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Analyzing the environmental effects of conventional and condensing combi boilers using natural gas

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Analyzing the Environmental Effects of Conventional and Condensing Combi Boilers Using Natural Gas

Highlights

- *Investigating the environmental effects of conventional and condensing combi boilers.*
- *Analyzing different type combi boilers using natural gas.*
- *The experimental results showed the positive effects of using condensing combi boiler.*
- *CO_2, NO and NO_x emissions significantly reduced by utilizing condensing type combi boiler.*

Graphical Abstract

In this study the effects of combi boiler type on pollutant gas emissions have been experimentally analyzed.

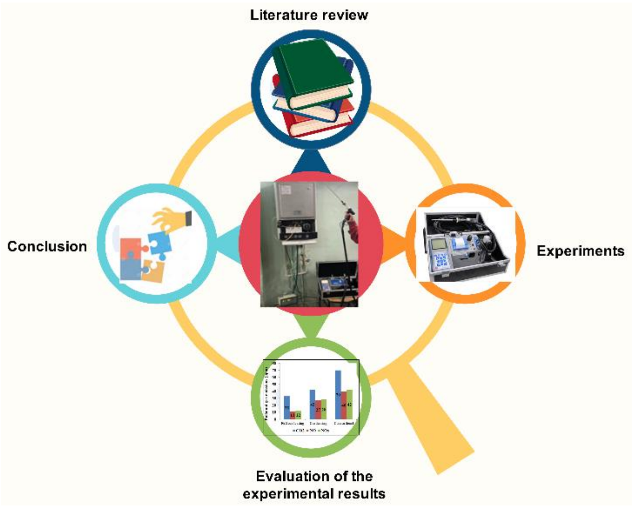

Figure. Main steps of the present work

Aim

The main aim of this study is analyzing the effects of combi boiler type on pollutant gas emissions.

Design & Methodology

In this work, three various combi boilers including conventional, condensing and full condensing type combi boilers have been experimentally tested to determine their environmental effects.

Originality

There is no study in the literature which compares different combi boilers pollutant gas emissions.

Findings

It can be stated that utilizing condensing and full condensing combi boilers can be reduced pollutant gas emissions in comparison to conventional type.

Conclusion

This study showed that condensing and full condensing combi boilers can be more effective in comparison with conventional type, both in energy saving and environmentally friendly aspects.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Analyzing the Environmental Effects of Conventional and Condensing Combi Boilers Using Natural Gas

Araştırma Makalesi / Research Article

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ABSTRACT

Generally, space heating and hot water providing are done by combi boilers. Different types of combi boilers are available. In the recent years condensing combi boilers have been introduced that have high energy efficiency in comparison with conventional types. In the condensing type combi boilers, an additional heat exchanger is utilized to recover energy form flue gas. In this study the effects of combi boiler type on pollutant gas emissions have been experimentally analyzed. In this regard three different combi boiler including conventional, condensing and full condensing type combi boilers have been selected in the experiments. In addition, the experiments have been done in different temperatures to investigate the temperature effect. The obtained results showed that in all temperatures using condensing and full condensing combi boilers reduced CO_2, NO and NO_x gas emissions considerably. Also, by analyzing combi boilers emissions in different working temperatures, it can be said that in low temperatures CO_2 emission reduction in condensing combi is higher than its reduction in high temperatures in comparison with conventional one.

Keywords: Combi boiler, heat recovery, condensing, natural gas, pollutants gas emissions.

1. INTRODUCTION

Global energy demand increases day by day with increasing world population. Therefore, renewable and alternative energy resources and also efficient energy systems gain importance not only because of limited fossil resources, but also because of pollutant gas emissions. Approximately 40% of annual energy consumption is used in residential buildings and a major part of energy is used for space heating and hot water providing in buildings [1, 2]. Generally hot water and space heating in buildings are supplied by combi boilers. Different types of combi boilers are available. But in the recent years condensing combi boilers have been introduced which have high energy efficiency in comparison with conventional types.

