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Life Cycle Assesment (LCA) Based Environmental Impact Minimization of Solid Fuel Boilers in Lithuanian Industry

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Today Europe is facing unprecedented energy problems related to the EU dependence on energy imports, concerns about global supplies of fossil fuel and obvious climate change. However, despite all these problems Europe wastes at least 20 percent of energy due to its inefficient use [1].

The EU energy efficiency policy states that one of the biggest saving potentials lies in heating of the buildings whose current consumption is ~ 1725 Mt. The EU building sector is the largest final energy consumer [2].

This research deals with domestic solid fuel boilers that are used in buildings and their efficiency increase by applying life-cycle tools. This article analyzes the situation of manufacturing solid fuel boilers in Lithuania, the EU EuP policy, the main environmental issues of boilers production (their production and use phases). The impact of two different fuels (wood and coal) on the environment is also estimated, propositions of an ecological design of boilers are presented and a new solid fuel boiler is described.

Keywords: *environmental impact, solid fuel boiler, coal, firewood, life-cycle assessment.*

1. Introduction

This article analyzes Lithuanian home production of solid fuel boilers which use either coal or firewood with an output of 10 kW for heating up to 150 m^2 area and their lifetime being 10 years. The article aims at doing life cycle assesment (LCA) for a typical household solid fuel boiler produced in Lithuania, reducing its environmental impact by applying LCA methodology and providing recommendations and solutions for minimization of a negative boiler‘s impact on the environment throughout its life cycle.

Since 1970 the energy consumption around the world has grown twice, and it will rise three times after 2030 [3]. Solid fuel as well as liquid fuel and gas are running out which result in the rise of the energy prices. In addition, high emissions of CO_2 have an impact on our climate. Today energy efficiency has acquired an extreme importance. The maximum effect of energy efficiency can be achieved by reducing usage of mineral resources and increasing that of renewable energy.

There is a need of an effective use of resources, energy efficiency, technological processes with low greenhouse gas emissions, organic products, maximum avoidance of waste, and effective consumption of its raw materials and maximum use of recycled ones.

Increase in energy efficiency is one of the EU policy strategic directions, whereas energy efficiency is relevant and useful not only nationally, but to each its end user [3].

The changes in energy use are inspired by the growing consumers’ demands and market competition. It is looked for boilers that use less fuel charged to burn as long as possible, that control heat effectively and minimize emissions into the atmosphere.

Currently, solid fuel boilers cause a big impact on the environment. Significant environmental aspects of solid fuel boilers are the following:

1. Energy consumption during the use;
2. Emissions during the use:

- CO;
- OGC (hydrocarbons);
- Solid particles;
- Methane and nitrous oxide;
- Suphurnd nitrogen oxides;
- Nitrogen oxides and ammonia;
- Ash.

2. Analysis of environmental impact of solid fuel boilers

Until 1956 in energy balance dominated domestic energy sources - wood, peat and its briquettes, various waste and water energy making about 60% of the total fuel consumption of heating [26].

Since the middle of the last century energy consumption in the world is growing rapidly - in 50 years the total primary energy consumption has risen six times. Although after the rise of oil prices there has been much progress in enhancing energy efficiency, energy demand keeps to the overall growth trend [25].

A solid fuel boiler does not greatly differ in its structure from other boilers: it uses the same types of radiators and pipe-work, on the whole it can be used in the under floor heating systems. There are two major differences to be aware of when considering a solid fuel boiler, which are:

The fire inside the boiler providing the essential running heat can close down, but it cannot halt inside the boiler system completely, in other words, it must be active, even marginally, at all times. Because of this, a solid fuel boiler must always be connected to a hot-water system or a radiator so that the created surplus heat can be used.

According to the principle of combustion solid fuel boilers can be divided into two main categories: direct combustion and gas generation. Direct combustion is a classic, traditional fuel burning, when in the furnace combustible gases are released from wood and are immediately burned. There are two main types of direct combustion boilers: the upper and lower combustion. Currently, lower combustion boilers are produced. Their popularity can be attributed to the fact that the products of combustion heat are used better, they are easier in handling, and combustion control is more precise.

3. Analysis of environmental impact of solid fuel boilers produced in Lithuania

A qualitative study is chosen to investigate solid fuel boilers. Data have been collected by a questionnaire. The questionnaire is based on a list of questions. 12 key questions are handed in such a way that they could be used as responses to the diagnostic work. The obtained data are processed.

Solid fuel boilers have been studied and the results are as follows:

All boiler producing companies in Lithuania were established more than 16 years ago, some of them even earlier. This shows that this industrial area is not new in Lithuania, and it is well developed.

