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MANAGEMENT OF DOMESTIC HOT WATER SYSTEM BASED ON THE EXAMPLE OF A GAS-FIRED INSTANTANEOUS WATER HEATER

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Purpose: The aim of the study was to present the actual efficiency of a gas-fired instantaneous water heater for the production of domestic hot water.
Design/methodology/approach: The object of the study was a gas-fired instantaneous domestic hot water heater located in a flat in Krakow. Measurements with a suitable device were carried out for three basic variants of hot water preparation, defined as showering, washing hands and washing dishes.
Findings: The tests and analyses carried out have revealed that the current efficiency (average efficiency based on 3 measurements – 77.61%) differs radically from that indicated on the water heater data sheet. Such a drop in efficiency may be caused e.g. by fouling of the surface of the heat exchanger on the flue gas side and scaling of the exchanger on the heated side.
Research limitations/implications: The tests proved that the heater did not reach its nominal efficiency during the tests, but on the other hand, simulations of different intensities and durations of water consumption did not drastically change the efficiency of hot water preparation.
Practical implications: Regular cleaning of the exchanger would probably reduce the difference between the efficiency declared by the manufacturer and the one achieved during the tests. A clean heater will also ensure a sufficiently low level of carbon monoxide in the flue gas, which has a real impact on the safety of the appliance.
Social implications: The values obtained from the measurements for each operating mode can help occupants understand how to prepare water most efficiently with this particular appliance, which will have a real impact on the bills they pay. The user will be provided with information on what percentage of energy they use from the volume of gas burned.
Originality/value: Gas-fired instantaneous water heaters provide an efficient and energy-saving solution, especially in situations where the demand for hot water is low, and immediate access to it is crucial.
Keywords: hot water, hot water management, gas-fired instantaneous water heater.
Category of the paper: Research paper.

1. Introduction

Nowadays, in the face of growing challenges related to energy efficiency and sustainable development, the role of modern technologies in the field of hot water production is becoming crucial. In this context, gas-fired instantaneous water heaters respond to the needs of modern households and enterprises, offering not only an effective but also an economical solution for providing heated water. Gas-fired instantaneous water heaters are devices that warming up domestic water in an on-demand system. They are typically wall-mounted, commonly installed in bathrooms or attics. Their modern versions utilize the energy from condensing water vapor, making them condensing gas water heaters (Danielak, 2018). Gas-fired instantaneous water heaters are among the very popular heating appliances for domestic hot water preparation (Rodrigues, Gomes, 2014; Oleniacz et al., 2016). Just a few years ago it was estimated that there were about 2 million such appliances in operation in Poland. Their long service life is largely due to their short operating time compared with conventional solid fuel boilers. For this reason, many of them are over 20 years old, and the average age for old-type heaters is about 32 years. The average efficiency is estimated at 82%. Improper use, such as neglecting maintenance, leads to significant decreases in the efficiency of the appliances. Such a heater should be inspected and maintained at least annually by an appropriately qualified person. The inspection should be carried out by a person authorised by the manufacturer in order to comply with the terms of the warranty. This is also the way to ensure that appliance maintains its high efficiency for as long as possible and thus does not unnecessarily increase operating costs. In extreme cases, negligence can lead to dangerous situations, such as carbon monoxide poisoning (Czerski et al., 2010). Gas-fired instantaneous water heaters due to their widespread use in households, are the subject of research presented in publications (Czerski et al., 2013; Bourke et al., 2014; Huang et al., 2019; Raluy, Dias, 2020).

When operated properly, instantaneous water heaters can remain highly efficient for many years, and the use of new technologies can reduce carbon monoxide emissions by even several thousand times. Their simple design and small overall dimensions (the size of a small kitchen cupboard) mean that they can be installed in rooms with small floor space. According to the Regulation of the Minister of Infrastructure of April 12, 2002 (Journal of Laws 2022.0.1225, i.e.), the cubic capacity of such a room should be no less than 8 m^3 for appliances with an open combustion chamber and 6.5m^3 for heaters with a closed chamber.

Taking the above into consideration, several issues regarding the use of gas-fired instantaneous water heaters have been presented (Ciepło z natury, 2024):

- Instantaneous water heaters are known for their high energy efficiency. Unlike traditional tank water heaters, they do not store water, eliminating energy losses associated with maintaining water at a constant temperature.