Combi boilers and domestic heating systems have been investigated in different studies in various point of view [3,4]. In the literature different methods were used to enhance the thermal performance of energy systems like combi boilers. Some researcher used nanofluid to improve thermal efficiency of energy systems like combi boilers and heat pipes [5-8]. Also, some researchers used turbulator in the heat exchanger with the aim of increasing thermal efficiency [9]. In addition, some researchers investigated environmental effects of combi boilers. Vignali (2017) studied the environmental effects of two various combi boilers in 3 different climatic regions of Italy. The obtained results indicated that condensing combi boiler has 23% lower environmental impact in comparison with traditional one [10]. Haichao et al. (2013) investigated environmental impact of combined district heating system. They developed a model to analyze the pollutant emissions of heating systems. Their results illustrated the potential of combined systems to reduce CO_2 emission [11]. Aste et al. (2013) investigated environmental and energy impact of domestic heating from 1999 to 2010 in Italy in terms of NOx emissions. They indicated that by using new boiler technologies energy saving and pollutant emissions reduction can be achieved [12]. In another study, Comaklı (2008) evaluated economic cost and energy efficiency of condensing and conventional combi boilers. They reported that condensing combi boiler could provide fuel saving by 8% in comparison with conventional type combi boiler [13]. Atmaca et al. (2015) studied transient behavior of two various combi boiler for providing hot water. Their findings indicated that condensing combi boiler have priority in terms of high efficiency and comfort [14]. Weiss et al. (2009) analyzed market diffusion and cost-benefit of condensing type combi boilers in the Netherlands and exhibited energy saving potential and gas emissions reduction by utilizing this type combi boilers [15]. Bălănescu & Homutescu (2018) experimentally investigated the performance of condensing boiler and stated that maximum fuel savings of 17.5% can be achieved in comparison with conventional boiler [16].

The main aim of this study is analyzing the effects of combi boiler type on pollutant gas emissions. In this regard three various combi boiler including conventional, condensing and full condensing type combi boilers have been selected in the experiments. Also, the experiments have been performed in different hot water outlet temperatures to investigate the temperature effect.

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2. EXPERIMENTAL SETUP & PROCEDURE

This study investigates the effects of combi boiler type on pollutant gas emissions including CO_2, NO and NO_x. In this regard, three various combi boilers including; conventional combi boiler, condensing combi boiler and full condensing combi boiler produced by Buderus company have been used in the experiments. All of the selected combi boilers are used for space and water heating. To be able to compare the experimental results all selected combi boilers have the same heating capacity (24 kW) and can run on natural gas and liquefied petroleum gas (LPG). The main components of used combi boilers are given in Fig. 1-3. The first combi boiler (Fig. 1) is a conventional type that generally is used for domestic heating and hot water providing. The second one (Fig. 2) is condensing combi boiler which recovers thermal energy from combustion gases. In conventional combi boilers combustion gases discharged from combi and a big part of energy is wasted. But in condensing type combi boilers a further heat exchanger is used to recover energy form combustion gases. The working principle of full condensing combi boiler (Fig. 3) is similar to condensing boiler working principle. Available latent and sensible heat in combustion gases recovered in full condensing combi boiler like condensing combi boiler. But, in full condensing combi boilers condensation occur

