temperature stratification can be achieved by means of heating from the floor and cooling from the ceiling (Causoen et al., 2010). The opposite situation results in high discomfort due to the great temperature stratification (d'Ambrosio Alfano et al., 2014). Moreover, the air temperature stratifications depending on the heating systems may differ: during the experiment the convector achieved the worst air temperature stratification (Legera et al., 2018).

The tests were also conducted for radiant temperature distribution patterns generated by radiant heaters with different power outputs and suspended at different angles (Dudkiewicz and Jezowiecki, 2011). The results refer to parameters characterizing the thermal comfort of people in large capacity halls. Other research analyzed the heat enhancement by means of additional coatings or mesh structures (Chatys and Orman, 2017; Dąbek et al., 2019).

The studies of radiant panel heater evaluated the perception of indoor environment and investigated experimentally the comparison with conventional portable natural convective heaters, resulting with the conclusion that situating the panel heaters on the wall facing the window and on the wall close to the window, provides the best operative temperature distribution in the office room (Ali and Morsy, 2010).

Numerous examinations have been performed on convective-radiative heat transfer: the effect of turbulence has been modelled (Wang et al., 2014) indicating that the ratio between convection and radiation is directly proportional to the Grashof number and inversely to the surface emissivity. Turbulent natural convective energy transport above a heated element phenomenon has also been conducted statistically, dividing turbulent flow into three regions according to power spectrum distribution analysis (Zhang et al., 2016). The research also noted that the enclosure geometry presents high impact on determining the circulation configuration and heat transmission inside the enclosure (Miroshnichenko and Sheremet, 2018).

The underfloor heating system is also widely analyzed and described in the literature. The studies mainly are grouped in two fields: the economic analysis (Karimi et al., 2019) or experimental and numerical research of system design and performance (Magni et al., 2019). Recently, the interested has grown in the aspect concerning the energy transport and liquid circulation (Stepan et al., 2021).

Both not enough theoretical and experimental analyzes have been recently performed in order to research the convection heaters as an element of a central heating system in the building. The studies include the estimation of preheating time in case of buildings that are not continuously occupied, such as shopping malls, office buildings, and residential houses (Sun et al., 2022). Thermal analysis based on the obtained experimental laboratory results was used to assess the heating efficiency of heaters with parameters: different power consumption, geometric shape and dimensions (Bertolin et al., 2015).

The environmental protection issues, including the reduction of carbon dioxide and other pollutants emissions, involve the thermomodernization practices (Wciślik, 2017) with the energy efficiency of the heating system and economic analyzes required.

Due to the scarce scientific and academic achievements evaluating the convection heaters, the paper presents thermal study with the experimental results of convection heaters incorporated in the laboratory installation simulating the real central heating system operation. The scope of the experiments was to measure the isothermal filed of the heaters.

Methodology

Conducted research and the testing device

The research was taken during the heating period season in November in one of the lecture rooms in Energis – a laboratory and didactic building that is an intelligent, self-sufficient and modern part of Kielce University of Technology complex. The tested installation consists of hydraulic system with an electric boiler as a heat source, radiators, pumps, heating pipes with all necessary equipment such as: shut off valves, regulating valves, and others as shown in Figure 1. The system simulates the central heating operation on one outlet, and the domestic hot water on the other.

FIGURE 1. *Lecture room in Kielce University of Technology with tested installation*

To carry out the research one of the four panel radiators was connected to the DaqLab2000 data acquisition station using 8 thermocouples. The station collected the changes of the temperature on the surface of the tested radiator with dedicated computer software program. DaqLab2000 is a measurement system by IOTech equipped with an ethernet interface. The device allows the measurement of analog signals (8 channels, 16 bit converter/200 kHz), frequency measurements (4 channels, 16 bit/10 MHz). Additionally, the user gets 6 digital inputs/outputs available (+24 on DB37 connector).