- Gas-fired instantaneous water heaters offer the convenience of accessing hot water at any time. Additionally, they are often equipped with safety systems such as flow sensors and smoke detectors.
- They are typically smaller and lighter than traditional boilers, allowing for space savings in rooms.
- Due to their energy efficiency and the water heating system only operating when needed, instantaneous heaters can contribute to reducing energy bills.
- These devices provide hot water in real-time without the need to wait for it to heat up in a tank.
- Many models of instantaneous water heaters offer the option to adjust the temperature, allowing users to customize it to their individual preferences.
- They can be used both in homes and in workplaces, restaurants, hotels, or industrial facilities where there is a demand for a continuous supply of hot water.
- Compared to some traditional gas boilers, instantaneous water heaters may be more environmentally friendly as they minimize energy losses.

In 2022, anti-smog campaigns in Poland, involving measures like replacing old devices and slowing down new apartment constructions, maintained a dominant position in the device replacement market. Estimates suggest that this market held about 65-70% of the total sales volume, significantly impacting heating device sales (SPIUG, 2023). Gas boilers, despite still being the primary choice and holding slightly over 45% of the market share, experienced a 13% decline due to the uncertainties of 2022. Heat pumps claimed the second spot with an almost 35% share, driven by a nearly twofold increase in sales. Solid fuel boilers, primarily using biomass, ranked third with a share exceeding 15%, indicating a 7% drop compared to the previous year (Figure 1). Manufacturers reported a market slump for these devices in the second half of 2022, possibly reflecting the challenging market situation

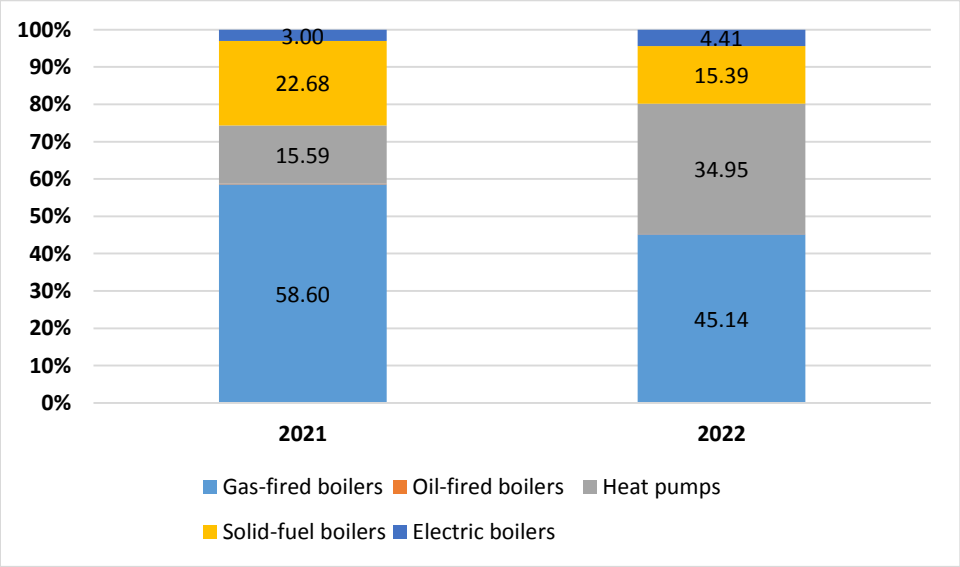


Figure 1. Share each technology in the sales structure of heating appliances in Poland in 2021 and 2022. Source: SPIUG, 2023.

The market for gas-fired instantaneous hot water heaters saw a sudden drop in sales of 32% in 2022 (Figure 2). This confirms earlier observations that this technology for producing domestic hot water is being displaced by other sources of hot water, such as combi boilers (Jedlikowski, Englart, 2018) and heat pumps (Rutkowska et al., 2015; Gużda, Szmolke, 2018; Chudzicki et al., 2019; Lenartowicz, 2020; Panagiotidou et al., 2021; Szczechowiak, 2022; Burzyński, 2023).

