KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

DEPARTMENT OF PRODUCTION ENGINEERING

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ANALYSIS OF SOLID FUEL BOILER DESIGN FOR PERFORMANCE COEFFICIENT IMPROVEMENT

Final project for Master degree

Academic supervisor:

Assoc. Prof. Dr. M. Rimašauskas

Kaunas, 2015

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Prepared by Stud. Vitalijus Grižauskas, MEM 3/9 ______________ ______________

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KAUNAS, 2015

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Analysis of solid fuel boiler design for performance coefficient improvement

DECLARATION OF ACADEMIC HONESTY

29 May 2015

Kaunas

I confirm that a final project by me, **Vitalijus Grižauskas**, on the subject "Analysis of solid fuel boiler design for performance coefficient improvement" is written completely by myself; all provided data and research results are correct and obtained honestly. None of the parts of this thesis have been plagiarized from any printed or Internet sources, all direct and indirect quotations from other resources are indicated in literature references. No monetary amounts not provided for by law have been paid to anyone for this thesis.

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Grižauskas, V. Kieto kuro katilo konstrukcijos analizė naudingumo koeficiento gerinimui. Magistrantūros studijų baigiamojo darbo vadovas Assoc. Prof. Dr. Marius Rimašauskas; Kauno Technologijos Universitetas, mechanikos inžinerijos ir dizaino fakultetas, gamybos inžinerijos katedra.

Kaunas, 2015. 53 p.

SANTRAUKA

Įvadiniame magistro darbo skyriuje pateiktas temos aktualumas, darbo tikslas (lengvai naudojamo 3D katilo modelio sukūrimas ir testavimas.

Pirmajame skyriuje išnagrinėti pramoninių katilų variantai bei jų panaudojimo būdai kasdieniniame gyvenime, darbo principas ir pateikti keli aspektai susieję su katilo saugumu.

Antrajame skyriuje aprašomi katilo efektyvumo principai ir pateiktos esamo tiriamo gaminio technines charakteristikos kartu su katilo pajungimo schema ir jos veikimo principu. Malkomis kūrenamas kietojo kuro vandens šildymo katilas skirtas įvairios paskirties pastatų, su uždara šildymo sistema, šildymui ir karšto vandens ruošimui

Trečiame ir ketvirtame skyriuose pateikti naujajam katilo modeliui visi siūlomi atnaujinimai su 3D CAD vaizdais, bei katilo atliktųjų testų naudingumo koeficiento ir kiti reikalaujamų bandymų parametrai. Katilas buvo išbandytas pagal LST EN 303-5 standarte nurodytus bandymų metodus padedantis nustatyti katilo šiluminė galia bei padės išaiškinti degimo produktų CO,CO2 koncentracijas.

Penktąjį skyrių sudaro abiejų katilų išlaidu sąrašai kurie parado ant kiek skiriasi senojo bei naujojo katilų išlaidu elementai, pridėtine verte it gamykline savikaina.

Išvadose apibendrinami pasiekti rezultatai ir gauta informacija apie naująjį katilo B-25E modelio eksploatacinės savybes .

Grižauskas, V. Analysis of solid fuel boiler design for performance coefficient improvement. Master degree final project supervisor Assoc. Prof. Dr. Marius Rimašauskas; Kaunas University of Technology, faculty of Mechanical Engineering and Design, Department of Production Engineering.

Kaunas, 2015. 53 p.

SUMMARY

In the introductory chapter of the master work the importance of the theme is presented as well as the aim of the work (development of 3D CAD model of the boiler and its testing)

The first chapter industrial boiler types are presented and their use in everyday life, their work principal and a few aspects considering safety issues.

The second chapter shows the boiler efficiency principals are shown as well as the technical characteristics of the experiment boiler version is presented along with the heating system and the work principle of a heating boiler fired with wood logs designed for heating various premises with closed heating systems and for production of domestic hot water

The third and fourth chapters present new upgrades for the boiler with 3D CAD model, as well as all the test results that were performed which show the boiler performance coefficient and other required parameters. The boiler was tested according to the LST EN 303-5 standards, by which the boilers thermal power and the concentrations of CO, CO_2 will be shown.

The fifth chapter contains list of expenses of both new and old boilers, which show all the expense elements, factory costs and added value of both products.

The conclusions summarize results of the tests and received information about the new B-25E boiler performance.

KAUNO TECHNOLOGIJOS UNIVERSITETAS

MECHANIKOS INŽINERIJOS IR DIZAINO FAKULTETAS

Tvirtinu:

Gamybos inžinerijos katedros vedėjas

____
(parašas, data)

____
(vardas, pavardė)

MAGISTRANTŪROS STUDIJŲ BAIGIAMOJO DARBO UŽDUOTIS

Studijų programa PRAMONĖS INŽINERIJA IR VADYBA

Magistrantūros studijų, kurias baigus įgyjamas magistro kvalifikacinis laipsnis, baigiamasis darbas yra mokslinio tiriamojo ar taikomojo pobūdžio darbas (projektas), kuriam atlikti ir apginti skiriama 30 kreditų. Šiuo darbu studentas turi parodyti, kad yra pagilinęs ir papildęs pagrindinėse studijose įgytas žinias, yra įgijęs pakankamai gebėjimų formuluoti ir spręsti aktualią problemą, turėdamas ribotą ir (arba) prieštaringą informaciją, savarankiškai atlikti mokslinius ar taikomuosius tyrimus ir tinkamai interpretuoti duomenis. Baigiamuoju darbu bei jo gynimu studentas turi parodyti savo kūrybingumą, gebėjimą taikyti fundamentines mokslo žinias, socialinės bei komercinės aplinkos, teisės aktų ir finansinių galimybių išmanymą, informacijos šaltinių paieškos ir kvalifikuotos jų analizės įgūdžius, skaičiuojamųjų metodų ir specializuotos programinės įrangos bei bendrosios paskirties informacinių technologijų naudojimo įgūdžius, taisyklingos kalbos vartosenos įgūdžius, gebėjimą tinkamai formuluoti išvadas.

1. Darbo tema:

Analysis of solid fuel boiler design for performance coefficient improvement

Patvirtinta 2015 m. gegužės mėn. 11d. dekano įsakymu Nr. ST17-F-11-2

2. Darbo tikslas: To increase the boiler class in efficiency by applying effective and non-complicated upgrades and perform required tests.

3. Darbo struktūra: **Review part:** Analysis of boilers on the current market. **Methodical part:**. Current boiler technical analysis and the review of new upgrades. **Research part:** Technical analysis of the new boiler and production methodology and test results.

4. Reikalavimai ir sąlygos: Naujojo patobulinto katilo sukūrimas ir testavimas

5. Darbo pateikimo terminas 2015m. gegužės mėn. 29 d.

6. Ši užduotis yra neatskiriama baigiamojo darbo dalis

Išduota studentui Vitalijui Grižauskui

Užduotį gavau Vitalijus Grižauskas

(studento vardas, pavardė) (parašas, data)

Vadovas Assoc. Prof. Dr. M.Rimašauskas

(pareigos, vardas, pavardė) (parašas, data)

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Introduction

Heat can be called as the essence of all life. Such assessment can be observed when the refrigerator breaks down and our groceries come alive after a short time. If heat came only from the sun's rays, large areas of the earth would be uninhabitable for man. Artificial heating (thermal heat) is therefore necessary, depending on the geographic position and season of the year. In addition to this, there are also a great number of technical processes that are only made possible through heat, for example, cooking, boiling and cleaning processes in the food and drink industry. But in many other branches, too, such as the paper, building, chemical or textile industry, many processes function only with heat (process heat).

Boilers are pressure vessels designed to heat water or produce steam, which can then be used to provide space heating and/or service water heating to a building. In most commercial building heating applications, the heating source in the boiler is a natural gas fired burner. Oil fired burners and electric resistance heaters can be used as well. Steam is preferred over hot water in some applications, including absorption cooling, kitchens, laundries, sterilizers, and steam driven equipment.

Boilers have several strengths that have made them a common feature of buildings. They have a long life, can achieve efficiencies up to 95% or greater, provide an effective method of heating a building, and in the case of steam systems, require little or no pumping energy. However, fuel costs can be considerable, regular maintenance is required, and if maintenance is delayed, repair can be costly. Boilers are often one of the largest energy users in a building. For every year a boiler system goes unattended, boiler costs can increase approximately 10%. Boiler operation and maintenance is therefore a good place to start when looking for ways to reduce energy use and save money.

Relying on this I have chosen for my Research Project – Solid fuel boiler design study for performance coefficient improvement.

The main aim of this work is to improve a heating boiler by removing or replacing older components and adding new ones.

The aim of the work is to **design and test a new version of a 25kW solid fuel boiler with an improved performance coefficient**

The objectives will be:

1) To analyze alternative boiler types that exist on the market.
2) To analyze the currently given heating boiler and perform reverse engineering operations.
3) To present and apply new improvements for the current heating boiler for efficiency improvement.
4) Create a 3D visualization of the new improved boiler.
5) To test the performance of the new boiler with the applied upgrades.
6) To analyze the cost expenses of the new designed heating boiler to make sure its cost efficient.

1. Design overview of an industrial boiler

Unlike pressure cookers industrial boilers can take much higher pressures. Such boilers are welded from thick steel plates that are up to 35 mm thick, making pressures of 30 bar and more possible. A stable, robust design is also essential – if a boiler of this type were to collapse, explosive forces comparable to the explosive power of a ton of gelignite would be released (milk boiling over in a pressure cooker is nothing in comparison to this). A thermal output of up to 38 MW is possible from a single boiler, which corresponds approximately to the power of 500 average VW Golf cars. Up to five boilers can be combined economically. A boiler of this type, filled with water and ready for function, can weigh as much as 165 tons, which corresponds to the weight of 120 VW Golfs. At full capacity a boiler of this size converts 3 000 liters of fuel oil or a corresponding amount of natural gas to thermal or process heat every hour. This would be sufficient to heat more than 2 000 houses [12].

Hot water or steam boilers are relatively similar in design (Fig.1.1). The boiler pressure vessel is a horizontal, cylindrical tube closed at both sides with an end plate and insulated all around. There is a flame tube (1st pass) in this pressure vessel, which is fired through a burner and an internally situated reversing chamber that reverses the flue gases and leads them back in the 2nd smoke tube pass. On the front of the boiler is an external reversing chamber, which again reverses the flue gases and leads them to the end of the boiler in the 3rd smoke tube pass. Hot water boilers are normally completely filled with water during operation. Steam boilers on the other hand are only 3/4 filled with water; the upper quarter is the steam space. Because of the huge volume of water and the multi-stage lead-through of the flue gases, some types of boilers like these boilers are also called three-pass shell boilers [9].

1. Waste gas connection to chimney
2. Smoke tube pass (2nd pass)
3. 1st Flame tube
4. Burner
5. Smoke tube pass (3rd pass)

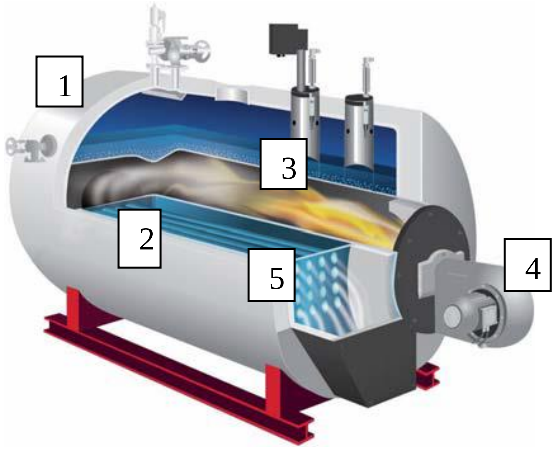


Figure 1.1 Sectional drawing of a three pass shell boiler [9]

1.1 Operation principal of industrial heating boilers

The design purpose of a heating boiler is for heating industrial and residential areas, manufacturing shops and other buildings with a closed heating system. Control and regulation devices are installed in the boiler, which automatically maintain the set water temperature, ensure economically efficient usage of the boiler and safe operation. Boilers of this type are designed to burn wood, partially generating gases. Gas is generated from the burning firewood in the upper combustion chamber of the boiler and burned in the lower chamber. The intensity of gas generation and combustion is regulated by the frequency and duration of air inflow into the combustion chambers.

The heart of an industrial boiler system is a hot water or steam boiler (Fig. 1.2) operated with a certain kind of fuel. The boiler heats up or evaporates the water inside it, which is then transported to the consumers via pipe systems. In case of hot water the transport energy is generated by pumps, in case of steam the transport is based on inherent pressure. The cooled water or the condensed steam returns to the boiler where it can be heated again. Loss of water must be compensated by treated fresh water to avoid corrosion. Flue gases created by combustion are discharged into the atmosphere through a chimney. Particularly efficient systems additionally use the residual heat in the flue gases [9].

Advantages of the boiler are the following:

• Gas generating combustion ensures effective burning of wood and a high efficiency coefficient since the burning process takes place at a high temperature of 900°C;

• The controlled heat output is within the range field of 40-100%. The electronic controller automatically assumes control of the boiler, by adjusting the ventilator inflowing into the combustion chambers on or off, or by setting the optimal speed of its rotation.

• The volume of the fuel chamber is increased therefore the combustion period of one fuel load is even longer

• Complete fuel combustion ensures cost-efficient fuel usage;

• The optimal amount of times for the removal of ashes is 1-2 times per week.