In the same time infrared camera Testo 890 was located opposite the measured radiator (Fig. 1) and several thermograms were taken during the heating process. For each of the four supply flow rates that were set during the experiment, the measurements lasted for 4.5 minutes with a 15 seconds interval. Thermal imaging camera used in the research has a resolution of 640×480 pixels, with the SuperResolution technology of 1280×960 pixels. Its thermal sensitivity is <40 mK which allows to see even the smallest temperature differences. Temperature measuring range is from -20°C to 350°C and the picture refreshens of 33 Hz.

During the experiment the electric boiler was set to the 50°C of flow rate and the system was heated up for several minutes to reach the required temperature. The temperatures changes in each of the fields were collected by the acquisition station and by the THV camera for four different flow rates (30; 60; 90; 120 l/h) selectable with the rotameter readers and with duration of 4.5 min each. At the same time the data of the heating medium on the supply and return side was measured using temperature sensors located as a part of the system. The radiator chosen for the experiment was Radson Integra type 11, which is one panel radiator with dimensions 600x600x57, height, length and width respectively. Its power is 563 W for parameters 75/65/20°C with bottom left connection as dedicated for this type of radiator. The heater is made of cold-rolled steel sheet in accordance with PN-EN 10130 and is painted with white colour RAL 9016. The max. working pressure is 10 bar, and max. working temperature is 100°C.

The front panel of the radiator was divided into 9 fields and on 8 of them thermocouples were located according to the Figure 2.

a)

b)

***FIGURE 2.** Tested Radiator with 8 no. field measurement location: a) actual photo, b) arrangement of the measured fields*

Emissivity of the tested object was tested in the beginning of the experiment by using tape of known emissivity and defined as 0.92. That factor was applied into THV camera during the experiment. The glossy surface of the heater and thus the reflection of radiation from surrounding objects was not include.

Results and discussion

Based on the results obtained from the measurement series for both THV camera and thermocouples, temperature distribution as a function of flow rate is shown in Figures 3, 4 and 5 depending on the location of the measuring points of the radiator (top, middle and bottom).

As shown in Figure 3 the points M2 and M3 located at the top of the radiator are with the highest temperature according to measurements with thermocouples and according to infrared camera. The mean temperature of the surface of the radiator rises with the flow rate. The M3 and M2 points are the closest points to main vertical channel that distributes the water inside the radiator and are the highest values. The differences in temperatures between the M3 and M1 points are between 0.74°C and 1.3°C with thermocouples and 0.36°C and 1.02°C respectively with infrared camera.

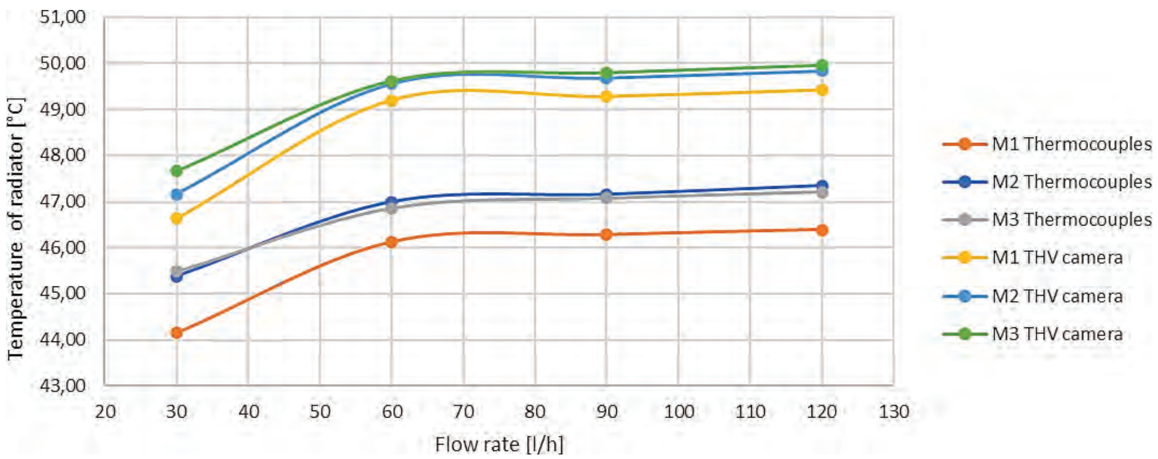

***FIGURE 3.** Temperature distribution in upper part of the radiator as a function of flow rate*

In the middle part of the radiator only two fields were measured with thermocouples, the M4 point is located at the left side of the heater and M5 on the opposite end, therefore the difference in temperature between the two is greater and is around 1°C with the min. and max. values of 0.74°C and 1.15°C respectively (Fig. 4).