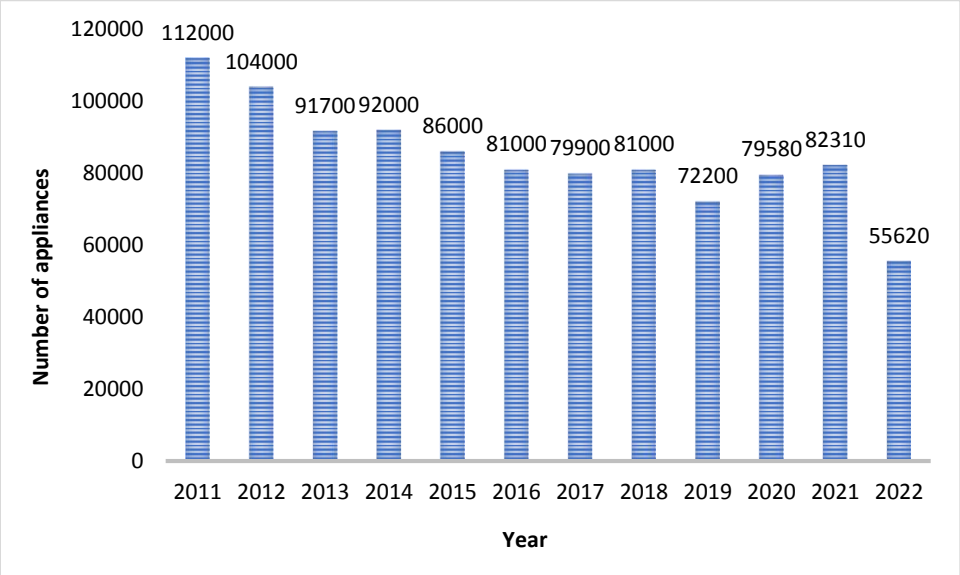


Figure 2. Sales of gas-fired instantaneous hot water heaters 2011-2022.
Source: SPIUG, 2023.

Currently, among all water heaters with a heat pump being produced, there is a growing popularity of models with low heating capacity, small dimensions, and relatively small water tank capacity. The increasing popularity stems from the potential application of these devices in small spaces, such as bathrooms, within residential buildings. Their compact size makes them an attractive option to replace existing gas-fired instantaneous water heaters and electric storage water heaters (Hendiger et al., 2019).

In today's times, the obvious necessity is to heat water for various domestic purposes. Often, residents are not aware of the specific solutions used in their homes; however, the priority is to maintain the appropriate water temperature (Szymański, 2017).

The article presents several interesting facts related to commonly used water heating products. This paper focuses on analyzing the process of managing the production of domestic hot water, citing specific examples and utilizing a gas-fired instantaneous water heater as a model case. This solution represents a new dimension in efficient energy management, eliminating the need to maintain a constant amount of water in the tank and enabling almost instantaneous delivery of hot water when needed.

The purpose of this article is to present the actual efficiency of a gas-fired instantaneous water heater for the production of domestic hot water. The object of the study is a common model of a gas-fired instantaneous water heater located in a flat in Krakow (Termet Ferro Goup,

2024). Measurements with a suitable device were carried out for three basic variants of hot water preparation, defined as showering, washing hands and washing dishes. The results obtained will illustrate under which conditions the water heater operates with the highest efficiency, by how much the efficiency of the appliance has decreased over the years compared with its rated value listed in the data sheet. The values obtained from the measurements for each operating mode can help occupants understand how to prepare water most efficiently with this particular appliance, which will have a real impact on the bills they pay. The user will be provided with information on what percentage of energy they use from the volume of gas burned.

2. General description of the object of the study

2.1. Gas-fired instantaneous water heater

Gas-fired water heaters are typically used in houses and flats that for various reasons do not have hot water supplied from the mains water supply. The commonly used gas-fired water heater is an efficient appliance that allows water to be heated to a temperature selected by the user. Due to the fact that hot water does not appear immediately at the tap, the appliance is only set in operation when the water starts to flow through it. In such a case, it takes a few to several seconds to effectively increase the water temperature. The amount of gas energy that is used depends on the amount of hot water that is needed at a particular time. Simply turning off the tap will automatically turn the appliance off. When the tap is turned on again, the water remaining in the pipes between the heater and the tap will not be heated so it must take a while before the flowing water is heated again (Danielak, 2018).