Figure 1.2 Solid fuel heating boilers [11]

Boilers operate on the principle of wood gasification. During the pyrolysis process, combustible wood gases are generated from fuel loaded in the upper chamber of the boiler, and later these gases are burned down in the lower chamber at a high temperature of about 900°C. Wood gasification has advantages over conventional wood firing, because higher combustion temperatures are achieved, and consequently, the solid fuel is fired down more completely with less ashes remaining as residuals of the combustion process. Less unburned but combustible gases, such as carbon monoxide CO, are emitted out into the atmosphere. Another benefit of such a boiler is its capability to regulate the heat output as mentioned before in the 40-100% range [1].

Other benefits are:

• The boiler heat exchanger parts which are in contact with combustion are manufactured from 6 mm thick special boiler steel, and other parts - from 4 mm steel sheets.

• The combustion duration of one fuel load is from 5 to 8 hours. If a boiler operates at 30% of its rated power, the firing time is extended to 8-12 hours.

• The operation of the boiler is user-friendly and simple.

• Have two types of control units - thermostatic and electronic and in some cases an option to be equipped with one or another of the type units mentioned [10].

• Boilers with an electronic control unit have an electronic controller which controls the boiler operation more effectively; the boiler reacts more precisely and quickly to the changing combustion conditions. Therefore, the combustion process results in better fuel economy, the duration of one fuel load firing is extended, less pollution is emitted into the environment, and the control of combustion is easier.

• An emergency cooling coil loop is installed. It prevents the boiler from overheating in case of electricity power failure or a circulation pump stop during the boiler's operation [11].

1.2 Use of boiler systems in everyday practice

Industrial hot water boiler systems for generating thermal heat are very similar to the household heating boilers in our cellars. The main difference is that industrial boilers are dimensioned significantly larger, so their heating capacity is not only sufficient for a family home but also for hotels, hospitals, skyscrapers, industrial buildings or entire districts. When using process heat generated by steam boiler systems the individual applications are far more versatile. They are used in many industry sectors [12].

- **Laundries and cleaning firms**

  This is an example of what steam is used for. It is just easier to get rid of spots and dirt when the washing water is heated. A washing machine at home does the same, however with electrical heating. In large laundries this would be inefficient as electrical energy is too expensive. Steam can also be perfectly used for downstream processes like pressing, using the mangle, ironing or finishing. We know this process from steam-ironing at home; steam simply removes all creases.

- **Food industry**

  Food must often be heated or boiled during processing. Thus this industrial sector obviously needs plenty of thermal energy. However, some steam applications are still stunning; a good example is potato processing.

- **Breweries**

  Most people know that a good and tasty beverage consists of hops, malt and water. However, before enjoying the beverage there is a complex production process. Malt has to be ground coarsely and mixed with water. The brewer calls this mashing. The mash must be heated to various temperatures in two to four hours. The steam we previously generated with the steam boiler. Subsequently, hops are added and the mixture has to cool down. Then yeast is added and triggers the fermentation so that the beverage gets the desired effect. Depending on the type the beverage still has to mature for up to three months until it can be filled in bottles or barrels [6].

- **Building materials industry**

Large amounts of steam are also necessary for the production of moulded bricks. The basic materials like sand, lime, water, etc. are mixed and pressed to relatively loose stone compounds. We remember that from making mud pies in the sandbox. Subsequently, the stones are transported to a huge pressure vessel (autoclave) which is then closed and steam is injected. The stones are to harden at a temperature of approximately 200 °C and a pressure of about 16 bar for a certain period of time and can then be withdrawn as finished stones. [6]

- **Sewer pipe rehabilitation**

If there is a drain leakage, then the problem can either be solved by means of excavation works at the underground pipes and renewal of the sewage pipe systems or with rehabilitation tubes. These tubes are over dimensioned hoses that are inserted in the pipes without excavation work and then inflated with steam. The plastic hose attaches itself to the sewage pipe under application of pressure and temperature and the pipe can continue to be used for many years [12].

… and many other industries

 Agriculture Animal food industry Automotive industry Bakeries

 Ceramic industry Cheese dairies Chemical industry Dairies Distilleries

 Dyeing factories Electrical industry Food packaging industry Fruit processing

 Glass fibre production Greenhouses Hospitals Metal-working industry

 Paper industry Pharmaceutical industry Plastics Primary industry Print office

1.3 Safety Issues

All combustion equipment must be operated properly to prevent dangerous conditions or disasters from occurring, causing personal injury and property loss. The basic cause of boiler explosions is ignition of a combustible gas that has accumulated within the boiler. This situation could arise in a number of ways, for example fuel, air, or ignition is interrupted for some reason, the flame extinguishes, and combustible gas accumulates and is reignited. Another example is when a number of unsuccessful attempts at ignition occur without the appropriate purging of accumulated combustible gas.

There is a tremendous amount of stored energy within a boiler. The state change of superheated water from a hot liquid to a vapour (steam) releases an enormous amount of energy. For example, 1 ft3 of water will expand to 1600 ft3 when it turns to steam. Therefore, if you could capture all the energy released when a 30 gallon home hot water tank flashes into explosive failure at 332oF, you would have enough force to send the average car (weighing 2,500 lbs) to a height of nearly 125 feet. This is equivalent to more than the height of a 14 story apartment building, starting with a lift off velocity of 85 miles per hour [5].

Boiler safety is a key objective of the National Board of Boiler and Pressure Vessel Inspectors. This organization reports and tracks boiler safety and the number of incidents related to boilers and pressure vessels each year. Their work has found that the number one incident category resulting in injury was poor maintenance and operator error. This stresses the importance of proper maintenance and operator training [5].

Boilers must be inspected regularly based on manufacturer’s recommendations. Pressure vessel integrity, checking of safety relief valves, water cut-off devices and proper float operation, gauges and water level indicators should all be inspected. The boiler’s fuel and burner system requires proper inspection and maintenance to ensure efficient operation [3].

2. Technical data and working scheme of the current heating boiler

2.1 Technical data

Table 2.1 the boiler which will be up for improvements is called G-25E

Boiler type	Wood gasification central heating boiler
Rated output, kW	25
Type of boiler control	Electronic (E) or thermostatic
Type of fan	In-feeding
Efficiency rate (wood logs), %	82
Heated area (when rate of thermal conductivity of building= 2,5), m^2	180-250
Boiler temperature setting range, °C	65...85
Fuel	Wood logs; sawdust, wooden chips and peat briquettes
Duration of one fuel load combustion, h.	4...12
One heating season fuel consumption (wood logs), m^3	18-25
Fuel chamber length, mm	546
Maximum appropriate humidity of fuel, %	20
Filling chamber capacity, l	105
Boiler water content, l	62
Boiler operating pressure, bar	2,0
Emergency water cooling loop power, kW	15
Minimum temperature of returning water, °C	65
Maximum allowable temperature of water in boiler, °C	95
Minimum draught, Pa	22

Boiler dimensions, mm	height (H)	1156
	width (B)	646
	depth (L)	965
Threaded connection, G‘‘		G1 1/2
Flue gases duct diameter, mm		152
Average temperature of flue gases, °C		188
Filling opening dimensions, mm		285x350
Weight (netto), kg		310
Electrical consumed power, W (230 V 50 Hz)		25

2.2 Current boiler working scheme and house heating system:

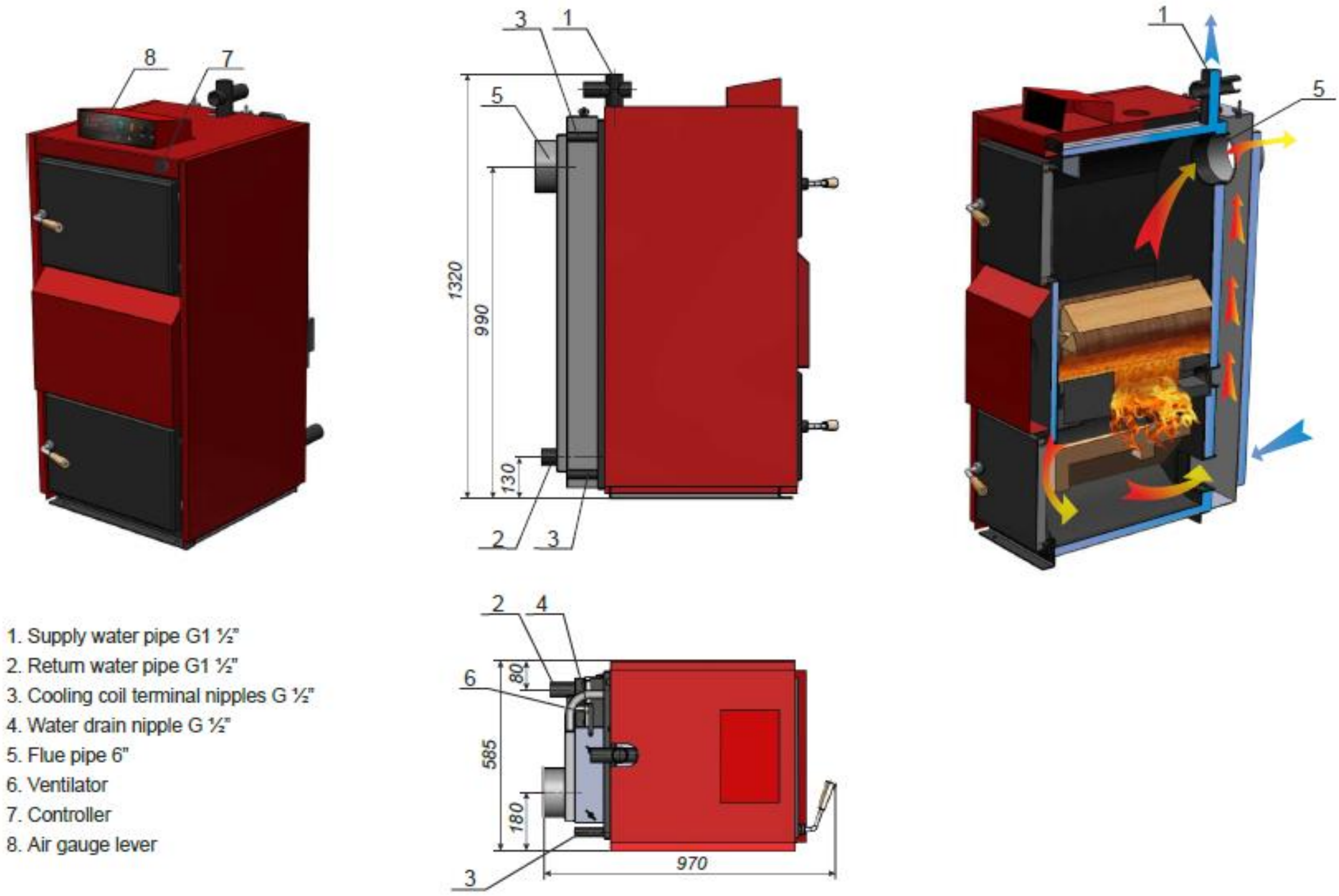


Figure 2.1 Working principle scheme of the current boiler [2]

Description of the House Heating System Scheme. (Fig. 2.2) The house heating system with an accumulation tank could be divided functionally into two circles: heat production and heat consumption. Both circles operate independently and interact in the accumulation tank. The heat production circle consists of a boiler, Laddomat 21 thermostatic mixing unit with a circulation pump installed in it, expansion vessel, fittings and accumulation tank. The intended use of this circle is to charge the accumulation tank only. To charge the tank, the boiler could operate on its maximum heat output and outflowing water temperature 85°C. That mode of boiler operation is optimal for the boiler and combustion process itself. The heat consumption circle uses the heat accumulated in the tank. The circle consists of a room thermostat or a programmed control processor, room or/and outside temperature sensors, 3-way servo drive, mixing valve, underfloor heating system, radiators, piping, fittings. The programmed processor controls a 3-way mixing valve, which allows more or less heat (45-60°C) into the radiators, according to demand. This way of heat consumption allows the heating of the house as long as the tank stores heat independently from the boiler[4].