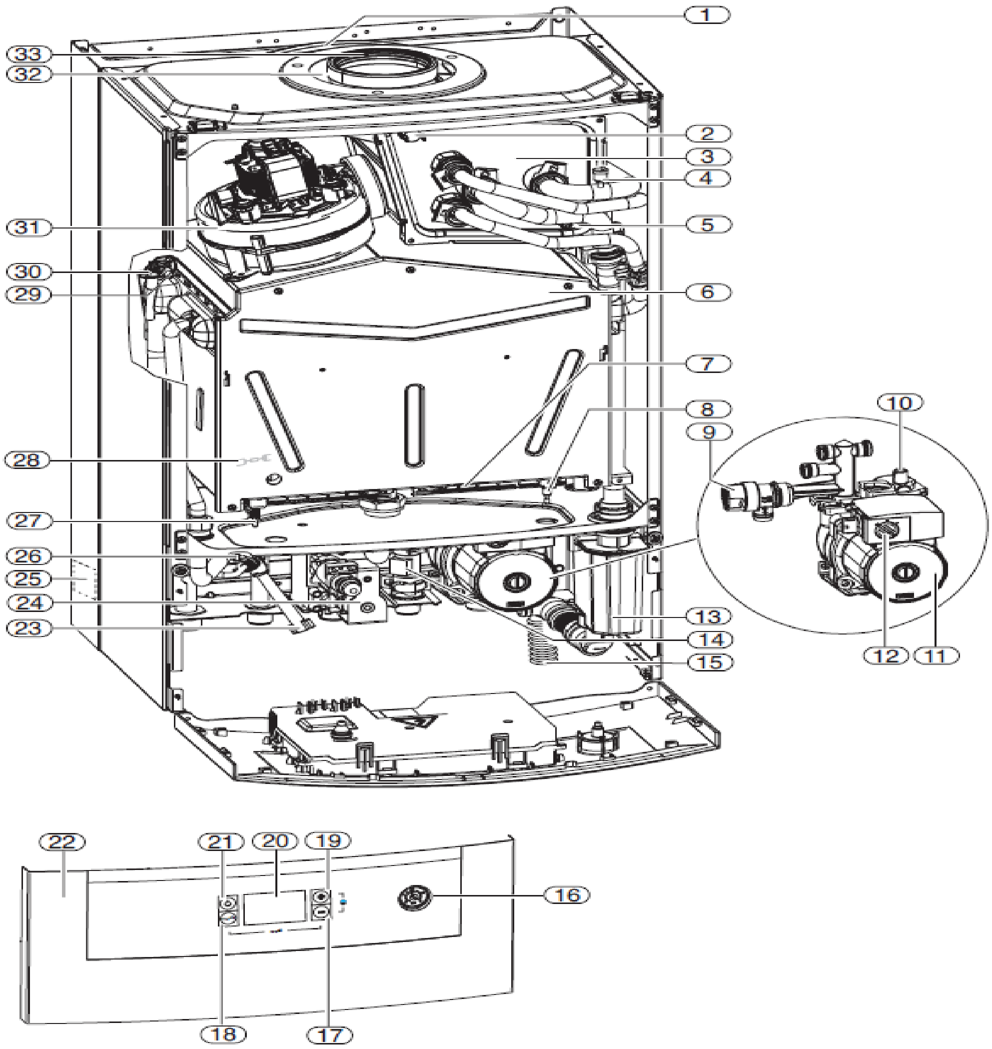


Figure 1. Conventional combi boiler components [17]; 1. Expansion vessel 2. Fan, 3. Combustion chamber, 4. Burner, 5. Ignition electrode, 6. Safety valve, 7. Inlet air vent, 8. Circulation pump, 9. Pump speed switch, 10. Gas armature, 11. Pressure gauge, 12. Control panel, 13. System filling device, 14. Plate heat exchanger, 15. Type label, 16. Pressure controller, 17. Detection electrode, 18. Water temperature sensor, 19. Safety thermostat, 20. Draught diverter, 21. Differential pressure switch, 22. Combustion air intake, 23. Exhaust gas outlet, 24. Temperature sensor, 25. Safety valve, 26. Flowmeter