Gas-fired instantaneous water heaters use natural or liquefied petroleum gas for power. These devices typically have a minimum output of 3 kW and a maximum output of up to 20 kW. The smallest of the heaters typically heat one to two litres of water per minute from a temperature of 10 degrees to 50 degrees Celsius (Podgrzewacze wody, 2023).

2.2. Division of heaters according to type of combustion chamber

Gas-fired instantaneous water heaters can be divided into two types, with either open or closed combustion chamber (Figure 3). They differ in terms of the requirements they must meet to be installed. An open combustion chamber requires a room with at least one external door, or one external window, and a larger room area (Czerski et al., 2013).

Heaters equipped with an open combustion chamber must be connected to a chimney. Heaters with a closed combustion chamber take in the air required for combustion through an air/flue duct which must be routed outside the building. In the same way exhaust fumes are expelled outside (Czerski, Strugała, 2014).

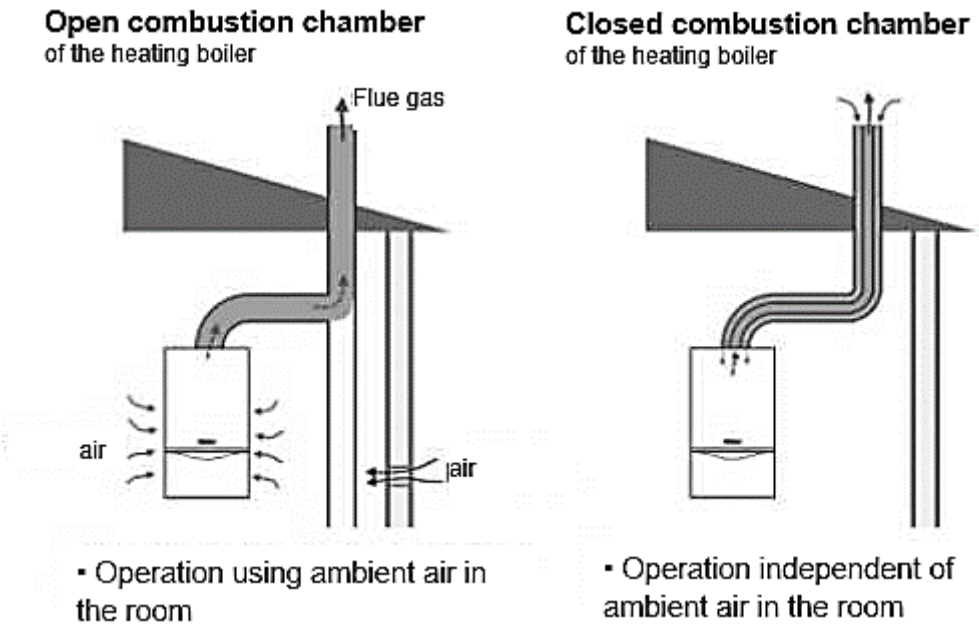


Figure 3. Types of combustion chambers.

Source: Zamknięta komora spalania kotła kondensacyjnego, 2012.

3. Appliances used

3.1. Termaq Electronic G-19-02

The heater manufactured by Termet is characterised by a compact design and an easy to use control panel (Figure 4). Burner power and water flow rate are operated using two knobs. The unit has a copper heat exchanger that ensures a high nominal efficiency of 88%. The thermal power is adjusted depending on the water flow rate, which enables maintaining a constant hot water temperature. Unlike very old heaters, the appliance does not have a pilot light, but electronic battery ignition, which results in annual gas savings of approx. 70 m^3. It is equipped with a number of safety features, including protection against gas outflow, heat exchanger overheating protection and lack of chimney draught protection. The appliance operates evenly and quietly, and thus it could be installed in the kitchen above the sink. It can be supplied with gas type 2 Lw-G27 (natural gas GZ-41.5) or 2 Ls-G2.350 (natural gas GZ-35) (Termet, 2024).