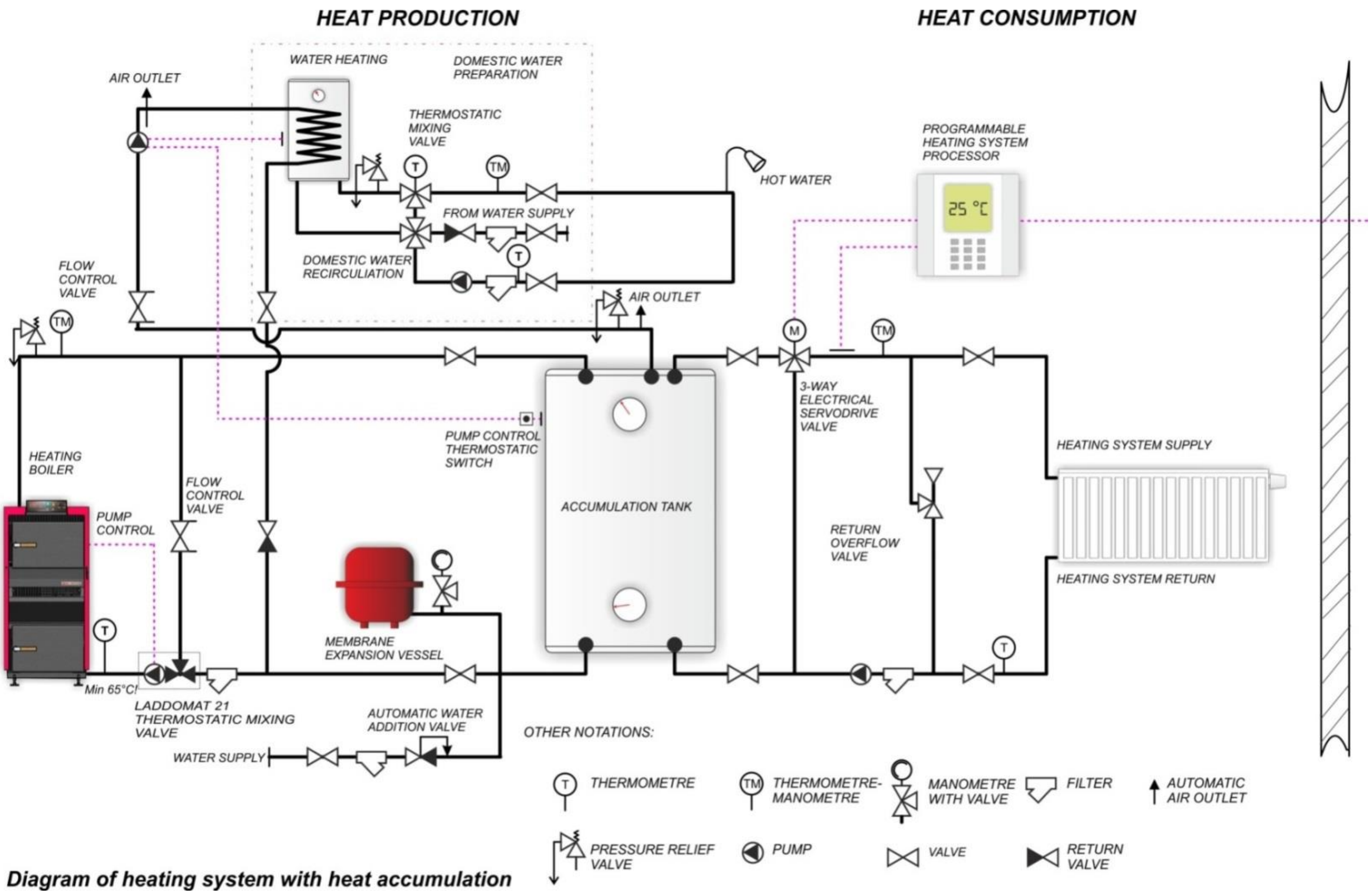


Figure 2.2 Heating system [3]

2.3 Efficiency

The percentage of the heat energy contained in the fuel that is captured by the working fluid (e.g. water) in the current boiler is defined as the combustion efficiency of the boiler (Fig.2.3). Combustion efficiencies of 80% or higher are usually possible for hot water boilers and low pressure steam boilers for commercial buildings [2].

Complete combustion results when a hydrocarbon fuel such as natural gas or oil burns and produces only carbon dioxide, water and heat. If there is insufficient oxygen and/or poor mixing of fuel and oxygen, then incomplete combustion will occur resulting in other products of combustion including carbon monoxide and unburned fuel [5].

When incomplete combustion occurs, the chemical energy of the fuel is not completely released as heat and the combustion efficiency is reduced. This is also a safety concern as unburned fuel could ignite in the stack and cause an explosion. Boilers must be tuned to achieve complete combustion. One strategy to ensure complete combustion is to provide some amount of excess air. However, as shown in the figure below, a small amount of excess air will improve combustion efficiency, but a large amount will reduce efficiency [5].

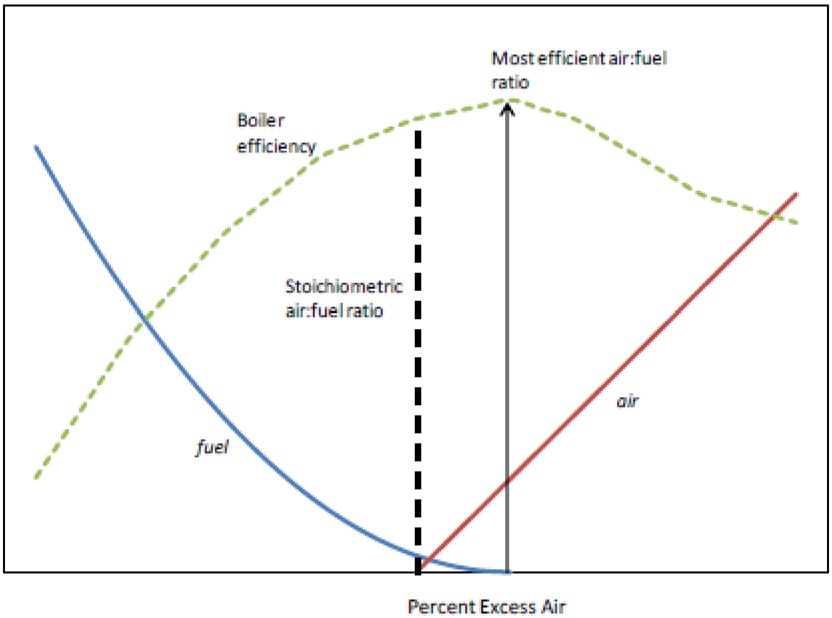


Figure 2.3 Combustion Efficiency vs. Excess Air [12]

For high overall boiler efficiency, the heat released by combustion must be efficiently transferred into the working fluid. Any heat not transferred into the fluid will be lost through the boiler shell or the flue gas. The temperature of the flue gasses in the boiler stack is a good indicator of this heat transfer and thus the efficiency. There are practical limits to how low the stack temperature can be. The temperature will be higher than the working fluid in the boiler. In non-condensing boilers, it must be high enough so that the water vapour in the exhaust gas does not condense and bathe the heat transfer surface in the corrosive condensate. Condensing natural gas boilers are designed and built with materials designed to resist corrosion. As such, they may have exhaust temperatures less than 150°F. Capturing the heat from the condensate can result in combustion efficiencies of greater than 90% [12].

2.4 CAD view of the new proposed boiler

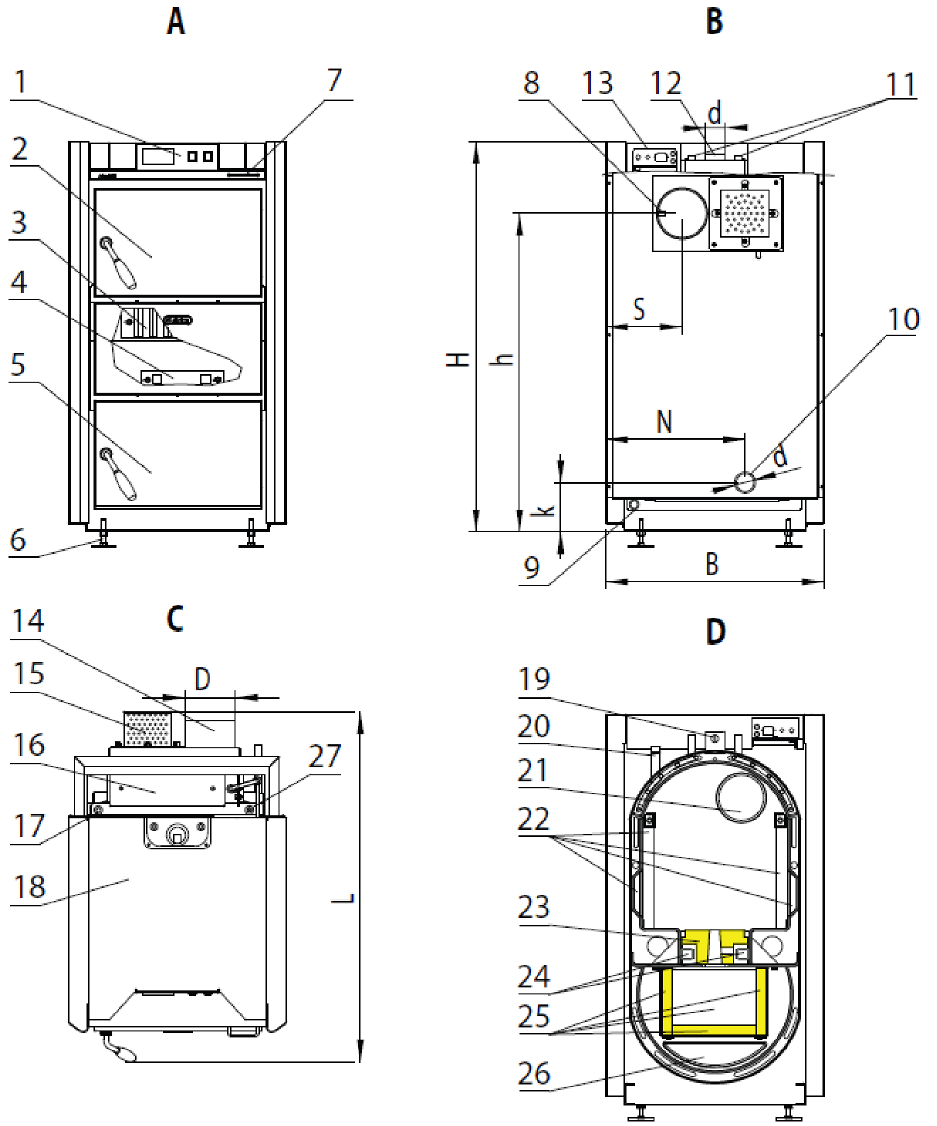


Figure 2.4 General view of the simple boiler

A – front view; B – Rear view; C – top view; D - section.

1. Front control panel; 2. Fuel chamber door; 3. Primary air regulation shutter; 4. Secondary air regulation shutter; 5. Combustion chamber door; 6.Adjustable support legs; 7. Handle of the upper flue damper; 8. Smoke temperature sensor; 9. Water drain nipple; 10. Return water pipe; 11. Connections of the cooling serpentine; 12. Flow water pipe; 13. Rear control panel; 14. Flue; 15. Exhaust fan with the protective shield; 16. Flue cleaning cap; 17. Sensor immersion pocket ½” of the safety temperature limiter 95°C valve; 18. Rooftop cover; 19. Water temperature sensor; 20. Safety ventilator shutdown 95°C thermostat sensor; 21. Upper combustion chamber opening to the flue; 22. Primary air inlet openings; 23. Ceramic burner; 24. Secondary air inlet openings; 25. Segments of the ceramic basket; 26. Opening to the flue; 27. Bleed valve.

3. TECHNICAL UPGRADES

3.1 Regulation of primary and secondary air supply

There is a simple combustion triangle containing three elements that are required in order for combustion to take place. These elements are: fuel, heat (ignition) and air (Fig.3.1). The requirements for both fuel and ignition are obvious. However the requirements for air are trickier and are often ignored. Without any one of these elements the combustion process would stop and the combustion triangle would collapse [5].

Figure 3.1 Combustion triangle

If the combustion air supply is closed off, the fire starts to smoke, because the air supply is exhausted. Incomplete combustion occurs and carbon monoxide is generated. The fire then goes out, but often before the flame detection system can act to close the fuel safety shutoff valve(s). The accumulation of fuel is re-ignited as oxygen seeps in through cracks and crevices; a furnace explosion frequently occurs with disastrous effects on personnel and property [3].

Unlike the original boiler design (fig 3.2), the possibility to be able to regulate the primary and secondary air supply in the boiler would increase the efficiency of the boiler since it would be possible to adjust the burning intensity of the fuel. The idea behind this upgrade is to make two additional air supply vents of the right diameter in front of the boiler through which air could flow in to the upper chamber and the ceramic burner. The air supply could be regulated by adjustable shutter [7].

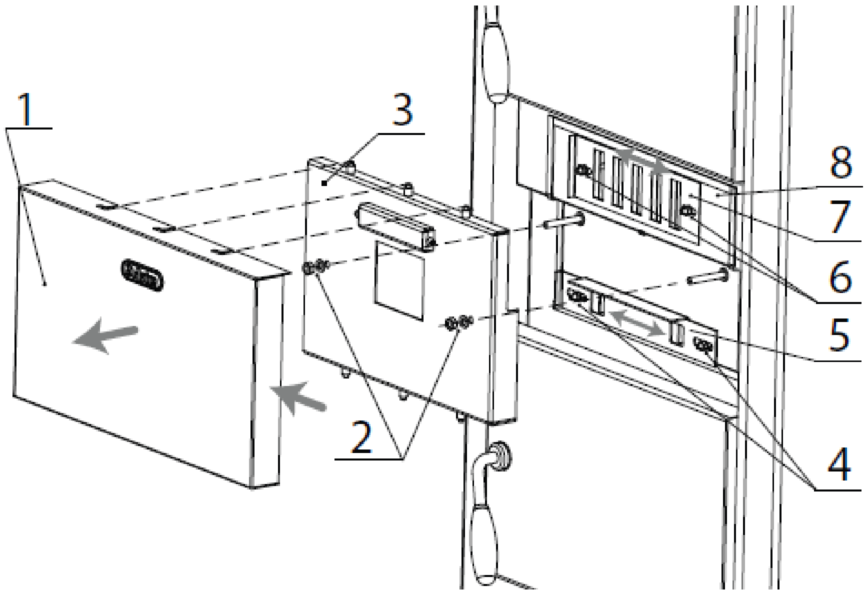


Figure 3.2 Regulation of primary and secondary air supply [6]

The work principle of this new design aspect would be as follows: a proportion of the primary and secondary air supply is set in the factory and in most cases does not require additional adjusting. Despite of this, the proportion could be regulated to meet individual requirements. Push the face panel 1 (Fig.3.3) leftwards until halting and remove it. Unscrew two nuts 2, remove washers and take off the air preparation casing 3. To regulate the primary air, loosen nuts 6 and move the shutter 7. To adjust the secondary air, loosen nuts 4 and move the shutter 5. When regulating air supply, pay attention that the shutter would not close the primary air supply openings diameter by more than 35%. The secondary air slots area should not be closed by more than 25% in any case.

