On-site research with a thermal camera on industrial heating

Veneta Yosifova, Nikolay Stoimenov and Milena Haralampieva
Institute of Information and Communication Technologies, Bulgarian Academy of Sciences
Acad. Georgi Bonchev 2, Sofia, Bulgaria
e-mail: veneta.christova@gmail.com

Abstract. This paper submits the on-site research made with a thermal camera for investigating the practices of heating technologies in industrial premises. The experiments are made during the winter season of 2019/2020 and give a preliminary overview of the heating methods, their positive and negative effect, and their contribution to energy consumption and efficiency. Models for worker's practices and space zoning are observed to optimize heat distribution. Based on the experimental work a series of findings are made and described for future recommendations in heating systems design for industrial buildings.

1. Introduction
An important issue related to the energy efficiency of buildings has been heating large spaces. Some of the problems that the designers face are high ceilings, large spaces, wide openings, circulation of heat. In old buildings occur other problems like lack of wall insulation, old window frames, and poor roof insulation. The type of purpose of the industrial building also has an influence on the heating requirements, for example, a warehouse with special temperature storage characteristics, production using high-temperature processes, manufacturing with many workers in one place, hall with mobile transportation with often wide opened doors, etc. The winter season characteristics also have an impact as outdoor air infiltration has a significant role in the indoor thermal environment [1].

This study submits the findings from a practical study of the winter thermal performance in industrial spaces with different heating methods. The article presents the most interesting cases observed. The main problems in heating, thermal bridges, heat loss as well as the good practices are examined.

2. Thermal camera
Thermal imaging is very effective when it comes to discovering heat flatus in electronics, HVAC systems, and building elements. It records the intensity of radiation in the infrared part of the electromagnetic spectrum and converts it to a visible image, which allows temperature values to be read from an image. This means that every pixel in the radiometric image is a temperature measurement.

A thermal camera is a non-invasive tool for monitoring and diagnosing the condition of buildings and helps in building inspections. With thermal images, some important problems, otherwise invisible to the human eye can be detected and repaired before further problems occur. Most of the applications in civil engineering are the visualization of:
- Faults in supply lines and district heating
- Heat and energy losses
- Missing insulation or bad exploitation
- Air leaks
• Thermal bridges location
• Moisture and mold in construction elements
• Water infiltration in flat roofs
• Construction failures
• Electrical faults

A thermal image that includes accurate temperature data provides building experts with important information and further measures can be planned [2]. Because of these advantages, we were using a modern thermal camera to submit on-site results.

3. Experimental work

It is important to guarantee safe working conditions for the workers in production in terms of climate and ventilation, since they are exposed to many risks such as heavy work and chemical reactions, and usually their duties require uncomfortable heavy clothing. This is why a suitable ambient temperature in the premises should be provided. The Bulgarian national standards set out several temperature variations depending on the season and the type of work (Table 1) [3].

| Category of work | Acceptable temperatures in °C | Summer | Winter |
|-----------------|--------------------------------|--------|--------|
| Constant working places | Moving working places | Constant working places | <23W/m³ | >23W/m³ |
| Light <210W | 18±25 | 15±26 | 28±31 | 28±33 |
| Medium 210-350W | 15±23 | 13±24 | 28±31 | 28±33 |
| Hard >350W | 10±19 | 12±19 | 20±29 | 20±31 |

For this article, four industrial buildings are presented and all observations are made with thermal camera Flir P640. The experiments were held in the winter season with outside temperatures around 0 °C to discover thermal bridges and heat loss if necessary. The buildings have different sizes, functions, and methods of heating. The inside temperature of the premises was measured in different spots of the area with infrared and sensor thermometer in order to achieve better observation. The methodology of the experiments was based on taking thermal images of different spots of each industrial building, where there are challenges in heating.

3.1. Factory for railway elements

The first building which was observed was a factory in a company that produces railway switches and spare parts for them, materials for the railway superstructure, as well as components for the systems of control, management, and operation of railway switches. The company also offers many services for its installation, regulation, repair, and maintenance. The factory was renovated in the last decade with new PVC window frames and outside 15 cm EPS insulation. It was divided into two large production spaces (width of 20 by the length of 70 meters, each) and a solid wall with windows between them. The heating system is district heating (DH) with heating pipes surrounding the whole area (Figure 1).

The overall concept of DH today is the supply of heat from one or several central heat sources thru a network of pipes with hot water or steam to heat exchangers. According to the EU Strategy on Heating and Cooling in 2016, the contribution of DH in the EU accounts for 9% and mainly fossil fuels such as gas (40%) and coal (29%) are used. DH networks have a high potential for the transition of the heat sector in terms of technical and organizational implementation. They allow the use of renewable
energies so that energy efficiency can be improved, as well as to facilitate sector coupling (coupling between heating, electricity, and mobility) [4].

![Figure 1](image1.jpg)

**Figure 1.** District heating system in a railway factory.

The outside temperature was -2 °C and the humidity of 65%. The inside temperature was measured at 16 °C, which is in the prescript range. Because of the high ceiling (15 m) and the position of the pipes (at 3m above ground level) it was observed with the thermal camera, that near the roof the temperature was higher which leads to the conclusion that the heat distribution is uneven, and most of it escapes thru the steel, uninsulated roof (Figure 2).