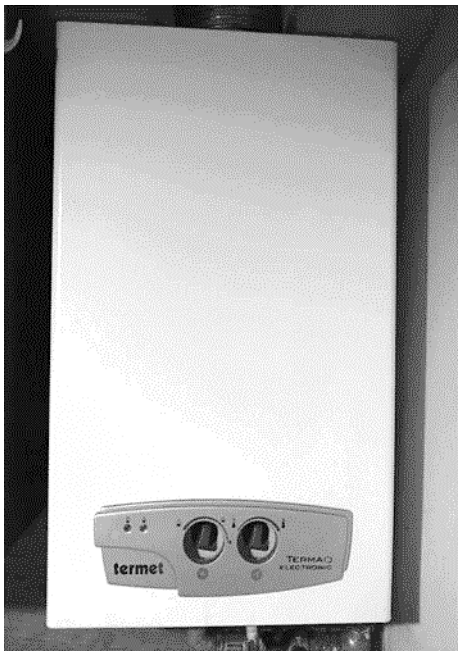


Figure 4. Tested gas-fired heater in an enclosure.

Source: own work.

3.2. Compact heat meter CQM-III-K

The CQM-III-K compact heat meter manufactured by Apator is a device comprising a heat meter, an impeller flow meter and a pair of temperature sensors in a single housing (Figure 5). This version of the device allows it to be installed both at the hot water supply and return. It is mainly intended to measure thermal energy in detached houses, flats and offices. The device is battery-powered and thus independent of the mains supply. It can operate with a heating medium up to a temperature of 90°C and a maximum operating pressure of 16 bars. Compact heat meters are specifically designed for measuring the amount of thermal energy consumed, primarily in single-family houses, as well as in multi-family buildings equipped with a vertical central heating installation (Alsabry et al., 2010).

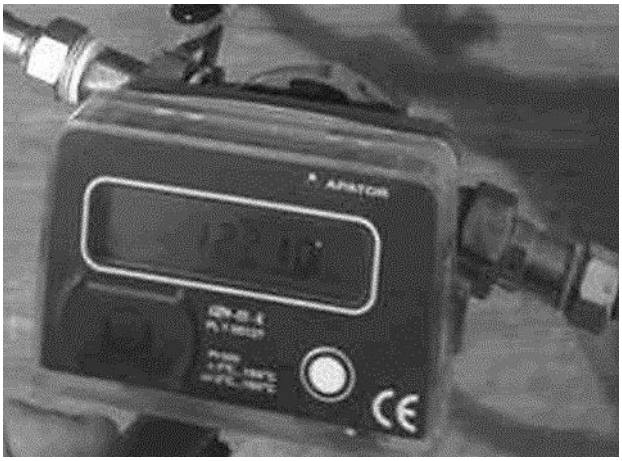


Figure 5. The heat meter used.

Source: own work.

3.3. Residential diaphragm gas meter RF1

This device has been designed to accurately measure the volume of natural gas consumed (Figure 6). It has a measuring unit with a capacity of 2 litres. It is equipped with a twin-chamber displacement diaphragm meter (Serediuk, Warsza, 2017a, 2017b; Pinkas, 2020). Each of the twin chambers is fitted with a flexible and gas-tight diaphragm. When one of the chambers is filled due to the difference in the inlet and outlet pressures, the gas moves into the other opposite chamber through a port on the valve. This reciprocating movement is transmitted to the mechanical index of the gas meter. The measuring unit is housed in a gas-tight casing. The gas meter is resistant to tampering. It is maintenance-free and requires no servicing, and the manufacturer guarantees long-term durability and measurement accuracy. It is so designed as to be suitable for all modern gas systems as well as those to come in the future. Gas meter safety mark – B (Itron, 2024).

Figure 6. Gas meter.
Source: Itron, 2024.