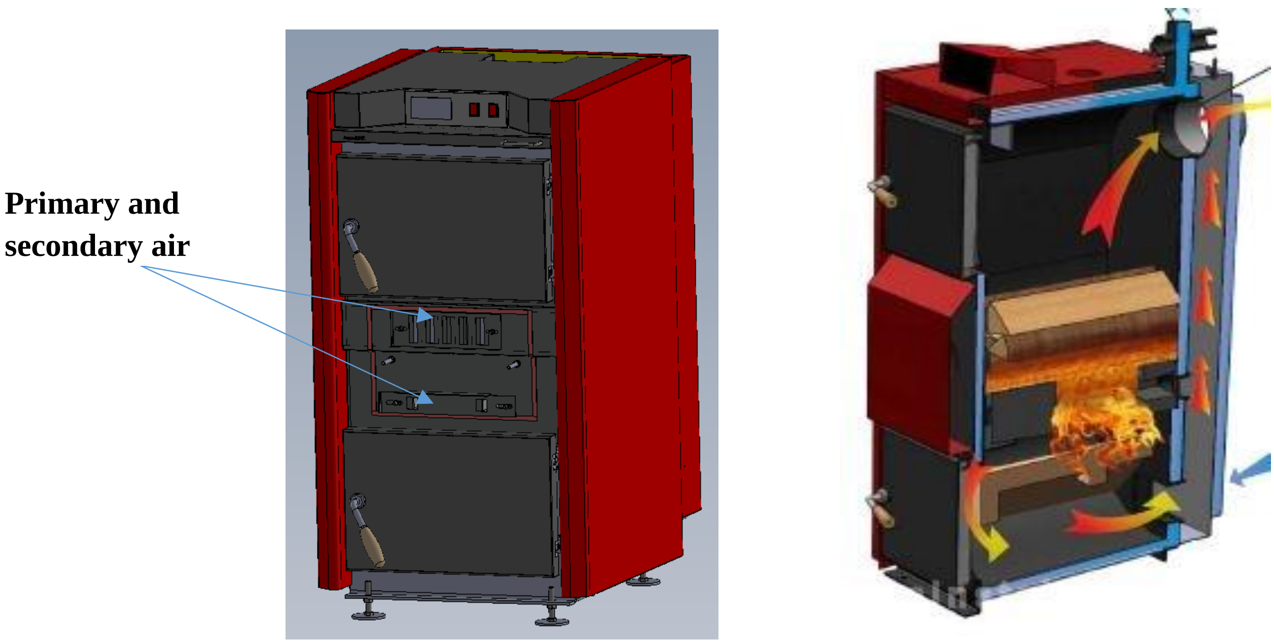


Figure 3.3 Old (right) and new (left) solid fuel heating boilers

Extra air flow channel

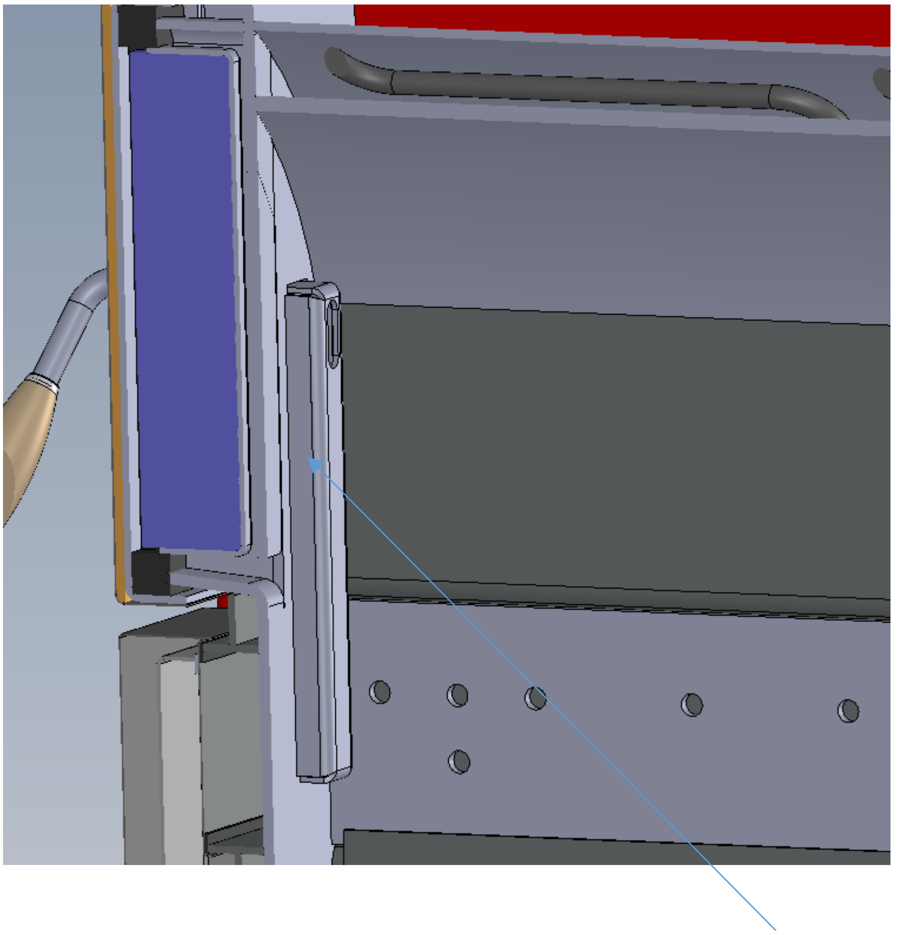


Figure 3.4 CAD model of the air flow tube

Extra airflow channel. Two extra airflow tubes (Fig. 3.4) will allow a larger amount of air to get through to the top end of the upper chamber through the primary air supply vent. The extra air would give the boiler extra power and would improve the burning process.

To achieve the goal of the research, a set of experiments were conducted using an experimental stand which is intended for biomass boiler testing. The experimental stand is shown in (Fig. 3.5). The laboratory stand consisted of a 25 kW pellet boiler, monitoring equipment, a heat accumulation tank, and a heat exchanger for boiler cooling. For determination of flue gas chemical composition (NOx, CO, O2), the flue gas analyser Testo 350XL was used. All concentrations were calculated under equal conditions – at 10% of O2. Flue gas temperature, chemical composition, amount of dust content in flue gas flow rate, chimney draught, fuel consumption, and thermal performance of the boiler were monitored during the test. The K-type thermocouples were used for the flue gas measuring.

502 The water flow rate was measured using a magnetic flow meter. PT 100 temperature sensors were used for water temperature measuring. The pressure into the flue gas stack was regulated manually and was determined using the differential manometer DPT ± 100-R2-Az-D-Span. For determination of fuel consumption, the pellet boiler was put onto the industrial weighing platform Svenska Vag HCPS-4 and changes in the weight were recorded automatically. All data was gathered scientifically using Campbell data and was transferred to a PC for data processing.

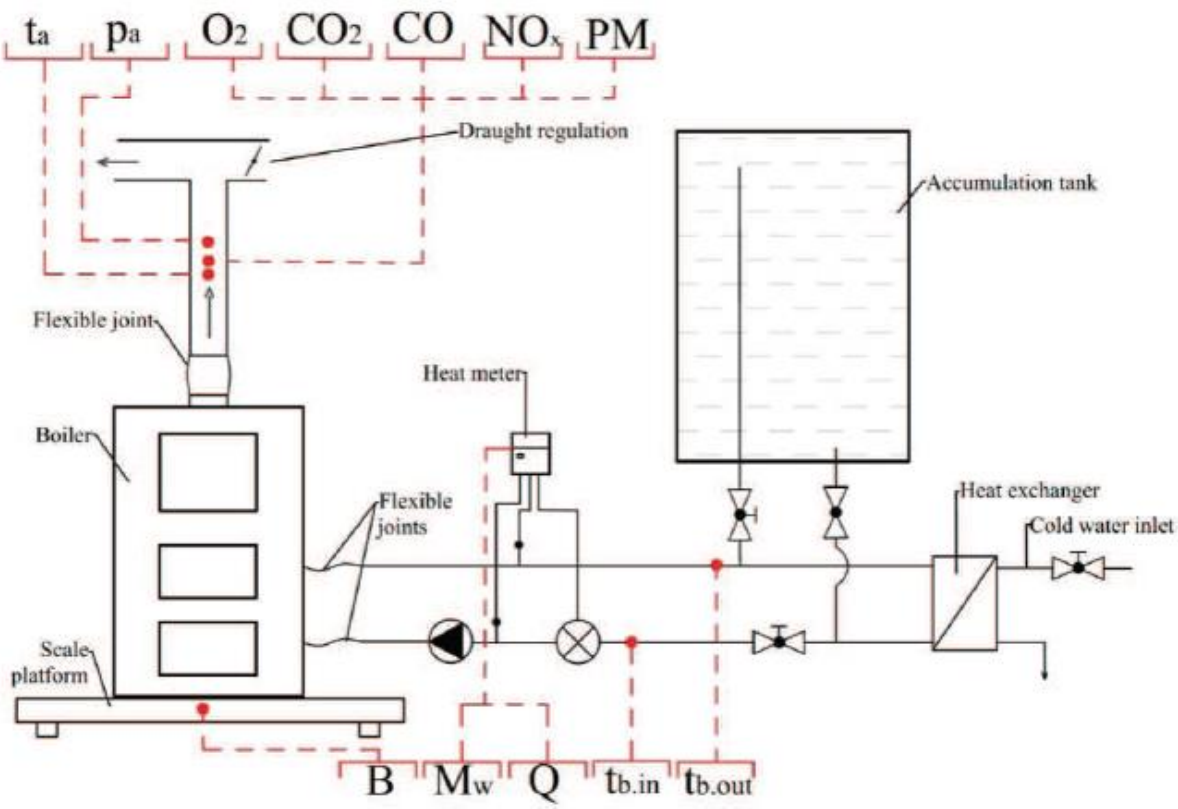


Figure 3.5. The principal scheme of the boiler stand [2]

The nomenclature used in Fig. 10: B – mass of the test fuel (kg h-1), Mw – water flow rate (kg h-1), Q – heat output (kW), B heat input (kW), Qb – chemical heat losses in the flue gases, referred to the unit of mass of the test fuel, (kJ kg-1) ta – flue gas temperature (°C), pa – draught in the chimney (Pa), tb.in – boiler input temperature (°C), tb.out – boiler output temperature (°C).

The boiler efficiency was calculated according to the standard EN 303-5:2001 using the direct method. The amount of the fuel used, produced heat, and the net calorific value were taken into account for the boiler efficiency calculations.

3.2 Separately assembled chimney and turbulence plates

Separately assembled chimney. In order to increase productivity the choice was made to simplify and make a separately assembled chimney (Fig. 3.6). For manufacturing, the benefits of assembly line production are enormous. An inherent part of the idea of assembly lines is that each item produced from a certain product line is as close to identical as possible. This allows quick and easy assembly throughout the process, and it also means that maintenance and replacement of worn or broken parts is a much simpler task down the road.

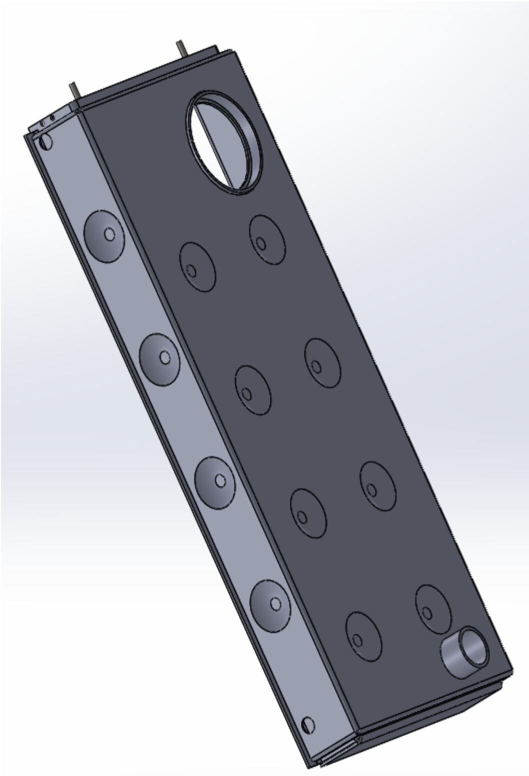


Figure 3.6 Chimney CAD model

Separately assembled chimney would remove an extra hydraulic analysis that is necessary to test for any leaks in the boiler. This would save a lot of time and resources during the production process. In addition the chimney will be designed so, that on the top there will be an additional hood in between which water will be contained surrounding the chimney from all sides, thus improving the heat reduction.

Turbulence plates used for capturing more heat from the hot exhaust smoke by increasing the smoke travel distance from the exhaust to the chimney thus reducing its temperature from 400^{o}C to about 150 ^{o}C (Fig.3.8). The turbulence plates are made from simple steel S235JR with a 4mm thickness. It forces the exhaust smoke to hold, become turbulent and thus transfer more heat to the adjacent heat exchanger. The core of the device consists of the turbulence plates, positioned at an angle in the rectangular shaped flue channel of the boiler. The inspection aperture 1 is installed on the top part of the flue channel (Fig. 3.7), covered with a screw-on cover with a gasket. This aperture is used for cleaning the flue channel and placing/removing the turbulence plates.