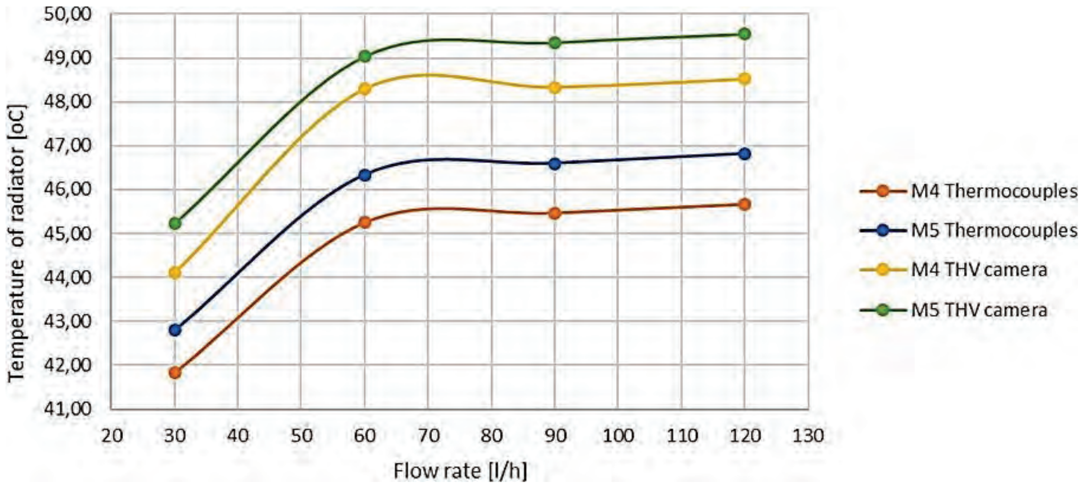

FIGURE 4. *Temperature distribution in middle part of the radiator as a function of flow rate*

Figure 5 represents the bottom part of the examined heater which is the coolest area in the radiator according to the research that took place. The temperature changes between the M8 and M7 and M6 is greater than in the middle part and is in range from 0.55°C to 2.19°C. The temperature differences between the points are lower according to thermovision camera then thermocouples, despite the higher temperature rates achieved by infrared camera.