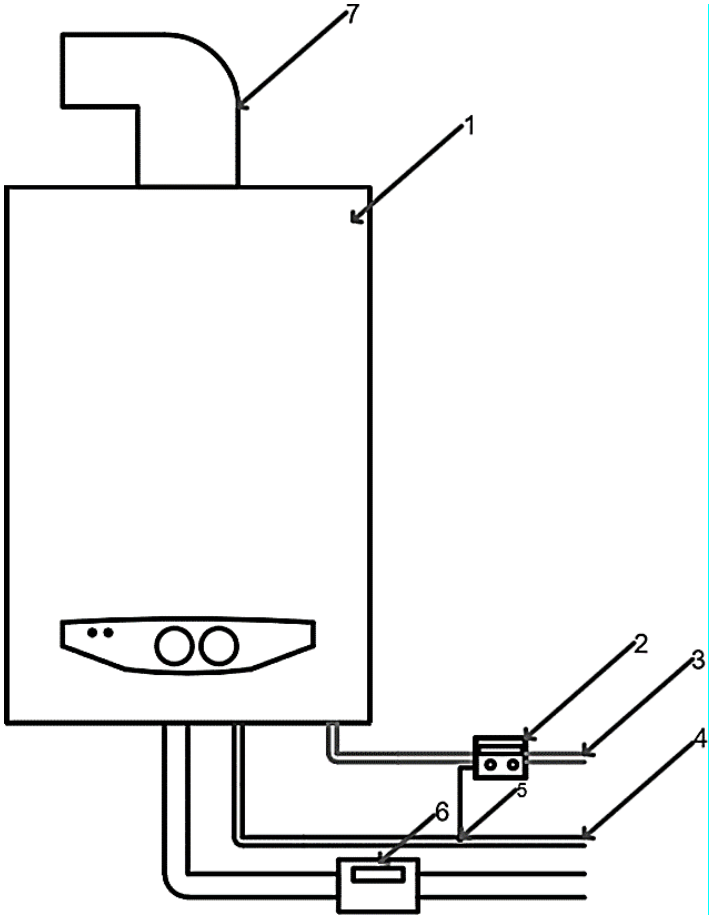
4. Methodology

4.1. Site schematics

Gas-fired instantaneous water heater is a small appliance that can be wall-mounted in order to heat water. The entire process takes place in a small heat exchanger that sits above a gas burner or has heating elements attached. The device is activated when water starts flowing. During the flow, temperature sensors monitor the water temperature at the inlet and outlet of the water heater. This information is crucial for regulating the heating process. Based on the temperature sensor data, the controller adjusts the operation of the gas burner. If the water temperature is below the set value, the burner is activated, supplying heat to the heat exchanger. Subsequently, the water is rapidly heated in the heat exchanger through the action of the burner.

This process is efficient because heat is generated only when water actually flows through the device. As the heating occurs during the water flow, the user has immediate access to hot water without the need to wait for the water to heat up in a tank.

The simplified diagram of the test equipment with necessary devices is presented in Figure 7.



1 – Gas-fired instantaneous water heater TERMAQ ELECTRONIC G-19-02, 2 – Compact heat meter CQM-III-K, 3 – Hot water outlet from the heater, 4 – Cold water inlet to the heater, 5 – Cold water thermometer, 6 – Residential diaphragm gas meter RF1, 7 – Flue gas outlet to chimney.

Figure 7. Simplified diagram of the test equipment.

Source: own work.

The construction of a gas-fired instantaneous water heater involves several key components that enable effective water heating on demand. Below is a general description of the construction of such a device (Figure 8):

- External casing: It serves as the outer protective layer that shields the water heater from atmospheric conditions.
- Sensors: Monitor water temperature and gas pressure to optimize the operation of the heater and ensure safety.
- Water tubes: Water flows through the heater via tubes, which are heated by the heat exchanger.

- Heat exchanger: This is a crucial element of the water heater. It is where the heating gas (such as propane or natural gas) transfers heat to the water flowing through the tubes.
- Gas burner: Responsible for burning the gas, which then transfers heat to the heat exchanger.
- Electronic control unit: Controls the heating process, monitors parameters such as temperature and pressure, and maintains safe operating conditions.
- Safety valves: Integrated safety valves aim to protect the water heater from potential failures, such as overheating or exceeding permissible pressure.
- Control panel: This panel allows the user to control the settings of the heater, such as water temperature.
- Connectors and pipes: Used for the passage of water and gas through the heater.
- Water outlet: Where the user draws heated water.