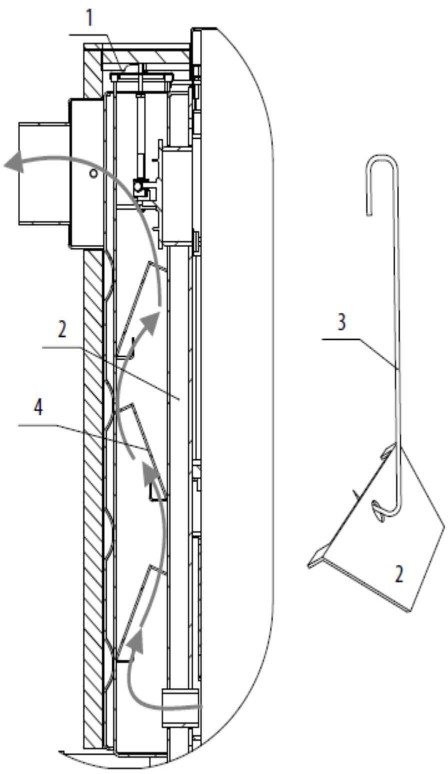


Figure 3.7 Turbulence plate technology

1. Inspection aperture; 2.Turbulence plates; 3. Poker; 4.Heat exchanger of the boiler flue.

The turbulence plates 2, shown (Fig. 3.7), maintain their position in the flue due to their force of gravity alone. They are inserted into the flue channel or removed using a poker 3, which is provided with the boiler. Poker 3 (Fig.3.7) is bent at an angle of approximately 80° to the handle, so that the hooked plate does not slide off. In order to be able to hook the turbulence plate 2 with a poker, a hole has been made in its upper part for hooking with a poker. The plate rests upon the heat exchanger 4 of the boiler flue on four supports: two bottom and two upper supports.

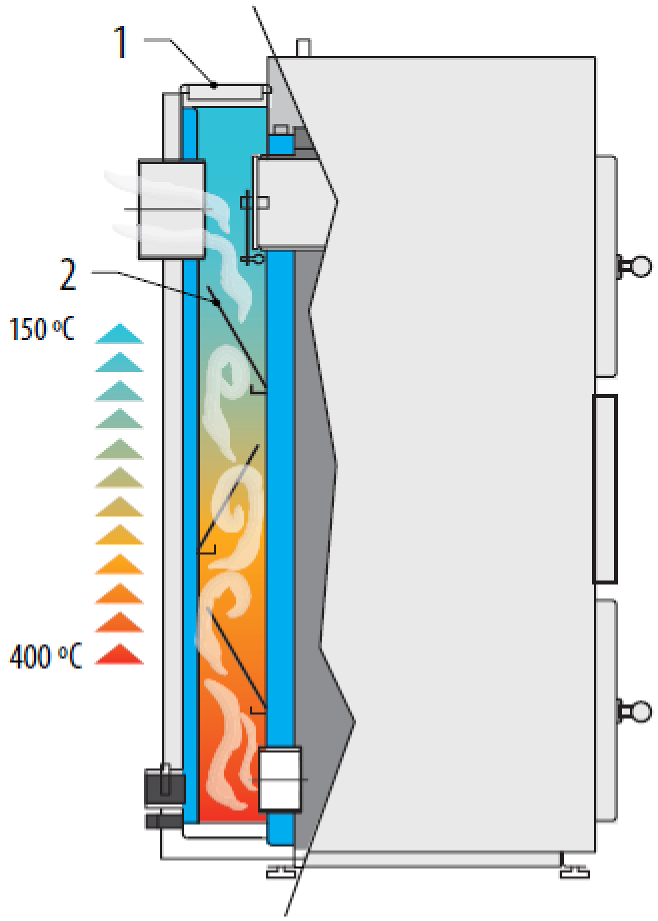


Figure 3.8 Smoke temperature in the chimney

When inserting the plate 2 with a poker 3 into the flue channel, first the lower position is found, and after slightly loosening the poker, yet without removing it from the hole, the plate is allowed to descent onto the opposite side of the heat exchanger due to the force of gravity until it touches the wall of the heat exchanger with its upper supports. Then the tool can be removed and the next plate can be installed in a similar way. Turbulence plates decrease the temperature of the exhaust smoke. The boiler can be operated without the plates, but then greater losses of heat through the chimney will occur. Turbulence plates decrease the temperature of the exhaust smoke. The boiler can be operated without the plates, but then greater losses of heat through the chimney will occur.

To summarize, the benefits from such improvements are:

- ✓ The chimney has a “water shirt" from both sides. This improves heat transfer.
- ✓ Flue duct fitted with turbulence plates, which increase the path the smoke needs to travel through the chimney improving the heat exchange
- ✓ Turbulence plates reduce the smoke temperature by 40 ^{o}C-100 ^{o}C
- ✓ The plates don’t melt to the chimney since they only touch in a few points. They are easy to take out and clean up.
- ✓ Turbulence plates have a simple construction

NOTE: Additional boiler design changes will be applied in the new model

3.3 Additional upgrades

- **Heat resistant boiler doors**

With the old boiler model it was noticed that the boiler doors during the burning process would start to heat up higher than the allowable temperature of 90 °C that is permissible by the EN-303-5 standards. Such problems affect the boiler performance and can cause safety issues for the consumer.

To get a better understanding on how much exactly do the upper and lower boiler chamber doors over heat, a test was performed with a help of a heat sensor during a 1 hour burning process by using standard doors during testing the boiler temperature was 83 °C and the surrounding temperature was 12 °C. The results were as follows (Fig.3.9.1):

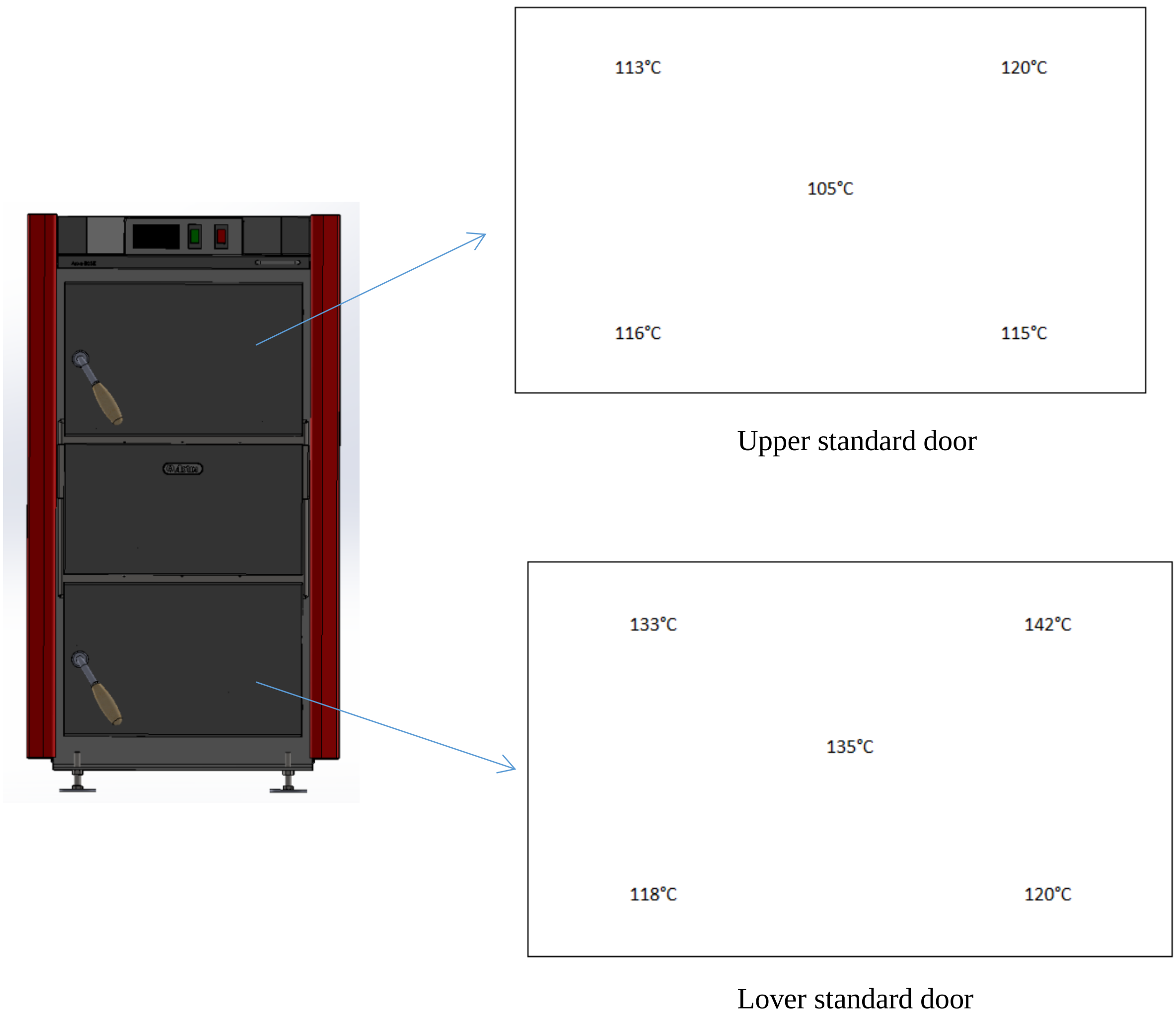


Figure 3.9.1. Standard boiler door temperature test results

The test results show that the boiler door temperature during the burning process exceed he allowable temperature. To resolve the issue additional free 5mm space was added to make an additional 2 layers of air. In addition an extra metal screen was added to withstand heat (Fig. 3.9.2)

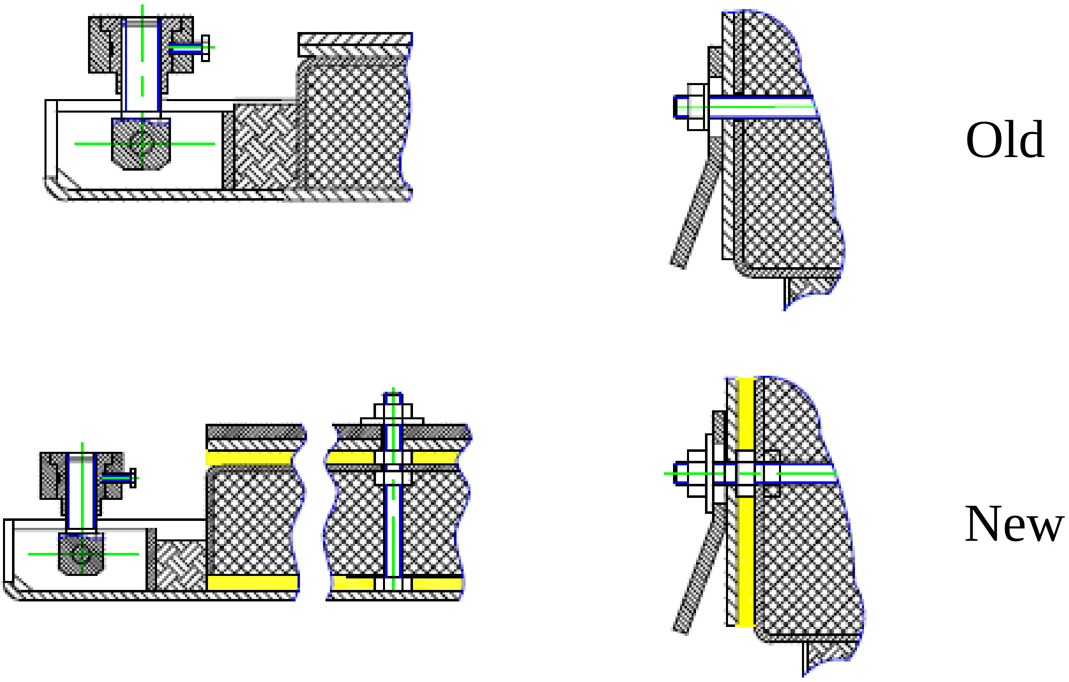
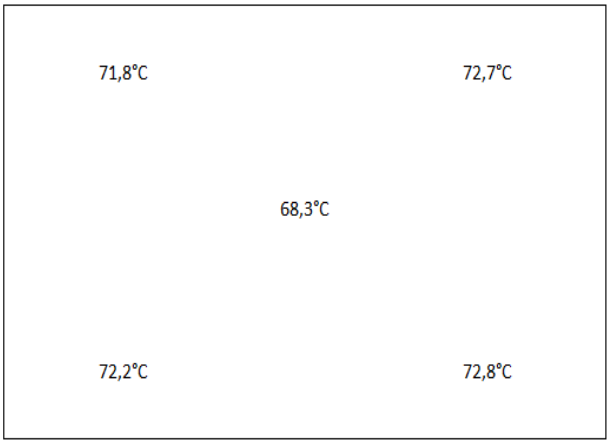
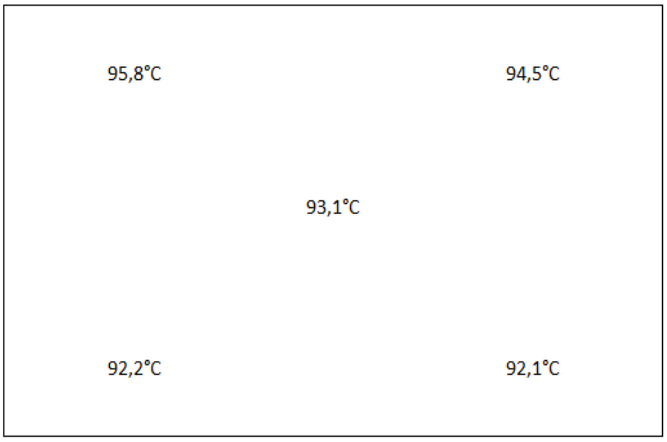


Figure 3.9.2 Old and new door models

After applying these upgrades and performing the same testing process, the results were as follows (Fig. 3.9.3):