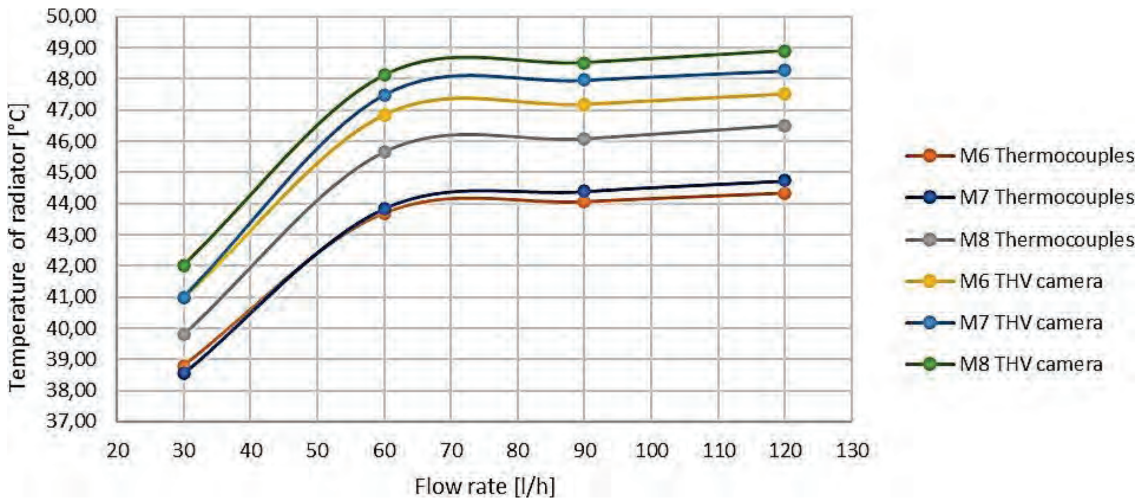

FIGURE 5. *Temperature distribution in bottom part of the radiator as a function of flow rate*

The mean values were calculated for all three parts of the radiator that were tested and Figure 6 represents the results. The distribution analysis show that the surface is not isothermal despite the applied method. The greater the flow rate the changes in temperature difference are smaller, but with its minimum flow rate 30 l/h value the dT is even 5.96°C with thermocouples and 5.82°C with infrared camera between the fields (regarding the mean values for each of the part studied). The overall mean temperature surface of the radiator is 44.92°C and 47.66°C for each of the research method. Standard deviation for the mean temperatures depending on difference flow rates was calculated as 2.32 in terms of thermocouples and 2.43 regarding infrared camera experiment. Figure 7 illustrates characteristics of temperature difference between the two measurement method for each of the 8 points and show that the temperature difference between is significant and at some points it reaches even dT 3.65°C.

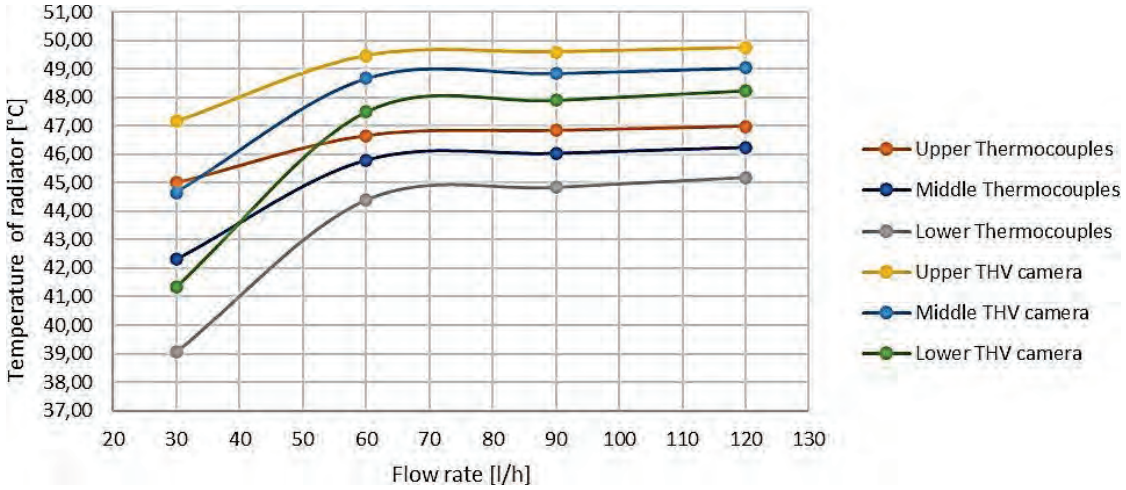

FIGURE 6. *Mean temperature distribution in top, middle and bottom part of the radiator as a function of flow rate*

