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# The use of IR thermography for testing operation parameters of plate steel and accumulative wood stoves

**Abstract**

This paper shows the possibility of the use of IR thermography for testing the operational parameters of wood stoves. The study showed differences in the operation parameters of the plate steel wood stove, plate steel wood stove with accumulation and accumulative wood stove. There were compared temperature distribution on the external surfaces of tested units and the amount of energy transferred to heated rooms. Moreover, there were also tested two types of units dedicated to heat recovery from flue gas: flue gas to air steel heat exchanger and accumulative ceramic heat exchanger. The use of IR thermography allowed to simplify measurements and gave approximate results in comparison to more detailed tests.

**Keywords**: IR thermography, plate steel wood stoves, accumulative wood stoves, energy efficiency.

## 1. Introduction

The indoor fireplace is a technology that dates from the Middle Ages, when people in medieval castles and homes used them for warmth. Modern solutions completely differ from their originality. There are several types of stoves currently in use for residential applications, including e.g. cast iron wood stoves, plate steel wood stoves (optionally with accumulative layer), and accumulative wood stoves. When comparing cast iron versus plate steel wood stoves, the first thing to be aware of is that they are both made of the same material – iron. There are more differences if we include in comparison also accumulative stoves:

- **Construction**. Joints between the panels of a cast iron stove are sealed with bolts and caulk, while the joints of steel stoves are welded shut (what reduce the need of regular maintenance and prevent air leakage). The accumulative stoves are made from ceramic plates and bonded together using silicone.
- **Heating**. Plate steel wood stoves heat up and cool down faster than cast iron stoves. Accumulative stoves, however, are able to prevent overheating rooms and hold their heat even better than plate steel and cast iron stoves.
- **Looks**. A wood stove is not just an appliance but it is also part of home's décor. Cast iron wood stoves come in a variety of attractive designs, whereas plate steel stoves are plain and more utilitarian looking. The accumulative stoves are designed to be covered by decorative tiles.

This paper is focused on the heating aspects of the plate steel and accumulative wood stoves' operation. The main method used in this investigation is infrared thermometry. This method is widely used for noninvasive measurements of surface temperature, and is useful for validations heat flow numerical models [1]. As shown in [2] analysis of thermal images allows for detecting defects of insulation. Infrared thermography is also useful in measurements of convective heat transfer and in some applications of fluid dynamics [3,4]. In the paper similar technique of thermal imaging of the wood stoves surface were applied to analysis its performance. Except the analysis of the heating and cooling of the stoves two ways of combustion heat recovery were considered: the use of flue gas to air heat exchanger and accumulative heat exchanger.

## 2. Experimental rig and measurement procedure

The measurements have been conducted on the experimental rig equipped which following devices:

a) **Stove 1:** typical plate steel wood stove,
b) **Stove 2:** plate steel wood stove with accumulation layer and flue gas to air heat exchanger,
c) **Stove 3:** 550 kg accumulative wood stove with 1050 kg ceramic heat exchanger (see Fig. 1).


Fig. 1. Three stoves tested during presented study

Control and measurement system was equipped with resistance and thermocouple temperature sensors connected to the WAGO PFC200 programmable logic controller [5,6]. In each series, temperature was measured in selected point located inside combustion chamber, inside flue gas channel as well as inside and outside accumulative heat exchanger. To carry out more detailed thermal analysis of the external surface of tested devices, a high resolution thermographic camera NEC Thermo Tracer H2640 was used. This camera features a 640 × 480 image resolution, 0.03°C accuracy and temperature range from 0 to 500°C. The analysis of the data was realized using dedicated software (WAGO e!Cocpit for PLC controller and Radiometric Thermography Studio for infrared camera respectively). The general scheme of the experimental rig is presented in Fig. 2.

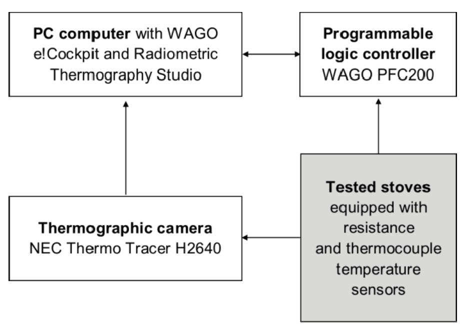


Fig. 2. The general scheme of the experimental rig

In the first part of this work, the dynamic of a heating and cooling surface have been carried out for each device and compared. In the second part, the similar tests have been conducted for two tested heat exchangers, Each time 8 kg of oak wood characterized by caloric value 15 MJ/kg and humidity <15% was burned.