Upper upgraded door



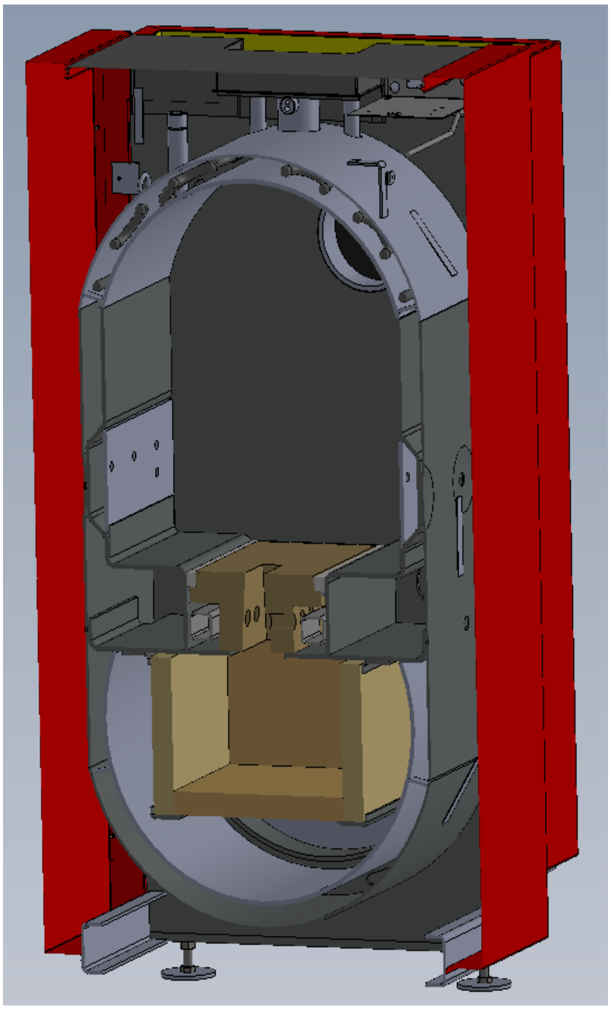
Lover upgraded door

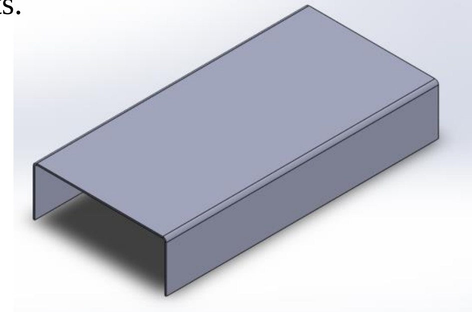
Figure 3.9.3 Upper and lower upgraded door temperature results

Conclusion: The test results show that additional 2 layers of air and an extra metal screen doe's show promise and match the requirements of the EN-303-5 standard and will be applied in the new boiler model.

- **Rectangular vault**

Replacing the original shape of the vault with a rectangular one (Fig. 3.9.4). This would simplify the production process of the part since it would require a simple bending operation and also would make the part easier to place during the assembly process and increasing the upper chamber volume. The only possible disadvantage is, that the part would require more material to produce, thus increasing the financial costs.





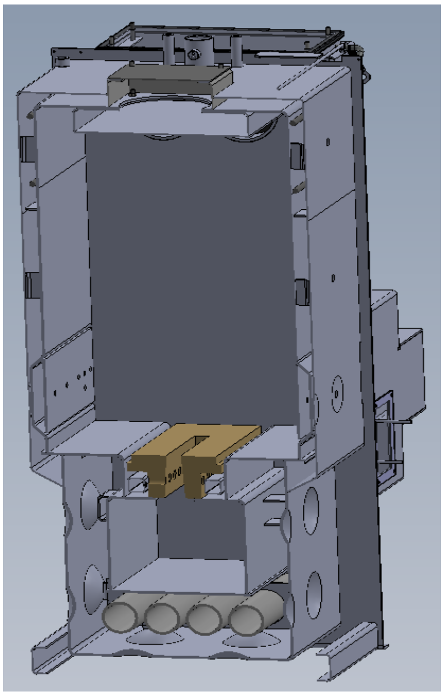


Figure 3.9.4 CAD of old and new boiler model

NOTE: This upgrade will not be applied in the new boiler model.

Conclusions

1. Higher efficiency coefficient will be supported by lower smoke temperature tc° C,better insulation,more efficient heat take-off, improved heat exchanger.
2. The new improvements look promising assuming the testing results will be positive, however the big question is whether or not they will be cost effective.
3. To be sure if the improvements will be successful additional performance tests to make sure, that there are no flaws.

4. Testing results of the new upgraded boiler

TEST METHOD

Boiler was tested in accordance with test methods described in the standard LST EN 303-5:2012 (EN 303-5:2012). In addition, concentrations of emissions were measured according to requirements of the standard LST CEN/TS 15883:2009 (CEN/TS 15883:2009). Dust concentration was measured according to requirements of the standards LST EN 303-5:2012 (EN 303-5:2012) and LST EN 13284-1:2006 (EN 13284-1:2001).

TEST OBJECTIVES

The objective of the tests is to control conformity of the solid fuel boiler(s) with the applied new upgrades with performance and security requirements of European standard NF EN 303-5

TEST RESULTS

Test results are presented in pages below.

NOTE: Test results are assigned only for the product under the test.

SUMMARY CONCLUSION

Operating parameters of the water heating boiler under test conform to the requirements of 4 class described in the standard LST EN 303-5:2012 (EN 303-52012) except the requirements of electrical safety (4.3.9.2) and electromagnetic compatibility (4.3.9.3) that have not been tested.

4.1 TEST OBJECT DESCRIPTION AND CHARACTERISTICS

Purpose

Water heating boiler fired with wood logs designed for heating various premises with closed heating system and for production of domestic hot water.

Construction

The new boiler in testing is designed to burn wood logs using gas generation principle. Boiler consists of two combustion chambers and heat exchanger. Burning wood logs releases (generates) combustible gas in the upper combustion chamber of the boiler. Formed combustible gases are sucked into the ceramic burner placed at the bottom of the upper combustion chamber, there mixes with supplied secondary air and finally burns in the lower combustion chamber. Flue gases from the bottom combustion chamber flow into the heat exchanger. Special plates are mounted in the heat exchanger for better heat exchange. Dampers for the primary and secondary air supply are mounted on the front of the boiler under removable decorative shield. Primary and secondary air supply is adjusted manually by dragging the grids of the dampers and selecting necessary areas of air supply through the holes. Air is drawn into the combustion chamber by exhauster. The combustion process is adjusted by a controller. The boiler is equipped with the emergency cooling coil. The frame of the boiler is welded from sheet steel and covered with decorative thermal insulating shields. Upper combustion chamber is loaded with fuel manually. The boiler during the test is presented in the figure 4.1.

Figure 4.1 Boiler overall view during test.

Safety and other devices

Table 4.1 Safety and other devices

Title	Safety temperature limiter	Device for control of dissipating excess heat	Exhauster	Controller
Type	Campini Ty 95-H	Danfoss BVTS	RH18Z-2EP.WA.1L	KR4.4
Technical data	Adjustment range (90÷110) °C	Opening temperature 95 °C; T_{max} – 110 °C; P_{max} – 10 bar; Q_{max} – 2.4 m^3/h	P – 0.07 kW n_{max} – 2600 min^{-1}	Adjustment ranges: T_{water} – (65÷90) °C $n_{exh.}$ – (0÷100) %
Adjustment	94 °C	95 °C	Automatic	$T_{water.max}$ – 87 °C
Supplier	Termoregolatori Campini - Corel S.p.A.	Danfoss sp. z o.o	Ziehl-Abegg SE Heinz-Ziehl-Strasse, D-74653 Kuenzelsau	UAB „Linoma“
Certificate / declaration of conformity	Certificate No. 107866	EC declaration of conformity	EC declaration of conformity	EC declaration of conformity

Basic technical data declared by manufacturer

Nominal heat output	25 kW
Efficiency	85%
Boiler class in accordance with EN 303-5	3
Flue gas temperature	150 ^oC
Maximum operating pressure	2 bar
Maximum operating temperature	87 ^oC
Boiler water capacity	70 l
Overall dimensions	648x1038x1200 mm

4.2 ENVIROMENTAL CONDITIONS DURING THE TESTS

Atmospheric pressure	mm Hg st.	746÷767
Ambient air temperature	^{o}C	16.3÷22.9
Ambient air humidity	%	32.9÷43.5

4.3 TEST EQUIPMENT AND MEASURING INSTRUMENTS

Table 4.3 List of test equipment and measuring instruments

Designation of equipment or measuring instrument, type	Measuring ranges
Thermal equipment testing facility	to 400 kW
HFID analyzer VE7: - OGC concentration	(0÷100000) ppm
Gas analyzer Environnement S.A MIR 2M: - CO_2 concentration - CO concentration	(0÷25) % (0÷20000...100000) ppm
Gas analyzer Environnement S.A TOPAZE 32M: - NO_x concentration	(0÷10000) ppm
Automatic isokinetic dust sampler TCR Tecora Isostack Basic HV	(0÷103.5) kPa (0÷3556) Pa (-20÷1200) °C (0.5÷35) l/min
Temperature sensors TOPI-61 – 5 units, analogue-digital converter 34980 A	(-200÷600) °C
Temperature sensor ITH-22, analogue–digital converter 34980 A	(0÷100) °C
Temperature sensors PT 100 – 2 units, analogue-digital converter 34980 A	(0÷150) °C
Temperature sensors PT 100 – 9 units, analogue-digital converter 34980 A	(0÷150) °C
Flow meter Promag W53	(2.2÷22.6) m^3/h
Electromagnetic flow sensor SDM-1 and heat meter SKS-3	(0.15÷15) m^3/h
Electronic balance KD1500	to 1500 kg
Electronic balance XS205 DU/M	(0÷220) g
Electricity meter Kamstrup	(0÷80) A (3×230/400) V
Multimeter Agilent 34970A	(0÷1) A (0÷300) V
Manometer MO	(0÷16) kG/cm^2
Differential pressure gauge APRE-2000	(0÷100) mbar
Differential pressure gauge APRE-2000G	(0÷50) Pa
Pressure sensor ASHCROFT XLdp	(0÷0.75)″ WC
Low temperature laboratory electric furnace SNOL/60/3000LFN	(10÷300) °C
Testo 400 with temperature sensor 0614.9993	(-200÷600) °C
Testo 400 with humidity and temperature sensor 0636.9741	(0÷100) % (-20÷70) °C
Barometer aneroid M67	(600÷800) mm Hg st.
Stopwatch VAN ALLEN 32800	(0÷30) min
Calipers SC-II	(0÷250) mm
Tape-measure KMC-32S	(0÷5) m

4.4 TEST FUEL

Table 4.4. Test fuel parameters

Parameter	Value	Expanded uncertainty, ÷%
Fuel type	Birch wood logs	
Moisture	12,39%	0,07*
Ash content	0,56%	0,02*
Carbon (C) content (water free)	51,22%	1,17*
Hydrogen (H) content (water free)	6,01%	0,44*
Nitrogen (N) content (water free)	0,24%	0,31*
Sulfur (S) content (water free)	≤0,01	---
Net lover calorific value (water free)	18797 kJ/kg	0,62
Net lower calorific value (as fired basis)	16183 kJ/kg	0,63
Wood logs length	(0,42÷0,46) m	---

*uncertainties given in the absolute values.

4.5 TEST RESULTS

Pressure test

The boiler was tested according to requirements of subsection 5.4.1 of the standard EN 303-5[8]

Test duration 10 min. The leakage and noticeable permanent deformation not appeared.

Conclusion: The tightness and resistance to pressure of the boiler conform to the requirements of subsection 5.4.1 of the standard EN 303-5. The type test pressure is 2xPS using hydraulic pressure (PS is the maximum permissible operating pressure). During the duration of the test no leakage or deformation occurred.

Soundness of gas side

The test is not applicable because the boiler operates at a negative pressure.

Nominal heat output, efficiency and combustion period

The boiler nominal heat output, efficiency and combustion period were set according to requirements of subsection 5.2, 5.3, 5.7, 5.8, and 5.10 of the standard EN 303-5.

The measuring instruments (subsection 5.2) are selected in such a way that the error limits do not exceed:

- For efficiency ±3% points;
- CO: ± 10% of the measured value or ±10 ppm (whichever is greater);
- THC: ± 10% of the measured value or ± 5 ppm, (reference gas: Propane or Methan)
- NO_x: ±5% of the measured value or ± 15ppm(whichever is greater);
- O_2: ±5% of the measured value or 0.4% volume(whichever is greater);
- CO_2: ±5% of the measured value or 0.4% volume(whichever is greater);
- Dust: ± 10mg/m^3 of the measured value;

Test fuel

Fuel of commercial quality is used for testing heating boilers and characteristics of the type of fuel as declared by the manufacturer according to Table 4.5. For the purposes of wood test fuels birch, oak, spruce or hornbeam can be used as declared by the manufacturer.

Table 4.5 test fuels

	Bituminous coal		Brown coal (incl. briquettes)		Coke		Anthracite	Wood logs	Chipped wood		Compressed wood	Saw-dust	Non woody biomass or other solid fuels
	a1	a2	b1	b2	c1	c2	d	A	B1	B2	C	D	E, e
Water content (as received)	≤ 11 %		≤ 20 %		≤ 5 %		≤ 5 %	12 % to 20 %	20 % to 30 %	40 % to 50 %	≤ 12 %	35 % to 50 %	According to the range specification of the manufacturer or EN 14961 (all parts)
Ash content[a] (as received)	2 % to 7 %		5 % to 20 %		5 % to 15 %		5 % ± 3 %	≤ 1 %	≤ 1,5 %		≤ 0,5 %	≤ 0,5 %	
Volatiles[a] (as received)	15 % to 30 %	> 30 %	40 % to 50 %	50 % to 60 %	< 6 %	8 % ± 2 %	< 10 %	-	-	-	-	-	
Chlorine content[a]	-		-		-		-	-	-	-	-	-	
Sulphur content[a]	-		-		-		-	-	-	-	-	-	
N-content[a]	-		-		-		-	-	-	-	-	-	
Net calorific value[b]	> 28 MJ/kg		> 12,5 MJ/kg		> 28 MJ/kg		> 28 MJ/kg	> 17 MJ/kg	> 17 MJ/kg		> 17 MJ/kg	> 17 MJ/kg	> 16 MJ/kg
Size/length	According to the manufacturer's instruction[c]												-

[a] % of mass on dry base.
[b] Dry base.
[c] Max. 5 % of mass of the test fuel may have an oversize or an undersize.