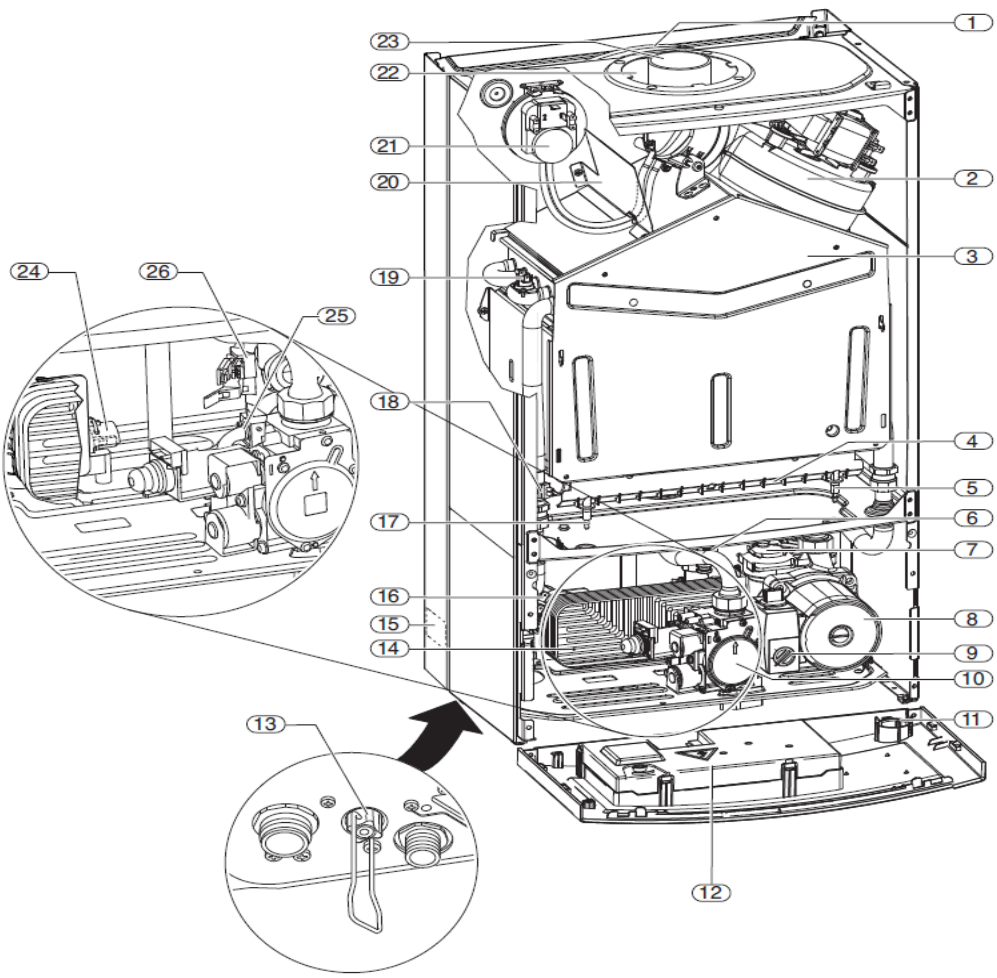


Figure 2. Condensing combi boiler [17];1. Expansion vessel, 2. Waste gas temperature controller, 3. Heat exchanger, 4. Manual air vent, 5. Condensate sensor, 6. Combustion chamber, 7. Burner, 8. Electrodes, 9. Safety valve, 10. Automatic air blower, 11. Circulation pump, 12. Pump speed variator, 13. Condensate trap, 14. Flowmeter, 15. Condensate discharge, 16. Pressure gauge, 17. Control key, 18. Mode, 19. Control key, 20. Display, 21. Stand-by mode, 22. Front panel, 23. System filling device, 24. Gas valve, 25. Control lid, 26. Temperature sensor, 27. Ignition electrode, 28. Combustion chamber, 29. Temperature sensor, 30. Temperature controller, 31. Fan, 32. Combustion air intake, 33. Waste gas duct

in the combustion chamber. This procedure leads to increase in combi boiler thermal performance.

To analyze combi boilers gas emission, ECOM J2KN emissions analyzer has been used and the amount of CO_2, NO and NO_x gases has been determined. ECOM J2KN emissions analyzer is shown in Fig. 4. Also, technical properties of ECOM J2KN gas analyzer are given in Table 1.

The experiments have been performed in 5 different hot water outlet temperature. In other words, when the temperature of the hot water outlet reached to the set temperature the data recorded. Hot water temperature was set to 40°C, 45°C, 50°C, 55°C and 60°C and each experiment repeated three time to obtain more reliable data. Fig. 5 shows gas emission analyzing in combi boiler using ECOM J2KN emissions analyzer.