## 3. Results and discussion

### 3.1. The comparison of temperature distribution on the surface of tested devices

One of the most important aspect of the stoves operation is the amount of heat transferred to the heated rooms. The variation of the average and maximum temperature on the tested stoves' surfaces during the combustion process is shown in Fig. 3.

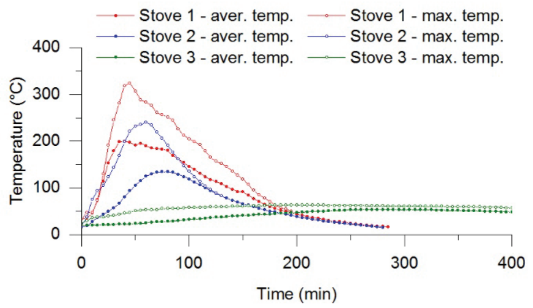


Fig. 3. The comparison of average and maximum temperature on the surfaces of the tested stoves

As we can see in Fig. 3, the highest temperature is reached on the surface of typical plate steel wood stove (stove 1). Considering whole process, the average temperature of the stove 1 is 1.5 times higher than average temperature of the stove 2, and 3 times higher than average temperature of the stove 3. The main reason for this situation is high heat conductivity of a steel (about 60 $W \cdot m^{-1} \cdot K^{-1}$) in comparison to about 2.6 $W \cdot m^{-1} K^{-1}$ for ceramic modules.

Besides the level of the temperature, the another important aspect of heat transfer to the rooms, is the uniformity of temperature distribution on the surface of heating device. This parameter was determined for each tested stove (at time, when its average temperature was the highest) and it is presented in Fig. 4.

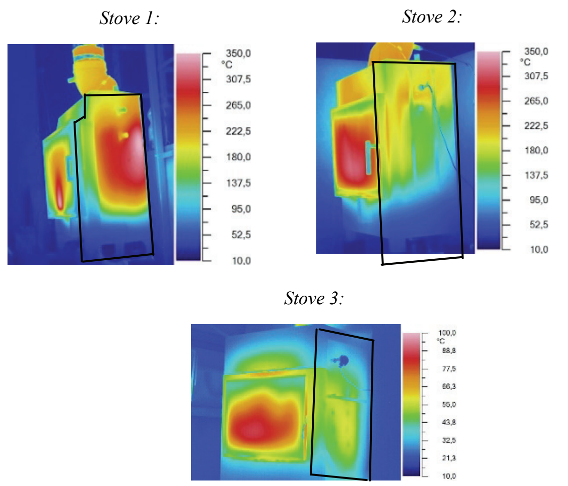


Fig. 4. The temperature distribution on the surfaces (marked by rectangulars) of the tested devices

To better evaluate the uniformity of temperature distribution on the stoves' surfaces, the thermogram of temperature appearance on the surfaces of the tested devices was determined and it is presented in Fig. 5.

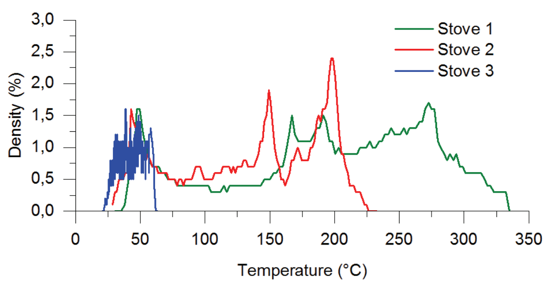


Fig. 5. Histograms of the tested surfaces temperature (indicated at Fig. 4)

As we can see in Fig. 5, the most uniform temperature distribution was measured for Stove 3. The average temperature is about 43°C in this case and it is significantly lower in comparison to average temperature in the other cases (135°C for a stove 2 and 240°C for a stove 1). Such a low temperature allows to avoid overheating rooms in a case of energy saving and passive houses, as well as to ensure a higher thermal comfort in these objects.