To determine the heat output, boiler efficiency, combustion period, composition of the combustion gas, exit flue temperature, draught and emission properties, the boiler is operated throughout the tests within the heat output range. At nominal heat output the boiler is operated in such a way that continuous running is possible (with thermostat cut-off prevented). The minimum heat output on boilers shall be regulated automatically by a control device without a manual intervention. The boiler is to be brought to operating temperature before the start of any measurements. The ambient air temperature shall be between 15 ^{o}C and 30 ^{o}C.

The draught is to be set according to the minimum draught to manufacturer's instructions. In the test the mean value of the draught shall not vary from the specified value of the manufacturer by more than ±3.0 Pa.

During the test period, manual intervention in the form of poking or raking or any adjustment was not permitted.

The uncertainty shall be calculated with 95 % confidence interval.

Duration of initial ignition period was 188 min, burned quantity of fuel – 26.17 kg.

Settings of the control devices:

- Water operating temperature 87 ^{o}C
- Opening of primary air damper 6 mm
- Opening of secondary air damper 16 mm

Table 4.6 Nominal heat output test results

Parameter	Unit	Value			Expanded uncertainty
		1 combustion period	2 combustion period	Average	
Test duration	h	2.13	2.25	2.19	±0.0003
Fuel quantity	kg	14.84	15.26	15.05	±0.01
Fuel consumption	kg/h	6.96	6.78	6.87	±0.006
Water flow rate	m^3/h	1.62	1.62	1.62	±0.001
Inlet water temperature	°C	71.1	71.1	71.1	±0.07
Outlet water temperature	°C	85.6	85.5	85.5	±0.07
Different of water temperature	°C	14.5	14.4	14.4	±0.1
Heat input	kW	31.3	30.5	30.9	±0.7
Nominal heat output	kW	26.5	26.3	26.4	±0.6
Efficiency	%	84.7	86.3	85.5	±2.3 *
Draught	Pa	31.1	31.1	31.1	±1
Flue gas temperature	°C	147.5	149.3	148.4	±0.03
Ambient air temperature	°C	21.7	22.7	22.2	±0.07

*uncertainty given in the absolute value.

Diagrams of inlet and outlet water temperatures, flue gas temperature and nominal heat output are given in Figure 4.1.

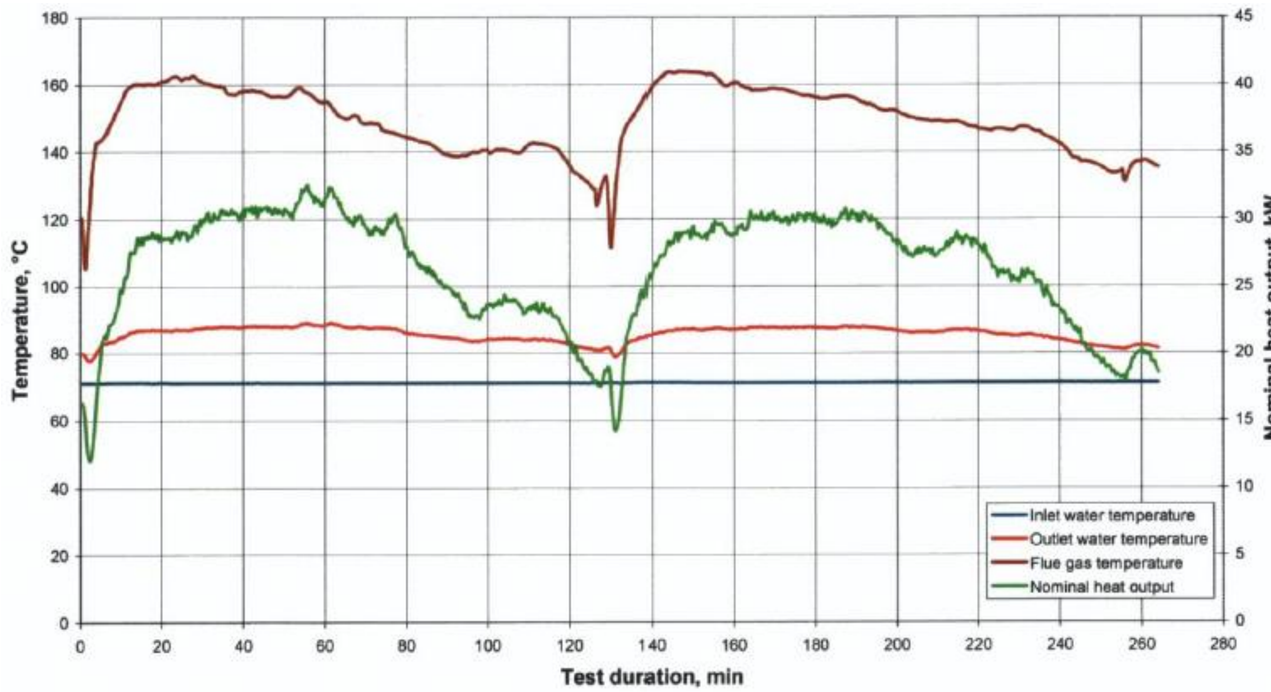


Figure 4.1 Inlet and outlet water temperatures, flue gas temperature and nominal heat output

Boiler efficiency μ_k is calculated by ratio of the delivered useful heat output to the heat input expressed in percentage as shown in equation 1:

$$\mu_k = \frac{Q}{Q_B}\ x\ 100\% \qquad \text{(eq. 1)}$$

From the equation 1 we can derive the boiler efficiency:

$$\mu_k = \frac{26.4}{30.9} x\ 100\% = 85.4\%$$

With the obtained efficiency number the requirement of class can be determined by the diagram shown in figure 4.2:

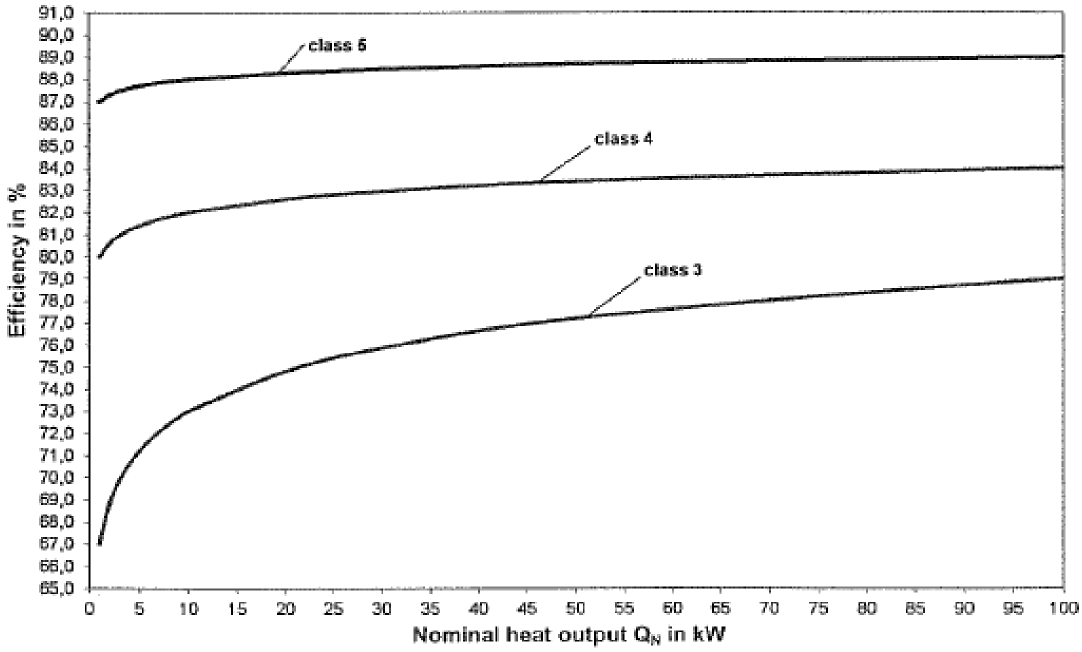


Figure 4.2 Boiler efficiency in percent

Conclusion: After applying new upgrades the efficiency of the boiler conforms to the requirements of 4 class which is an improvement from the previous 3rd class. The combustion period as stated by the manufacturer at nominal heat output was 2h. During testing the heat output specified by the manufacturer was determined within ±8%, the nominal heat output was achieved during the combustion periods as claimed by the manufacturer. The nominal heat output and combustion period conform to the requirements of subsections 4.4.5 and 5.8.2 of the standard EN 303-5.

Minimum heat output

The test is not applicable because the manufacturer does not declare the minimum heat output and specifies that the boiler shall be operated with accumulator tank.

The emissions values

- **CO_2, CO, OGC and NO_x concentrations**

CO_2, CO, OGC and NO_x concentrations were measured according to requirements of subsections 5.2, 5.3, 5.9 and 5.10 of the standards EN 303-5 and to requirements of the standard EN 15883

Table 4.7 CO_2, CO, OGC and NO_x concentrations

Parameter	Unit	Value			Expanded uncertainty
		1 combustion period	2 combustion period	Average	
CO_2 concentration	%	12.6	12.3	12.4	±1.0 %
CO concentration	ppm	2466	2919	2699	±1.1 %
	mg/m^3 *	2649	3207	2935	
	mg/MJ	1289	1561	1428	
OGC concentration	ppm	31	19	25	±1.0 %
	mg/m^3 *	49	31	40	
	mg/MJ	24	15	19	
NO_x concentration	ppm	83	84	84	±2.4 %
	mg/m^3 *	163	168	166	
	mg/MJ	79	82	81	

*value given at O_2 concentration of 10%.

Diagrams of CO_2, CO, OGC and NO_x concentrations at nominal heat output are given in Figures 4.3 and 4.4.