![Figure 2](image2.jpg)

**Figure 2.** Thermal image of the roof from the inside of a factory.

The workers are divided into several zones, depending on the scope of work. It is interesting to point out, that in the welding zone, the ambient temperature was higher at around 4 °C (Figure 3). In productions that include high-temperatures as welding, it is important to take into consideration the output heat that they generate. In the welding process, this range is very wide, starting from the ambient temperature and rising to the melting point of the processed materials. For example, for steel, the melting point is approx. 1520 °C. Of course, the second stage of the process is the cooling time of the material, depending on its type and structure, where specific requirements are valid [5].
3.2. Re-engineering of an industrial robots manufacturing hall

The second visit during the research was a company specialized in the development and implementation of specialized systems for automation of industrial production, mechatronic systems, VPN diagnostics and service, industrial engineering, CAD design, and CNC processing. In 2016 the company opened a new manufactory hall (width 25 m, length 40 m, height 10 m) compliant with energy efficiency requirements involving modern HVAC and lighting technologies. The heating is put in effect with a heat pump connected to an underground thermal water source. The geothermal heat pump draws heat from, or removes heat to the ground or groundwater, instead of air. In the summer, the heat transfer process is reversed; the ground or groundwater absorbs heat from the living or working space and cools the air. The heat pump does not have to work as hard to gain heat from the ground or groundwater since the temperature is higher as from the cold air in winter, which makes it more economical. The energy efficiency of a geothermal system is thus higher than that of a conventional heat pump [6]. In this situation, the hot water goes thru pipes that surround the inside walls of the building (Figure 4).

Along with the surrounding pipes, effective floor heating is integrated into the system (Figure 5). With this bespoke system, the inside temperature was measured at 19 °C, while the outside temperature was 1 °C with 70% humidity.
3.3. Car service center

A large car service center was visited (width 18 m, length 45 m, height 6 m), situated near Sofia, Bulgaria. The building has reinforced concrete construction, with a sandwich panel surrounding insulation elements. The outside temperature during the observation was -2 °C, the humidity of 64%. The heating technology used is a heat pump and an integrated system of conductor pipes and a hot water air heater unit (Figure 7). The heating system wasn’t working at its full capacity and the ambient temperature was around 16 °C.
Figure 7. Heat pump technology in car service.

Because of the working process, there were 12 working places separated (one for each vehicle repaired). Depending on the working schedule, not all stations work at once, this is why spot heating where needed may be a good solution in reducing energy consumption. The problem of this type on-premises is that often the wide sectional doors, otherwise well-insulated) stay open for the entering vehicles which lead to great heat loss and draughts (Figure 8). This is a prerequisite for the inefficient use of the heating method.

Figure 8. Garage door in car service.

3.4. Garage doors production facility
Companies with a wide product assortment, need more storage capacity. A thermal observation of a facility where various products: aluminum automatic sliding doors; sectional doors; entrance integrated mats and other elements, are produced.

The building has concrete construction (width 8 m, length 35 m, height 7 m) insulated with sandwich panels. Because of the periodic presence and work in the territory, there wasn’t working heating. The ambient temperature was low (9 °C) (Figure 9).

When production starts, depending on the order, the workers switch on an adjustable infrared heater. This type of heating uses infrared radiation, which concentrates in areas where it is needed and used, rather than spreading throughout the room and also does not flow through enclosing structures. The air temperature remains almost the same throughout the room height, which is highly effective in small working zones in large spaces [7].
Figure 9. Storage without a heating system.

After switching in on, the infrared radiation heated the working place immediately and increased the temperature of the working zone by 2-3 °C (Figure 10). The advantage of this type of heating in such working practices is that there is no need to warm up the whole space, but only the workstations, when needed. It is very effective when there are irregular work processes, the constant moving of the working stations around the production area, constantly opening wide doors, or poor insulation. The opportunity to integrate it into a building management system improves the management of energy consumption and increasing energy efficiency.

Figure 10. The warming effect of an infrared heater on a working station.

4. Conclusion
Heating large industrial spaces is a challenge to the architects, engineers, and designers of HVAC systems since they should bear with huge volumes, take into consideration the working processes and workstation positions and building peculiarity. During the winter season 2019/2020, a series of observations were made over industrial premises with a thermal camera to better understand the problems that may occur in designing modern heating systems that are energy efficient. Based on that research the following conclusions were made:
1. Many of the production buildings have high ceilings because of the working process that requires the presence of a heavy load crane or the need for storage capacity. This is an obstacle for heating and ventilation systems since the hot air goes up and the ground level, where the workstations are, stays colder. This makes many technologies ineligible in terms of energy efficiency.
2. Still many old-build production facilities haven't changed the old steel-framed windows with energy-saving PVC windows. The old steel doors also are not modernized with high-speed doors (for inside openings) or insulated sectional doors (for outside openings). This is a prerequisite for thermal bridges to appear because of the temperature difference between outside and inside climate, which makes the available heating methodology inadequate in terms of cost and energy savings.

3. When it comes to working practices in industrial buildings it is very common that only a small part of the facility is adopted for workstations. This makes the heating of the whole space indecisive in terms of high consumption and expenses. This is a good example of where infrared heating, IoT, and smart home technologies might be applied for heating management and increasing energy efficiency.

4. During the interviews taken from factory owners and managers, the conclusion that energy consumption is an important issue for industrial companies was made since most of them use old methods of heating. They are willing to put more effort into improving energy management with smart systems and IoT modules. Since heating is a bigger issue than cooling in large spaces, such systems will provide a better function of the heating appliances according to working habits and production peculiarities.

From the on-site research it is clear that when new methodologies such as insulation, suitable heating system, lack of thermal bridges, and optimal workstation alignment are taken into consideration for increasing the energy efficiency, the good results are visible. Owners claim that their investment will be returned in a few years, the comfort of their employees is assured and better production results will follow. As next steps planned an optimization plan will be developed in terms of heating technologies combined with BMS to achieve better energy efficiency of industrial buildings according to the EU measures for reducing energy consumption and carbon footprint for a safe future.

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