66% of the enterprises are classified as small by the number of employees, an average number of employees being about 15, 17% of the companies are classified as medium-sized (50-250 employees) and 17% are large companies (> 250 employees).

In addition, all companies have indicated that they are producing solid fuel boilers only.

30% of the companies supply solid fuel boilers to the other EU countries, the rest of them - 70% sell boilers in the local market because due to their low efficiency it is difficult to compete with boiler producers of the EU countries.

All companies have evaluated a preliminary boiler's effect on the environment during exploitation; the laboratory testing was also carried out.

65% of the companies state that consumers purchasing boilers are not interested in their environmental impact, 35% state that there is a partial interest, but it is not essential. Among the consumers it is not popular enough to evaluate an environmental impact, there is a lack of the basic information on environmental protection.

Also, 65% of the companies are planning to increase the products' energy efficiency, 17% of the companies say that there is no need to change the efficiency of boilers, and 18% state that because of the threat of bankrupcy an increase in energy efficiency is not planned in the future.

It is found out that not all companies have the boiler control equipment (except thermostat),. 40% of the companies indicate that they have control equipment and use it for some products, but not always, 40% say that they have no such equipment and 30% indicate that all products have the control equipment.

83% of the companies currently do not apply life-cycle assessment to their eco-design products, 17% plan to do it in the future. This shows that only a small percentage of producers are interested in product performance and seek to minimize the effect on the environment at all stages of the production.

4. Methodology of solid fuel boiler LCA study

Life-cycle assessment (LCA) is a holistic approach to the product when there is an evaluation of a product's environmental impact throughout its life cycle: from raw material extraction, transportation, processing and finishing with the collection of waste (Figure 1) [16].

Each stage of the life cycle is associated with a greater or lesser impact on the environment. This is water and energy consumption, waste water contaminated with various chemicals, transport emissions during the transportation of raw materials and products, and wastes. Therefore, when designing a product it is sought to assess the impact on the environment in various stages of production, as well as during exploitation and product processing.

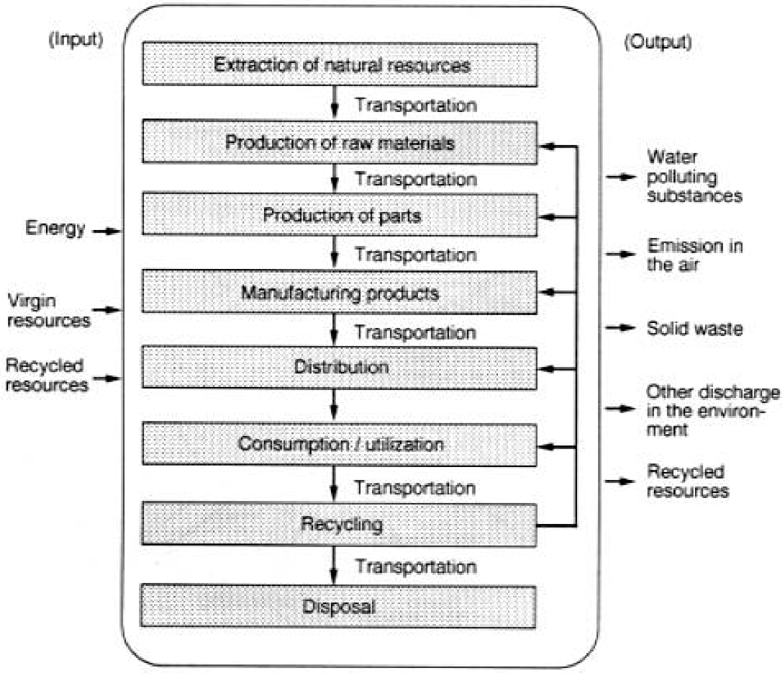

Fig. 1. Principal LCA scheme (according to Pepper et al. 2006) [16]

LCA can be used in comparing multiple products that are performing the same function e.g. which product: polystyrene cup or paper cup, textile cloth or disposable one, a car using diesel fuel or propane gas has a smaller impact on the environment. Product comparisons are always interesting and useful, but uncertainties, inaccuracies are inevitable: one product can be produced of recycled materials, but exclude more pollutants during its production, manufacture of other products requires less energy, but more toxic substances, the manufacturing process of the third product may result in less emissions, but its recycling is a problem [5].

LCA together with the ecological balance and profile analysis of the environmental resources are a very suitable method for evaluation of the environmental consequences of the product or "from the cradle to the grave" process. The Environmental Toxicology and Chemistry Association defines LCA as "a process that is used to assess the impact of products, processes or activities on the environment" [16].