## 3.2. Calculation of the heat transferred via surface of heating devices

The average value of surface temperature was used to calculate the heat transferred via side walls of the tested devices (eq. 1 and eq. 2). It was assumed that both side walls were heating in the same way as observed one (the rear walls were omitted, because their location).

$$P = A \cdot [\varepsilon \cdot \sigma \cdot (T_{av}^4 - T_{amb}^4) + h \cdot (T_{av} - T_{amb})] \qquad (1)$$

where:

$A$ – area of heating surface, $m^2$
$\varepsilon$ – emissivity, -
$\sigma$ – Boltzmann constant, $5.67 \cdot 10^{-8}$ $W \cdot m^{-2} \cdot K^{-4}$
$T_{av}$ – average value of surface temperature, K
$T_{amb}$ – ambient temperature, K
$h$ – heat transfer coefficient for external wall, calculated from Alamadari and Hamond correlation [7], which is 5.09 $W \cdot m^{-2} \cdot K^{-1}$ for Stove 1, 4.42 $W \cdot m^{-2} \cdot K^{-1}$ for Stove 2, 3.19 $W \cdot m^{-2} \cdot K^{-1}$ for Stove 3 (averaged for periods from Tab. 1). The $h$ coefficient depends on value of temperature difference between surface of the stove and ambient temperature, therefore three different values were used for the calculations.

$$Q = \int_0^T P(\tau) d\tau = \Delta\tau \sum_i^P P_i \qquad (2)$$

where:

$Q$ – heat transferred from external wall to air, J
$P_i$ – temporary power, W
$\Delta\tau$ – time step, s

The results of calculations are presented in Tab. 1. The highest amount of heat was transferred via side walls in a case of stove 3 and it was nearly the same as in Stove 1, and 2 times more in comparison to stove 2.

Tab. 1. Heat transferred via external walls to air

| | Stove 1 | Stove 2 | Stove 3 |
|---|---|---|---|
| Heat transferred via external walls, MJ | 13.6 | 7.4 | 14.6 |
| Time of heat delivering, [h] | 4.75 | 4.67 | 19.67 |

In real conditions, the amount of heat transferred via side walls is reduced because there are covered with plaster or ceramic plates. Moreover, the values presented in Tab. 1 do not include the amount of heat transferred via stoves' glass and chimney losses. On the other hand, information about heat transferred via side walls is important from the standpoint of evaluate and compare operating parameters of different stoves.

## 3.3. The analysis of the operation of flue gas to air heat exchanger

The heat removed with hot flue gas to the environment may be utilized in a few different ways. The basic way to utilize heat from flue gas to heating rooms is using flue gas to air heat exchanger. Most of the stoves use natural convection to heat air surrounding the stove, but there are also exchangers with forced air flow. One of the available constructions of such heat exchangers is presented in Fig. 6. This exchanger is made of steel and has several tubes for flue gas flow. These tubes are cooled using air blown by air fan.

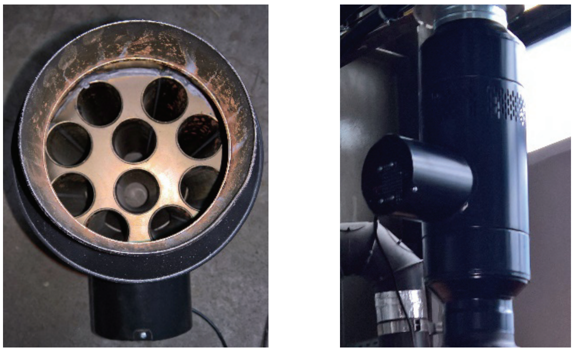

Fig. 6. Construction of the used flue gas – air heat exchanger

Analyzing flue gas temperature variations at the inlet and outlet from heat exchanger, average temperature drop about 90°C is observed (see Fig. 7).

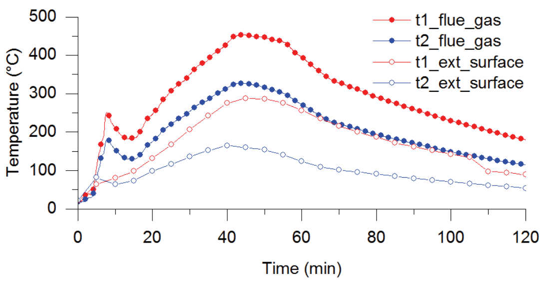


Fig. 7. Temperature variations of the flue gas and external surface of the flue gas – air heat exchanger

Comparing flue gas temperature and temperature of the external surface of chimney, we can observe strong dependence between these measurements values. Temperature of the surface is lower, but can be used to simply estimate the efficiency of the heat exchanger operation. On the other hand, if we analyze temperature distribution on the external surface of the exchanger, we can conclude that its construction isn't optimal. The bottom area (below the air fan) is not effectively cooled – the temperature in this part is about 200°C, while in the central part of the exchanger it is lower than 60°C. Also air outlet located in the upper part of the exchanger should be modified to maximize heat recovery from flue gas (see Fig. 8).