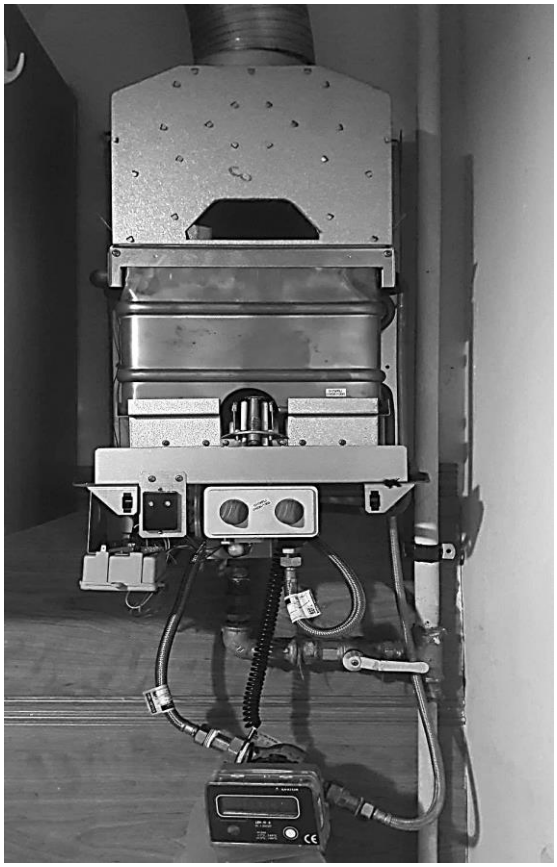


Figure 8. Actual test equipment.

Source: own work.

Before proceeding with the installation or maintenance of a gas-fired instantaneous water heater, it is crucial to strictly follow the manufacturer's instructions. Additionally, installation and servicing should be carried out by a qualified gas technician in accordance with local regulations and safety standards.

4.2. Taking measurements

In order to take the measurements, a compact heat meter had to be installed in the hot water system in the flat. First of all, the main water valve in the flat had to be turned off and likewise the taps had to be turned off to get rid of the remaining water. Then, in order to gain access to the plumbing connections of the water heater, the housing had to be removed. Using an adjustable spanner, a screw was unscrewed at the water heater where the heat meter was installed. A temperature sensor for the heat meter was mounted on the cold water supply to the heater. The use of waterproof sealant paste together with tows ensured that all connections were tight and no water was leaking anywhere, which otherwise might have adversely affected the measurements. Once access was gained to the gas meter, which was located outside the flat in the stairwell, and the main water valve was opened, it was possible to proceed to write down the values obtained for 3 different modes of simulated hot water use:

- Showering (5 minutes).
- Washing hands (repeated 10 times).
- Washing dishes.

After starting the heat meter in the basic operating mode using the function button, the following parameters (current data / instantaneous values) were accessed:

- Heat – [GJ].
- Medium volume – [m^3].
- Supply temperature – [°C].
- Return temperature – [°C].
- temperature differential – [°C].
- Flow rate – [m^3/hr].
- Heating capacity – [kW].

Only in the case of heat values it was necessary to switch the heat meter to the service mode (FL2) in order to write down more recent heat digits after the decimal point. After waiting a few minutes, the heat meter automatically switched back to the basic operating mode (Czerski, Strugała, 2014, pp. 2394-2411).

5. Results

Measurements conducted using a compact heat meter and a gas meter for a gas-fired instantaneous water heater constitute a crucial aspect in evaluating the efficiency and energy consumption in water heating systems. The compact heat meter is a dedicated device designed for the precise measurement of the amount of thermal energy transferred during the water

heating process. In turn, the gas meter is utilized to monitor the consumption of gas, which serves as the fuel for heating in the case of gas-fired instantaneous water heaters.

Table 1 shows all the data obtained by using the compact heat meter and the gas meter. These results were used to perform the calculations presented in the following tables.

Table 1.
Values obtained - heat meter readings

Parameters	Domestic activities		Showering (5 min)	Washing hands (10 repeats)	Washing dishes
	Unit	Stage	Value		
Gas meter reading	[m^3]	Initial	944.379	944.5	944.543
		Final	944.5	944.543	944.598
Heat	[GJ]	Initial	12.2169195	12.2202413	12.2214091
		Final	12.2202413	12.2214091	12.2228876
Water consumption	[m^3]	Initial	308.381	308.416	308.431
		Final	308.416	308.431	308.446
Hot water T1	[°C]		35.39	32.57	36.53
Cold water T2	[°C]		12.35	12.89	13.01
Temperature differential Δ T	[°C]		22.89	24.95	23.8
Heating capacity	[kW]		11.03	6.43	9.71
Flow	[m^3/hr]		0.418	0.241	0.364

Source: own work.