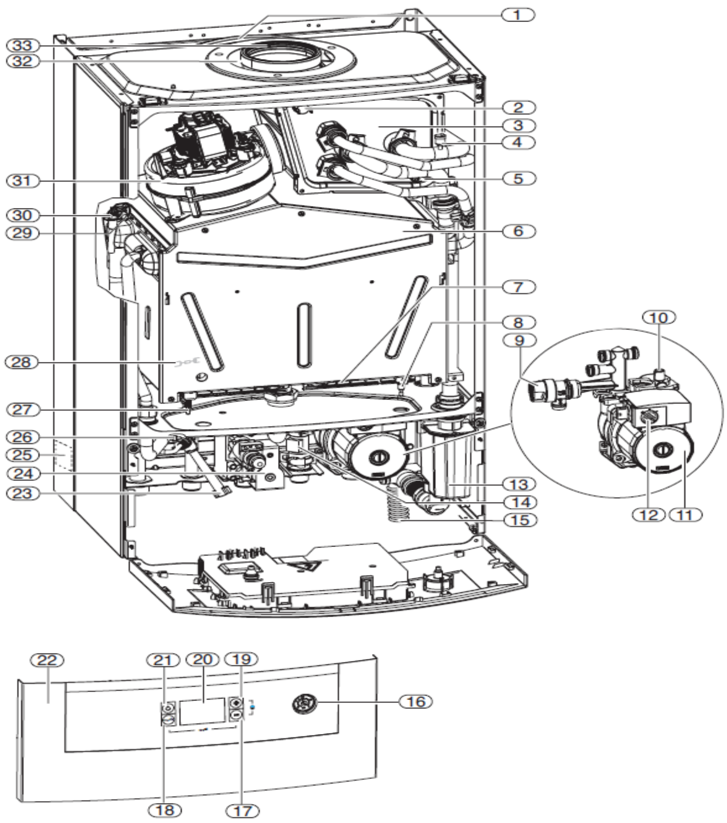


Figure. 3. Full condensing combi boiler [17]; 1. System filling device, 2. Temperature sensor, 3. Condensate drain, 4. Plate heat exchanger, 5. Waste gas temperature controller, 6. Gas pressure controller, 7. Maximum gas regulator, 8. Minimum gas regulator, 9. Expansion vessel, 10. Nitrogen filling valve, 11. Gas pipe, 12. Heating circuit outlet line, 13. Suction pipe, 14. Temperature sensor, 15. Inlet air vent, 16. Igniter, 17. Waste gas duct, 18. Combustion air intake, 19. Control lid, 20. Differential pressure switch, 21. Fan, 22. Waste gas backflow mixing unit, 23. Electrode Set, 24. Safety thermostat, 25. Heat block, 26. Condensate trap, 27. Control lid, 28. 3-way valve, 29. Type label, 30. Circulation pump, 31. Safety valve, 32. Flowmeter, 33. Filling and drain tap, 34. Control panel, 35. Pressure gauge

Figure 4. ECOM J2KN emissions analyzer

Table 1. Technical properties of ECOM J2KN gas analyzer

MEASUREMENT (KEY)	RANGE	ACCURACY	RESOLUTION
Oxygen (O)	0-21% vol.	± 2% Measured	0.1% vol.
Carbon Monoxide (C)	0-4,000 ppm	± 2% Measured	1 ppm
Carbon Monoxide (V)	0-40,000 ppm	± 2% Measured	1 ppm
Nitric Oxide (N)	0-4,000 ppm	± 2% Measured	1 ppm
Nitric Oxide (.N)	0-400 ppm	± 2% Measured	0.1 ppm
Nitrogen Dioxide (X)	0-500 ppm	± 2% Measured	1 ppm
Nitrogen Dioxide (.X)	0-50 ppm	± 2% Measured	0.1 ppm
Sulfur Dioxide (S)	0-5,000 ppm	± 2% Measured	1 ppm
Combustibles (H)	0-6.00 % vol.	± 2% Measured	0.01% vol
Gas Temperature	32-1800 F	± 2% Measured	1 deg F
Ambient Temperature	0-250 F	± 2% Measured	1 deg F
Draft / Pressure	± 40" H_2O	± 2% Measured	0.1% H_2O
O_2 Correction	0-20% Oxygen		
Smoke Scale	0-9		
Carbon Dioxide CO_2	0-CO_2 max of fuel	Calculated	
Efficiency	0-99.9%	Calculated	
Excess Air (Lambda)	1-infinity	Calculated	

Figure 5. Analyzing gas emissions in combi boiler by ECOM J2KN analyzer

3. RESULTS

In this section the experimental results are given and the effects of combi boiler type on pollutant gas emission are concluded. The effects of condensing type combi boiler on energy saving is obvious. But at the same time the environmental effect of combi boilers is important. Pollutant gas emissions like CO_2, NO and NO_x cause to global warming and acid rain. The main objective of these experiments is to clarify the amount of CO_2, NO and NO_x pollutant gases in the flue gas of different combi boilers. In addition, pollutant gas emissions for different hot water outlet temperatures have been analyzed. In other words, hot water outlet of the combi boiler has been adjusted in different temperature values and the amount of gas emissions related to each temperature has been measured.

Pollutant gas emissions for 40°C outlet hot water in different combi boilers is given in Fig. 6a. In the figure the amount CO_2, NO and NO_x gases in the flue gas are presented. As it can be seen in Fig. 6a full condensing combi boiler has the lowest amount of pollutant gas emissions and the conventional combi boiler has the highest amount of pollutant gas emissions. In addition, utilizing full condensing combi boiler led to reduction in CO_2, NO and NO_x emissions by 74%, 75% and 75% respectively in comparison to conventional combi boiler.

Flue gas temperature for 40°C outlet hot water in different combi boilers is given in Fig. 6b. Flue gas in the conventional combi boiler has the highest temperature value and in full condensing combi boiler has the lowest temperature value. In the condensing combi boiler, an extra heat exchanger was added to the system to recover the available latent and sensible heat in the flue gas. The result of recovering available heat in the flue gas led to reduction in the exit flue gas form the combi boiler. Full condensing combi boiler has the lower flue gas temperature in comparison to the condensing combi boiler because condensing phenomena occur in the combustion chamber. Simultaneous realization of combustion processes and condensation in the combustion chamber cause to more reduction in flue gas temperature and increase in combi boiler thermal performance. Consequently, low energy needed to obtain the same heating performance by using condensing technology.