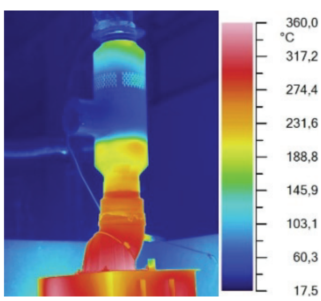


Fig. 8. The analysis of the external surface temperature of flue gas – air heat exchanger

## 3.4. The analysis of the operation of accumulative heat exchanger

The another method of utilization heat from flue gas is using ceramic heat exchanger. Heat produced during wood combustion is stored in the accumulative heat exchanger and dissipated up to 12 hours after the fire has died out. As a result, the thermal efficiency of stove may be increased up to 90% [8]. The operation of the accumulative heat exchanger may be analyzed using e.g. thermal infrared camera. As we can see in Fig. 9, temperature distribution on the external surface of exchanger (measured at a time when average surface temperature was the highest) isn't homogeneous and varies from ~25 to ~65°C. High temperature occurs exactly on a way of flue gas flow and there are some unheated areas. It is a result of a construction parameters of the accumulative exchanger (its geometry) and too low amount of burned fuel.

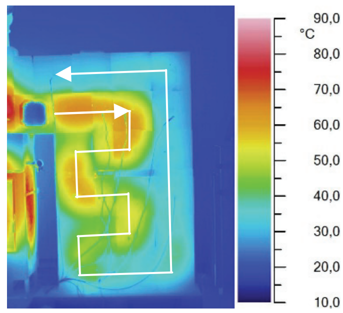


Fig. 9. Temperature distribution on the surface of accumulative heat exchanger

The more detailed description of the temperature variations on the accumulative heat exchanger surface (measured on a way of flue gas flow, which is marked by white line) is presented in Fig. 10. Due to irregular and rough construction of the exchanger's surface, the accurate measurement with the infrared thermal camera is quite difficult.

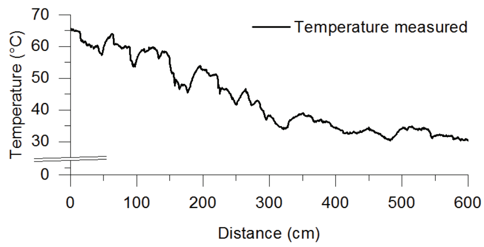


Fig. 10. Flue gas temperature distribution inside the accumulative heat exchanger

The analysis of accumulative heat exchanger surface temperature distribution shows dominant occurrence of temperature in the range from 30 to 40°C. Significantly lower area of exchanger is heated up to 50°C and above temperature. As was stated above, such a situation results e.g. from too low amount of burned fuel.

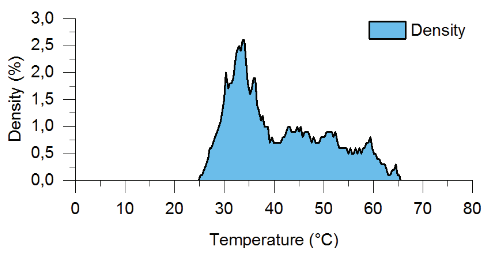


Fig. 11. Temperature distribution on the accumulative heat exchanger surface

## 4. Conclusions

The use of IR thermography allowed to determine and assess the basic operation parameters of plate steel and accumulative wood stoves.

The comparison of temperature distribution on the surface of tested devices shown that the average temperature of the typical plate steel wood stove is 1.5 times higher than average temperature of the plate steel wood stove with accumulation layer and 3 times higher than average temperature of the accumulative wood stove. But, summary, the highest amount of heat was transferred via side walls in a case of accumulative wood stove (14.6 MJ) and the lowest – in case of plate steel wood stove with accumulation layer (7.4 MJ). This information may be helpful to avoid overheating rooms in a case of energy saving and passive houses, as well as to ensure a higher thermal comfort in such objects.

Further analysis shown an operation parameters of typical flue gas – air heat exchanger and accumulative heat exchanger. It was shown that construction parameters of these exchangers have some disadvantages. In the case of the first one exchanger it was stated, that the bottom area (below the air fan) isn't effectively cooled and should be modified to increase heat recovery from flue gas. Also geometry of the accumulative heat exchanger doesn't allow to ensure homogeneous temperature distribution on the whole surface area. On the other hand, in this case a significant impact has too low amount of burning fuel during shown investigation.

In general, this paper confirms the possibility to use of IR thermography to analyze the operation parameters of different parts of wood stoves. This method allows to simplify measurements and gives approximate results in comparison to more detailed tests.

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