Table 2 shows the gas consumption as a result of heating water for various domestic activities.

Table 2.
Gas consumption for each measurement

Amount of gas consumed	Unit	Showering (5 min)	Washing hands (10 repeats)	Washing dishes
	[m^3]	0.1209	0.0430	0.0549

Source: own work.

Table 3 shows the amount of heat supplied to the water by the water heater. It is illustrated by the difference in the heat meter reading before and after the measurement for each simulation. The results were then converted into MJ.

Table 3.
Amount of heat supplied

Heat	Unit	Showering (5 min)	Washing hands (10 repeats)	Washing dishes
	[MJ]	3.3218	1.1678	1.4784

Source: own work.

The amount of water consumed is shown in Table 4. The result obtained in cubic metres was converted into litres.

Table 4.
Water consumption

Water consumed	Unit	Showering (5 min)	Washing hands (10 repeats)	Washing dishes
	[l]	35	14.99	15.0

Source: own work.

The efficiency of the heater was calculated as the ratio of energy converted to energy supplied using the following formula:

$$\eta = \frac{E_{wy}}{E_{we}} \tag{1}$$

where:

η – efficiency;

E_{wy} – energy converted;

E_{we} – energy supplied.

For the purpose of the calculations, the values for type E methane-rich natural gas (formerly GZ-50) were adopted; according to the tariff, the actual calorific value is approx. 35 MJ/m^3 (Czerski, Gebhardt, Strugala, Butrymowicz, 2013, pp. 237-244). The values were then standardised to kilowatt-hours (35 MJ = 9.7222 kWh).

Table 5 shows calculations of the actual efficiency for each of the three simulations.

Table 5.
Efficiency calculated

Parameters	Unit	Showering (5 min)	Washing hands (10 repeats)	Washing dishes
MJ in the volume of gas consumed	[MJ]	4.2349	1.5050	1.9249
Kilowatt-hours in the volume of gas consumed	[kWh]	1.1763	0.4180	0.5347
Energy transferred to water	[kWh]	0.9227	0.3243	0.4106
Efficiency	[%]	78.44	77.59	76.81

Source: own work.

The difference between these three domestic activities is approx. 1%. The highest efficiency was obtained for five-minute showering – 78.44%. Next in order was the efficiency obtained for hand washing – 77.59%. The lowest efficiency was obtained for the dishwashing simulation – 76.81%. It should be noted that all the activities were performed by the occupant of the flat in the same manner as they do them on a daily basis.

6. Summary

The tests and analyses carried out have revealed that the current efficiency differs radically from that indicated on the water heater data sheet. Such a drop in efficiency may be caused e.g. by fouling of the surface of the heat exchanger on the flue gas side and scaling of the exchanger on the heated side. Regular cleaning of the exchanger would probably reduce the

difference between the efficiency declared by the manufacturer and the one achieved during the tests (average efficiency based on 3 measurements – 77.61%). A clean heater will also ensure a sufficiently low level of carbon monoxide in the flue gas, which has a real impact on the safety of the appliance.

As expected, the heater achieved its highest efficiency during a five-minute water consumption simulating the use of a shower. This is when the appliance heats the water steadily, thus operating at its highest power and efficiency. In comparison with the other measurements, it can be concluded that this water heater achieves the highest efficiency at the highest water flow rate and high heating power.

A simulation of water consumption for hand-washing showed that such short but intensive hot water consumption does not significantly reduce the efficiency of the instantaneous water heater. Compared with the simulation of water consumption for dishwashing (a small amount of hot water consumed for a few minutes), the efficiency of hot water heating in the handwashing simulation was almost 1% higher.

The tests proved that the heater did not reach its nominal efficiency during the tests, but on the other hand, simulations of different intensities and durations of water consumption did not drastically change the efficiency of hot water preparation.

According to the measurements, the way in which the water heater is operated does not significantly affect the efficiency values that were obtained. Regular maintenance and keeping the hot water heater in good working order will keep the efficiency high for many years.

The market for gas tankless water heaters experienced declines in all quarters of 2022. It appears that this technology for producing domestic hot water is being displaced by alternative sources for DHW (domestic hot water) generation. Currently, such devices are no longer installed in newly constructed buildings and persist mainly due to replacements in the existing market.

Acknowledgements

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