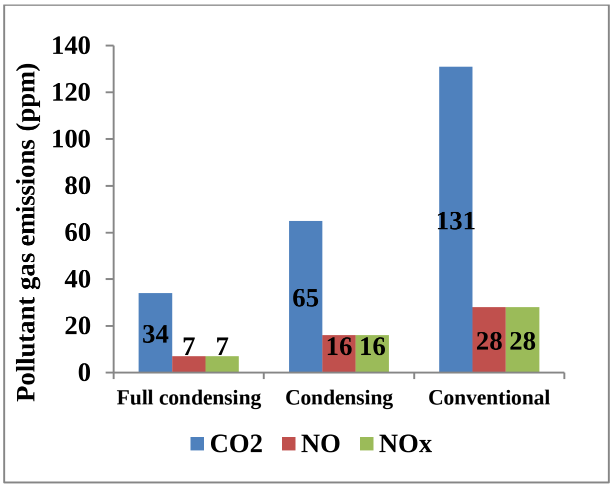
Fig. 7a shows pollutant gas emissions for 45°C outlet hot water in different combi boilers. The amount of CO_2, NO and NO_x emissions in the flue gas reduced in full condensing combi as 76%, 68.5% and 68.4%, respectively, in comparison to conventional combi boiler. Also, Fig. 7b shows flue gas temperature for 45°C outlet hot water for three combi boilers. As it can be seen flue gas temperature in full condensing boiler reduced as 46,5% in comparison with conventional combi boiler.

Pollutant gas emissions for 50°C outlet hot water in three various combi boilers is given in Fig. 8a. The same trend for pollutant gas emission is seen in 50°C. The amount of CO_2, NO and NO_x emissions in the flue gas decreased as 52.8%, 72.5% and 71.4%, respectively, in full condensing combi in comparison to conventional type boiler. Also, flue gas temperature for 50°C outlet hot water is given in Fig. 8b. Flue gas temperature in full condensing boiler reduced as 45% in comparison with conventional combi boiler.

In the Fig. 9a pollutant gas emissions for 55°C outlet hot water in three various combi boilers is presented. The amount of CO_2, NO and NO_x emissions in the flue gas decreased as 41.5%, 72.1% and 71.2%, respectively, in full condensing combi in comparison to conventional type boiler. Also, flue gas temperature reduced as 44% in comparison with conventional combi boiler (Fig. 9b).

Finally, pollutant gas emissions for 60°C outlet hot water in three various combi boilers is presented in Fig. 10a. The amount of CO_2, NO and NO_x emissions in the flue gas decreased as 23.7%, 70.4% and 69.5%, respectively, in full condensing combi in comparison to conventional type boiler. Also, flue gas temperature for 60°C outlet hot water is shown in Fig. 10b. As it can be seen flue gas temperature reduced as 44.5% in comparison with conventional combi boiler.

In this study pollutant gas emissions of three various combi boilers have been analyzed in different hot water temperatures (40-60°C). Generally, it can be stated that utilizing condensing and full condensing combi boilers can be reduce pollutant gas emissions in comparison to conventional type. By analyzing these combi boilers' emissions in different working temperatures, it can be said that in low temperatures CO_2 emission reduction in condensing combi is higher than its reduction in high temperatures. The desired temperature of the domestic hot water supply is between 40-45°C and the combi boilers usually are used in this temperature range. Therefore, condensing and full condensing combi boilers can be more effective in comparison with conventional type, both in energy saving and environmentally friendly aspects.