Product life cycle. Product life cycle includes not only current product's manufacturing processes, but also those processes that were performed in the past (i.e.: raw production and mining, transportation, energy production) or those that will take place in the future (i.e.: product use, reuse, recycling and final disposal). Typical product life cycle stages are:

– raw production - all the processes needed for extraction of raw materials and energy from nature, including transportation and processing;
– processing and manufacturing processes required to produce the desired product from raw materials and energy;
– distribution and transportation - final product delivery to final consumer;
– use, re-use and maintenance procedures that are associated with the use of the product;
– recycling begins when the product performs its original intended function, and it is processed in the same system (closed loop recycling) or transferred to the new product system (open loop recycling);
– waste management begins when the product performs its intended function and it is returned to the environment in waste form [6].

The combination of these stages forms the product's'from the cradle to the grave'.system.

LCA is one of the environmental management practices which is used for related environmental aspects of the products or services and for identifying and assessing potential impacts [6].

5. Environmental impact assessment using Ecoindicator'99

The Ecoindicator'99 method is a simplified LCA methodology which is specifically designed to be used during the product design. This methodology has been developed by the LCA expert group which consists of various representatives of European research institutions [7].

The Eco-indicator '99 database consists of many different tables in digital expressions that exhibit environmental impact of various materials, production processes, as well as transportation, power generation, and their d

6. LCA studies of solid fuel boiler

A typical solid fuel boiler has been selected for the study. This device is designed to heat dwellings (it is necessary to release the smoke through the chimney) equipped with an automatic or forced circulation heating system. The boiler is heated with coal or firewood. It is accepted that annually such a boiler burns about 1800 kg of coal (over 10 years, 489 GJ), or about 5400 kg of wood (over 10 years, 1031 GJ) (for the conversion of calories to GJ special conversion program has been used [9]). The II heat group: pine, alder, sallow firewood has been chosen for the study. Firewood humidity is 12-15%. Such firewood is burning well, yielding an excellent thermal effect. While burning dry wood, tar and water vapor do not exude, a combustion chamber and chimney are not polluted [10]. Calorific capacity of the II heat group firewood is about 4510 kcal/kg, cubic meter of that firewood weighs about 520-540 kg. The full weight of wood is needed to be multiplied to the calorific value - 4510 kcal / kg in order to obtain the amount of energy (10 years are taken). Also, the actual amount of released heat depends on firewood humidity. Referred humidity of 12-15% is reached within 1.5-2 years of storing wood in a covered, well-ventilated (purged) room. At that time, coal burning, depending on its brand, releases from 5000 kcal to 7000 kcal per kg (calculated as 6500 kcal) [11]. The boiler is intended to heat up to 110 m² area. The boiler is controlled by an adjustable choke.

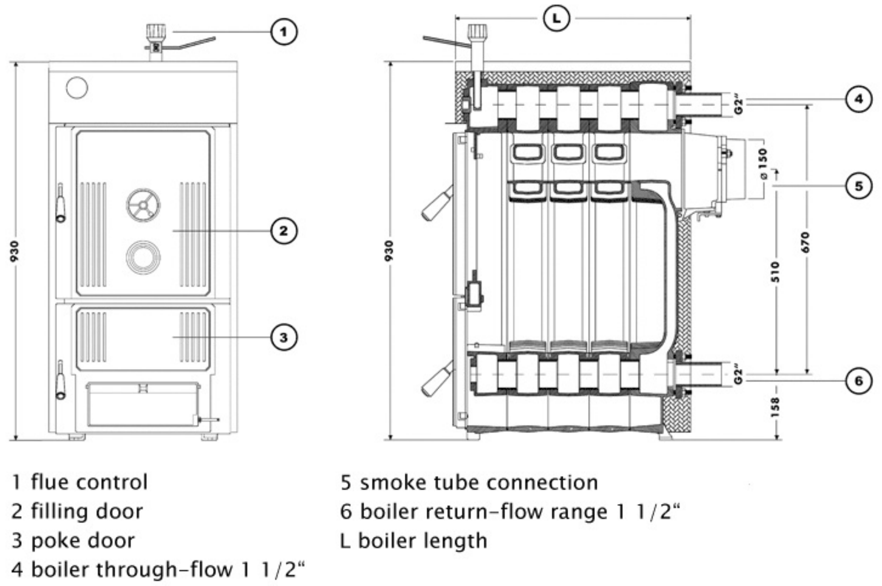

Fig.2. Boiler scheme

Details of solid fuel boiler parameters are presented in Table 1. The scheme is illustrated in Figure 2.

7. Analysis of environmental impact of solid fuel boiler

After calculation of eco-indicators (points) of the materials, processes and environmental impacts it has been revealed that all life cycle of the boiler makes 7452.28 points, the majority of which (7400 points) involves the use phase – burning of coal (3700 points burning of firewood). Coal-fired boiler in 10 years consumes 489 GJ and - 1031 GJ, if it burns only wood (Figure 3).