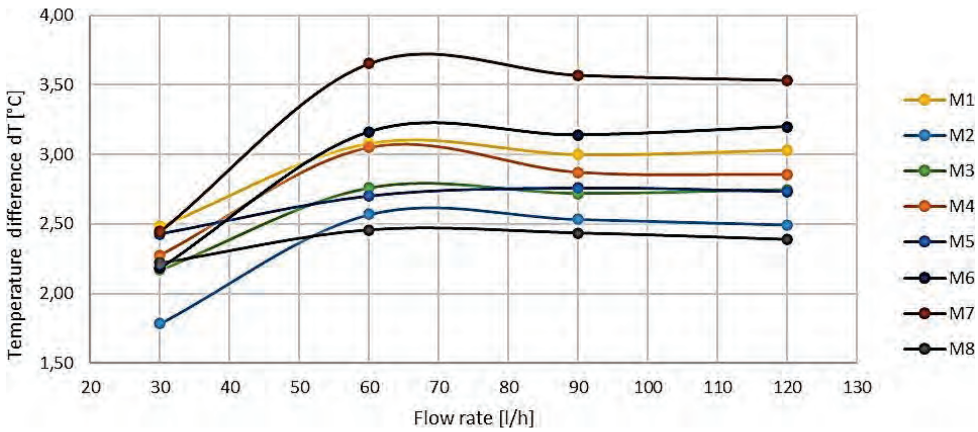

FIGURE 7. *Characteristics of the temperature difference between the thermocouples and the themovision camera measurements for M1 to M8*

Temperature change over time is shown in Figure 8 and Figure 9 for THV camera and thermocouples respectively. As noticed on both of the diagrams temperature increases equivalently with the flow. The highest temperature during the entire experiment was noted in points M3, M2 and M5 for each of the method. The curves were prepared for water flow of 120 l/min, which was the final test taken. The diagrams proof the non-isothermal temperature distribution on the heater, even thou the radiator was heated and the max flow rate was achieved.

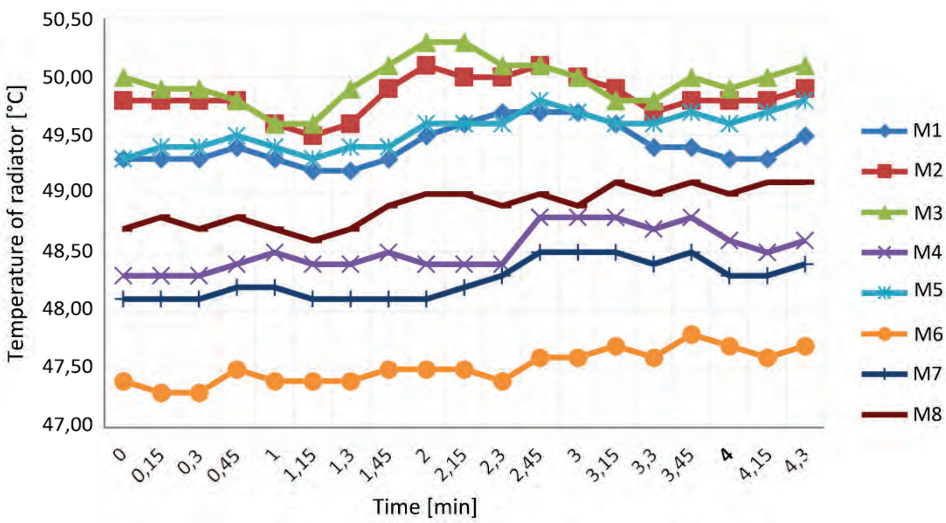

FIGURE 8. *Temperature change for 8 points M1 to M8 for 120 l/min water flow with infrared camera measurements*