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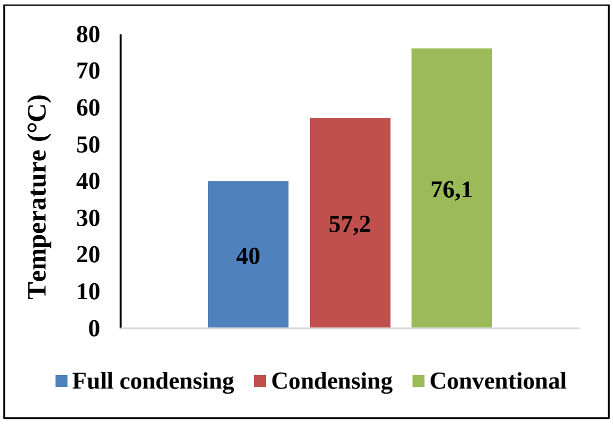
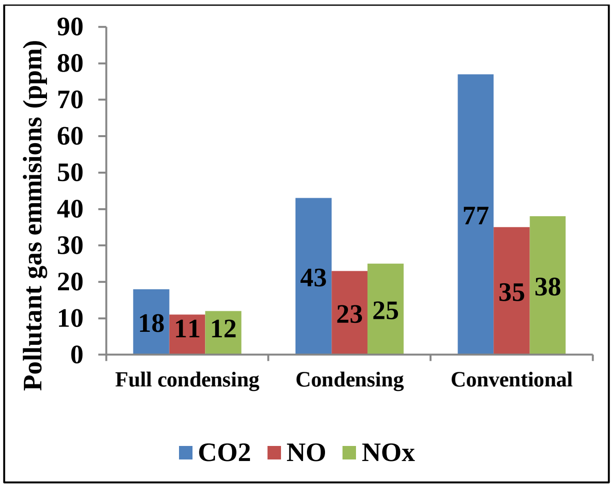


(b)

Figure 6. a) Pollutant gas emissions for 40°C outlet hot water, b) Flue gas temperature for 40°C outlet hot water.



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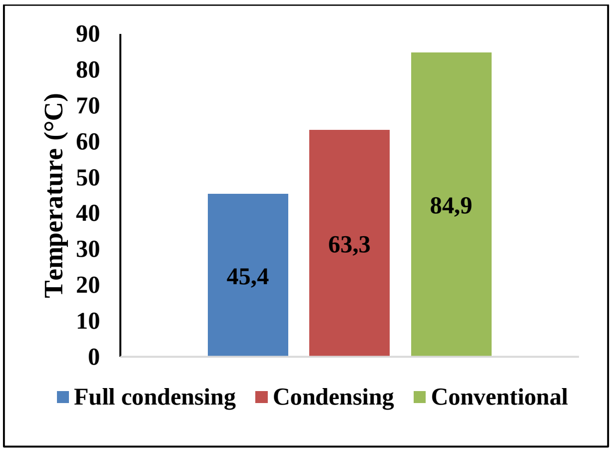
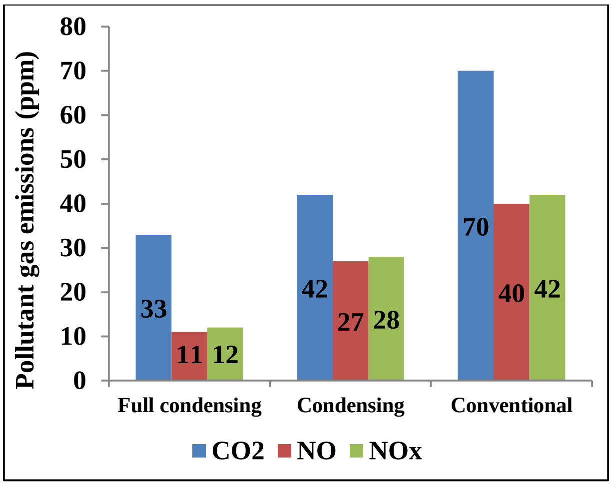


(b)

Figure 7. a) Pollutant gas emissions for 45°C outlet hot water, b) Flue gas temperature for 45°C outlet hot water.



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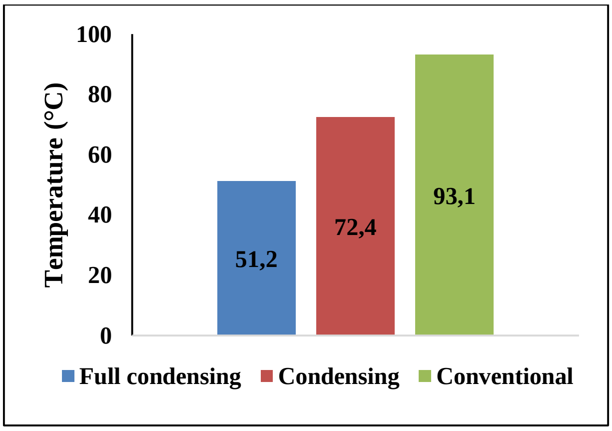
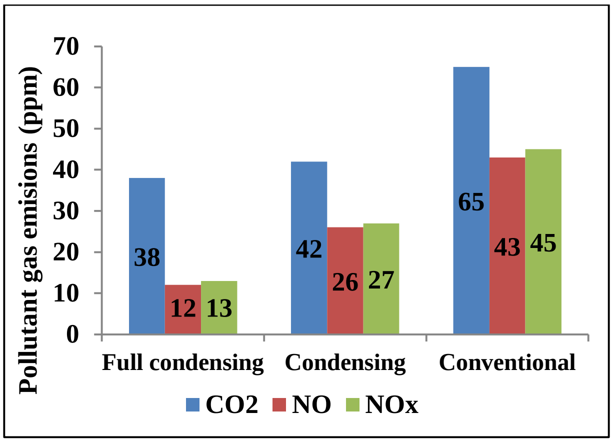