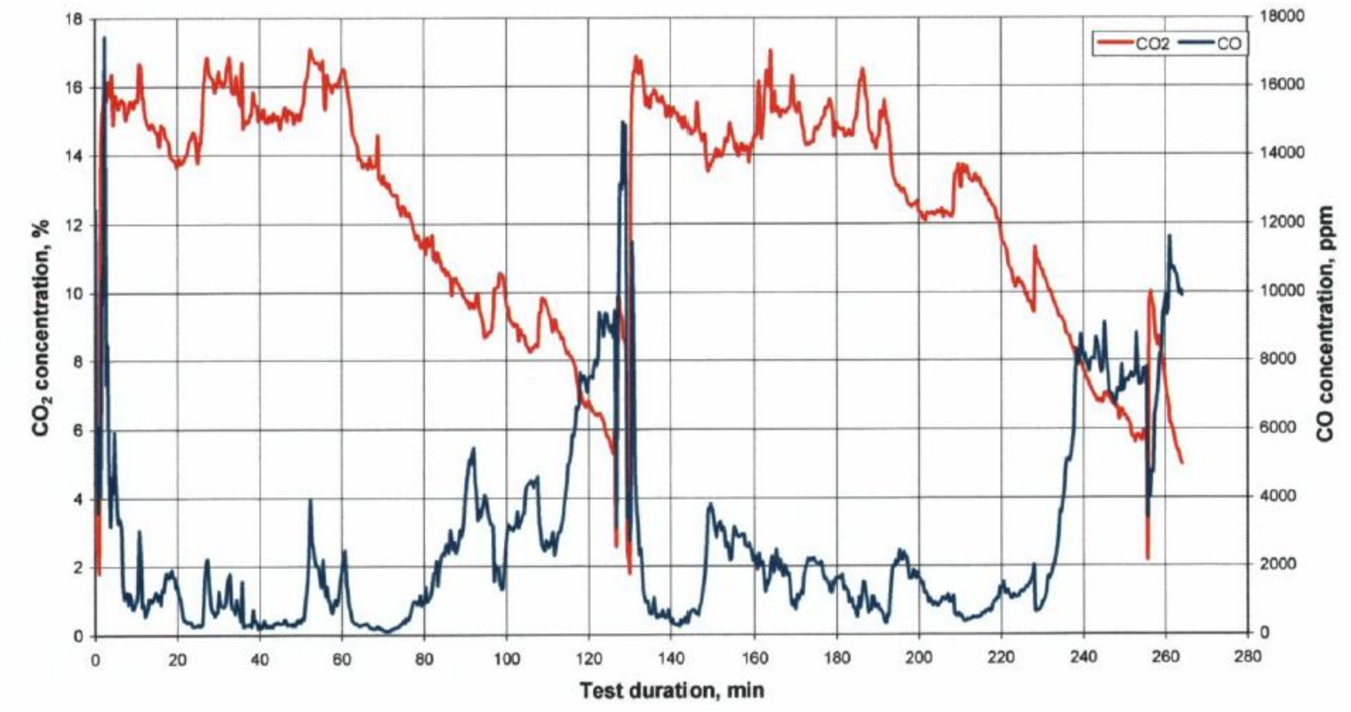


Figure 4.3 CO_2 and CO concentrations at nominal heat output

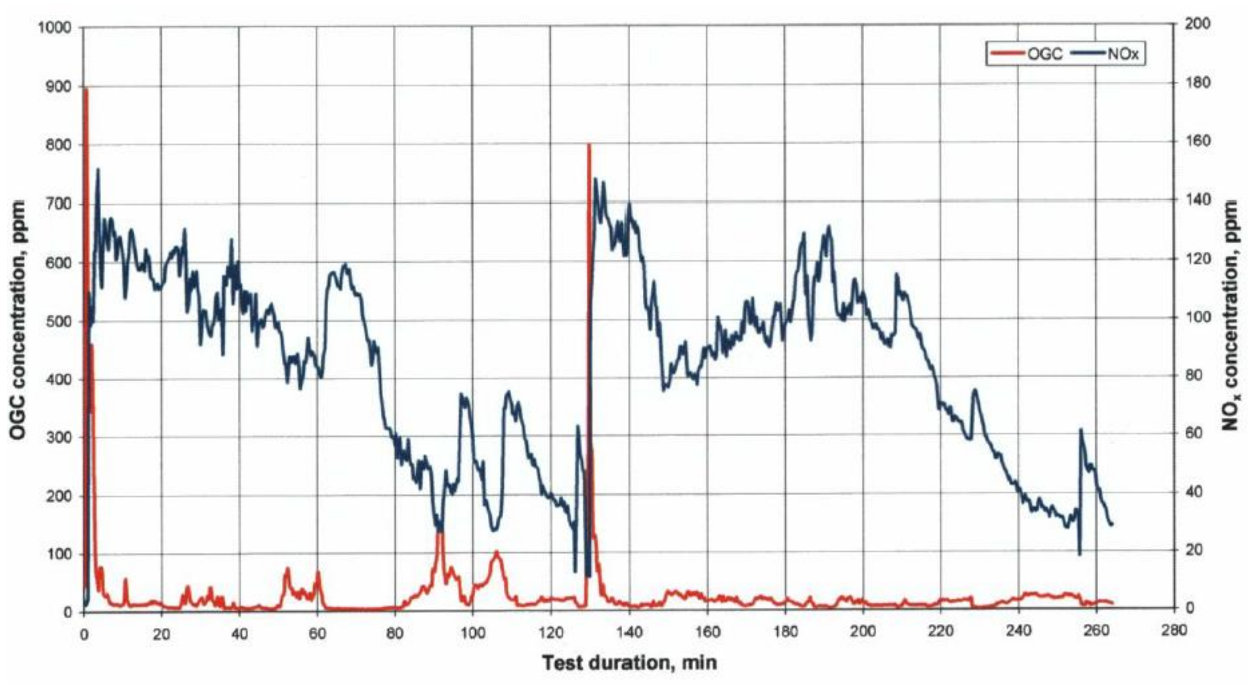


Figure 4.4 OGC and NO_x concentrations at nominal heat output

Combustion must be low-emission. The class requirements must be satisfied if the emission values shown in the Table 4.8 are not exceeded when operating at nominal heat output or, in the case of boilers with heat output range, when operating at nominal heat output and minimum heat output.

Table 4.8: Emission limits

Stoking	Fuel	Nominal heat output	Emission limits								
			CO			OGC			Dust		
			mg/m^3 at 10% O_2[a]								
		kW	class 3	class 4	class 5	class 3	class 4	class 5	class 3[b]	class 4	class 5
manual	biogenic	≤ 50	5 000	1200	700	150	50	30	150	75	60
		> 50 ≤ 150	2 500			100			150		
		>150 ≤ 500	1 200			100			150		
	fossil	≤ 50	5 000			150			125		
		> 50 ≤ 150	2 500			100			125		
		>150 ≤ 500	1 200			100			125		
automatic	biogenic	≤ 50	3 000	1000	500	100	30	20	150	60	40
		> 50 ≤ 150	2 500			80			150		
		>150 ≤ 500	1 200			80			150		
	fossil	≤ 50	3 000			100			125		
		> 50 ≤ 150	2 500			80			125		
		>150 ≤ 500	1 200			80			125		

[a] Referred to dry exit flue gas, 0 ^{o}C, 1013mbar.

[b] Boilers of class 3 for type E-fuels in this Table and marked with classification E-fuels and e-fuels do not need to fulfil the requirements for the dust emissions. The actual value has to be stated in the technical documentation and shall not exceed 200 mg/m^3 at 10% O_2.

Conclusion: The emissions value of CO conforms to the requirements of class 3 and emissions value of OGC conforms to the requirements of class 4 described in Table 4.8 of emission limits of the standard EN 303-5.

Dust concentration

Dust concentration was measured according to requirements of the standards EN 303-5 and EN 13284-1.

Dust sampling was carried out with an automatic isokinetic particulate sampling system. Dust collection filters used in the device was filled with glass wool. Equipment used for conditioning and weighing of the filters conforms to the requirements of the standard EN 13284-1. Samplings of the dust was carried out according to requirements of subsection 5.9.2 of the standard EN 303-5, where the arithmetic average CO_2 or O_2, CO, OGC (and NO_x where appropriate) contents are determined over the entire test period at nominal heat output. To determine the dust content the test period is divided into at minimum 4 equal time sections. The measurements begin in each case at the start of the sections, with the first measurement taken when the test begins. Time per filter is limited to 30 min. The suction time per filter is ≥ 30 min. The average dust content is determined from a minimum of 4 values. Sampling of overall blank was carried out, and after sampling filters and rinsing solutions were processed according to requirements of the standard EN 13284-1. Filters and cruets with precipitate of rinsing solutions were dried 1 hour at 160°C temperature.

Table 4.9. Dust concentration at nominal heat output

Parameter	Unit	Value				Average
		1	2	3	4	
Suction period	min	30	30	30	30	---
Sample volume	m^3	0.080	0.093	0.099	0.098	---
CO_2 concentration	%	15.3	11.0	14.9	12.8	---
Content of dust sample	mg	1.4	0.9	1.2	0.9	1.1
Dust concentration	mg/m^3 *	13.1	9.8	9.5	8.0	10.1
Dust concentration	mg/MJ	6.4	4.8	4.6	3.9	4.9

*value given at O_2 concentration of 10 %.

Expanded uncertainty of measurement of dust concentration is ±4.2%.

Conclusion: Dust concentration conforms to the requirements of the class 5 4 described in Table 6 of emission limits of the standard EN 303-5.

4.6. Electrical consumption

Electrical consumption was measured according to the requirements of subsection 5.8.5 of the standard EN 303-5. The average electrical power consumption during stand by shall be measured for a minimum duration of 10 min and is stated in watts.

Table 4.9.1. Electrical consumption*

Operating status	Measurement duration, min	Electrical energy, Wh	Electrical power consumption, W
Nominal heat output	263.0	140	31.9
Ignition	16.0	10	37.5
Standby mode	14.3	0.1	0.4

*tests were made by non-accelerated test method.

4.7. Waterside resistance

Waterside resistance was measured according to requirements of subsection 5.11 of the standard EN 303-5.Where the waterside resistance (measured in mbar) shall be determined for the flow which is equivalent to the rated output of the boiler at a temperature difference of Δt = 10 K and 20 K between the flow and return.

Table 4.9.2 Waterside resistance

Temperature difference at nominal output, °C	Water flow rate, m^3/h	Pressure difference, mbar
10	2.2	9.4
20	1.1	2.6

Conclusion: The Waterside resistances were determined for those flows which correspond to the nominal heat output with two temperature differences of 10 K and 20 K between the flow and return connections of the boiler. The results correspond with the values indicated by the manufacturer and conforms to the requirements of standard EN 303-5.

Surface temperature

The mean surface temperature is measured at nominal heat output. For this a minimum of 5 points on each boiler surface shall be measured. Under the same conditions the critical temperatures (e.g. boiler doors, operating levers) shall be measured. Surface temperatures were measured according to requirements of the standard EN 303-5.

During testing the surface temperature of operating levers and all parts which shall be touched by hand during operation of the boiler must not exceed the room temperature by more than the following values:

- 35 K for metals and similar materials
- 45 K for porcelain and similar materials
- 60 K for plastics and similar materials

Table 4.9.3 Surfaces temperatures

Surface	Measured temperature °C					Average. °C	Expanded uncertainty, °C
Right side surface	39	33	28	26	26	30	±0.04
Left side surface	31	31	29	28	28	29	±0.04
Front surface(controller area)	35	38	38	39	36	37	±0.04
Front surface(air supply area)	30	31	31	31	31	31	±0.04
Rear surface	39	30	29	28	30	31	±0.04
Top surface	34	37	34	31	31	33	±0.04
Floor below boiler	32	30	28	26	29	29	±0.04
Top doors surface	43	44	47	44	47	45	±0.04
Bottom doors surface	56	59	69	52	50	57	±0.04
Controller surface	32	33	33	---	---	33	±0.05
Handle of flue damper	32	32	32	---	---	32	±0.05
Handle of top doors	29	30	31	---	---	30	±0.05
Handle of bottom doors	29	30	30	---	---	30	±0.05
Ambient temperature	---					22	±0.07

Conclusion: The surface temperature of the outside of the boiler (including the bottom and doors but except the flue gas outlet and maintenance openings of natural draft boilers) did not exceed the room temperature by more than the allowable 60K and thus the temperatures of boiler surfaces conform to the requirements of the standard EN 303-5.

Function check of the temperature controller and safety temperature limiter

Function check of the temperature controller and safety temperature limiter was carried out according to requirements of standard EN 303-5. The water-side flow rate shall comply with that specified from the nominal heat output test. The flow temperature of 75 °C shall not be exceeded at the start of the test.

Outlet water temperature from the boiler has reached 96.8 °C and did not exceed the allowable temperature of 100 °C with temperature controller switched on.

After switching off the temperature controller, water temperature reached 94.8 °C, the temperature limiting device interrupted the boiler operation (the exhauster switched off). After 4 min. temperature reached 100.7 °C and did not exceed the allowable temperature of 110 °C. During the test CO concentration reached 1.4% and did not exceed the allowable concentration of 5%. The boiler operation was restored manually switching on emergency switch.

Conclusion: Functioning of the temperature controller and safety temperature limiter conform to the requirements of the standard EN 303-5.

Function test on the device for dissipating excess heat

Function check of the device for dissipating excess heat was carried out according to requirements of the standard EN 303-5. The firing is adjusted so that it corresponds to the nominal heat output Q_N of the boiler, a steady state condition is reached and the outlet pressure at the flue gas section is according to the nominal heat output. For the evaluation of the temperatures and the CO-concentrations only mean values at a maximum average time of one minute shall be considered.

When the boiler was operated at the nominal heat output the temperature controller was switched off and transfer of heat to the heating system was cut off. During the test water temperature reached 96.7 ^oC and did not exceed the allowable temperature 110 ^oC. During the test CO concentration reached 0.5 % and did not exceed the allowable concentration of 5%.

Conclusion: The safety heat exchanger or other devices for dissipating excess heat does ensure that a maximum boiler water temperature of 100^oC is not exceeded. Functioning of the device for dissipating of heat excess conforms to the requirements of the standard EN 303-5.

Loss of combustion air supply

Loss of combustion air supply test was carried out according to requirements of the standard EN 303-5. The safety of the heating boiler shall be checked at maximum heat input under the following conditions:

- Failure of the combustion air fan;
- Failure to close of the adjustable combustion air supply.

In each case only one failure shall be simulated.

The CO concentrations in the boiler shall not exceed 5 Vol. %

When the boiler was operated at the nominal heat output the exhauster was switched off. During the test CO concentration reached 1.7% and did not exceed the allowable concentration of 5%.

Note: Test was made by non-accredited test method.

Conclusion: Operation of the boiler during the loss of combustion air supply test conforms to the requirements of subsection 4.3.5 of the standard EN 303-5.

Note: Expanded uncertainty is stated as the standard uncertainty multiplied by the coverage factor k=2, which for a normal distribution corresponds to a coverage probability of approximately 95%. The standard uncertainty has been evaluated in accordance with EA-4/02.

5. Cost analysis

The cost expenses for the new boiler must be similar to that of the previous one, but at the same time have better efficiency then its previous predecessor. The necessary in-depth cost calculations were made for both new and old boilers and presented in the table 5.1 and table 5.2 A detailed cost analysis of both boilers is presented in the appendix section.

Table 5.1 boiler G-25E cost expenses

Boiler G-25E (old version) cost expenses		
	Cost elements	Eur/pcs
1.	Materials + packaging	512
2.	Galvanic coating	-
3.	Transportation costs	17
4.	Staff expenses	238
5.	Workshop costs	753
6.	Operating expenses	58
7.	Factory costs	826
8.	Profit	88
9.	Price	915
	Added value	387

Table 5.2 boiler B-25E cost expenses

Boiler B-25E (new version) cost expenses		
	Cost elements	Eur/pcs
1.	Materials + packaging	528
2.	Galvanic coating	-
3.	Transportation costs	17
4.	Staff expenses	238
5.	Workshop costs	772
6.	Operating expenses	58
7.	Factory costs	830
8.	Profit	96
9.	Price	926
	Added value	397

Conclusion: The two tables show, that the cost expenses between two boilers are nearly identical and won’t require additional funding in to its production. This means that the new upgrades are cost effective while the boiler technical characteristics are increased.

6. Conclusions

1. In this project I have introduced the main types of heating boilers, that are offered on the market.
2. Have analyzed the current older version of the boiler, performed the necessary reverse engineering operations and analyzed all the currently occurring issues.
3. After examining the collected data, presented new feasible upgrades in CAD models that need to be applied to the new version of the boiler.
4. The 3D CAD version of the new B-25E boiler was created for a better understanding on how the new upgrades will operate and to make sure that they will be simple and practical.
5. The testing of the new boiler was performed in accordance with standards standard LST EN 303-5:2012 (EN 303-5:2012). The test results show that the new boiler upgrades are functional and the goal of increasing the boiler class from 3 to 4 was achieved.
6. The cost expenses were analyzed and the results show that the new upgrades won’t require additional funding, which means that the new upgraded B-25E boiler is cost efficient.

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