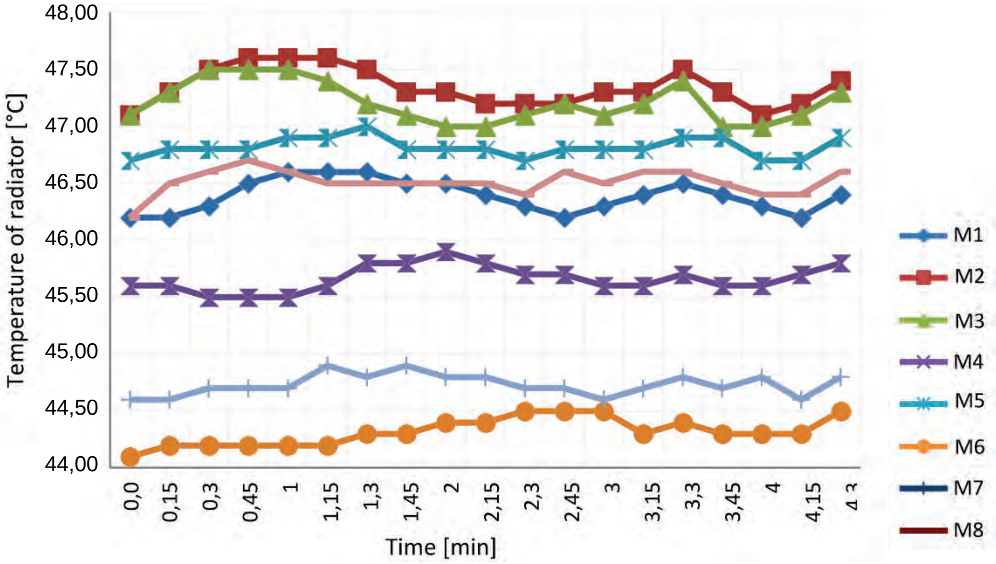

***FIGURE 9.** Temperature change for 8 points M1 to M8 for 120 l/min water flow with thermocouples measurements*

Using thermograms the infrared camera show how temperature fields are shaped. Figure 10 is an example thermogram taken at the flow rate of 30 l/h and at 120 l/h, the reddish colors show the hottest temperatures and the green and blue the coldest.

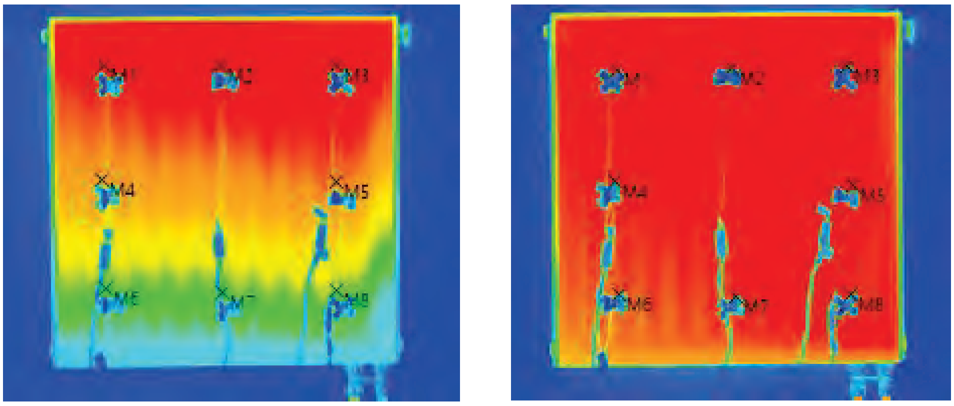

***FIGURE 10.** Thermogram of a radiator showing measured fields (M1 to M8) with 30 l/h and 120 l/h of flow rate*

The connection of the radiator to the hydraulic system right side bottom has a huge impact on the temperature distribution especially with the min flow rate required by the radiator. The right side of the radiator and also its upper side is warmer and is heated much faster than the rest of the radiator. This has a huge impact on the process of convection, and affects the thermal comfort of the occupants inside the environment. During the whole process internal air temperature was monitored and the temperature increased from 236°C to 25.5°C with the max. flow rate of 120 l/h. The outside air temperature was around 10°C.

Conclusion

Between the two methods the infrared camera and thermocouples there are differences in temperatures of top, middle and bottom part of the radiator with the min. of 1.78°C and max. of 3.65°C differences. The contact method with thermocouples and acquisition station seems to be more accurate. The thermovision method despite the camera accuracy and the examined emissivity factor have given highest temperatures. There are numerus reasons for that. One of them is the distance between the object and the infrared camera. The other one is the direct sun light that appear during the experiment and the room was not fully shaded. The mechanical ventilation and floor heating systems installed in the room could have increased the surface temperature of the panel heater. Based on the conducted study, further analysis of the measurement uncertainty of the devices can be performed as well as thermal comfort analysis of the occupants with the radiators as a main source of heating.

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