(b)

Figure 8. a) Pollutant gas emissions for 50°C outlet hot water, b) Flue gas temperature for 50°C outlet hot water.



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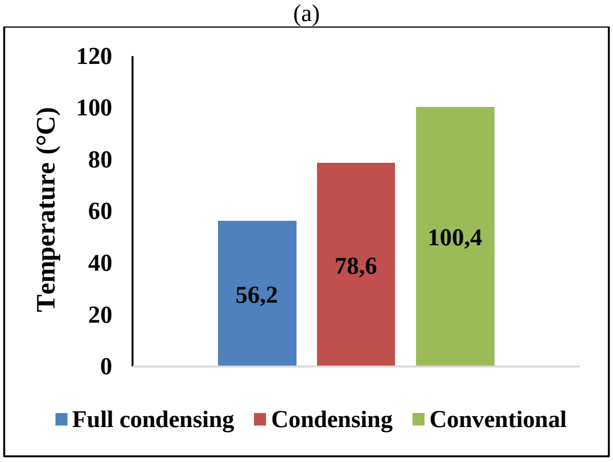
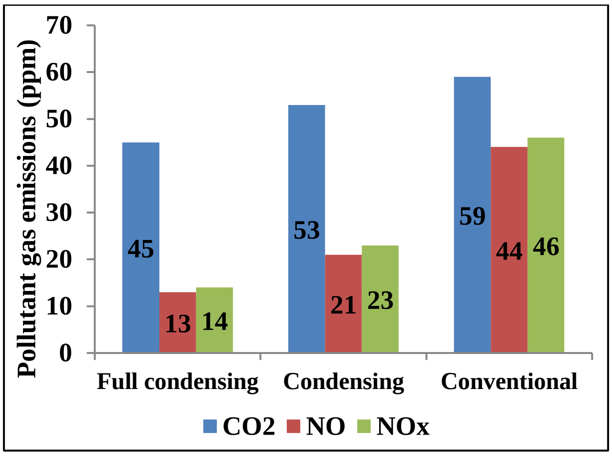


(b)

Figure 9. a) Pollutant gas emissions for 55°C outlet hot water, b) Flue gas temperature for 55°C outlet hot water.



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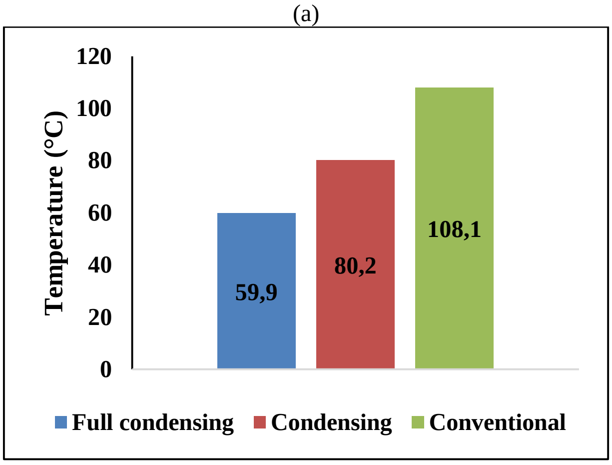

(b)

Figure 10. a) Pollutant gas emission for 60°C outlet hot water, b) Flue gas temperature for 60°C outlet hot water.

4. CONCLUSION

In the present study the effects of combi boiler type on pollutant gas emissions have been investigated. In this regard three different combi boiler including conventional, condensing and full condensing type combi boilers have been selected in the experiments. The measurements have been performed in different hot water outlet temperatures to show the effect of temperature. Generally, it can be stated that utilizing condensing and full condensing combi boilers can be reduce pollutant gas emissions in comparison to conventional type. Also, by analyzing these combi boilers emissions in different working temperatures, it can be said that in low temperatures CO_2 emission reduction in condensing combi is higher than its reduction in high temperatures.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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