Table 1. Technical data

Rated heat output:	10 kW
Efficiency:	80%
Water content:	55 l
Draft requirement:	18 Pa
Dimensions with burner (H/W/D):	1135x502x870
Permissible operating pressure:	1.5 bar
Exhaust gas temperature:	135 °C
permissible flow temperature:	95 °C
Exhaust outlet diameter:	150 mm
Weight:	230 kg

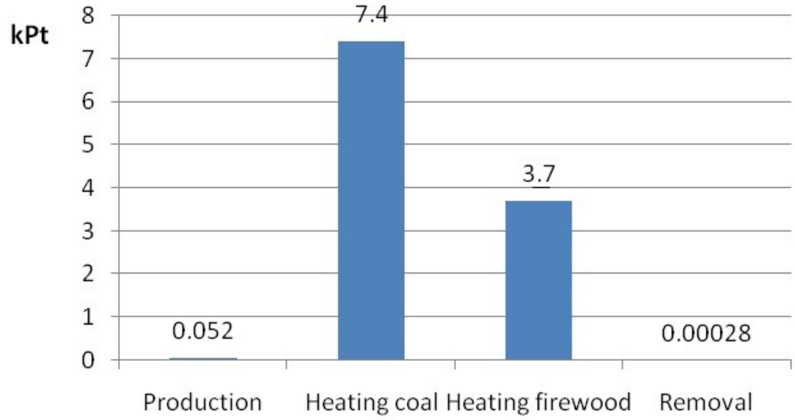

Fig. 3. Boilers using phases of coal and firewood

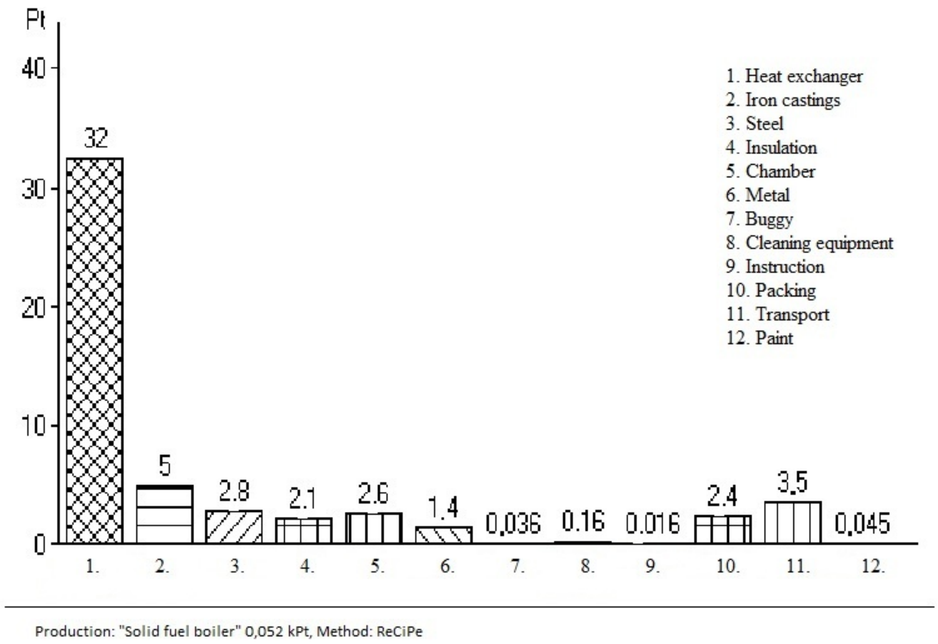

Fig. 4. Environmental impact of solid fuel boiler ingredients during production

The calculation of the eco-indicators (points) is presented in Figure 4. (Analysis was made using simplified life cycle assessment software (ECO-it) by using Ecoindicator'99).

After an environmental analysis using the Ecoindicator'99 methodology the following environmental aspects have been identified: (Eco-indicators are expressed by points (pt)):

– solid fuel consumption in the use phase 7400 pt when burning coal and 3700 pt when burning firewood;
– manufacture of boiler's components:
  • production of steel heat exchanger 32 pt and landfilling 0.089 pt;
  • cast iron casting 5 pt, because castings are recycled;
  • steel finish 2.8 pt, during elimination there is no environmental impact because steel is recycled.
– Production of boiler's accessories:
  • packaging 2.4 pt and packaging landfilling 0.057 pt;
  • b) paints 0.045 pt and paints landfilling 0.079 pt.
– Transportation 3.5 pt.

8. Strategies for solid fuel boiler's eco-design and the options for its improvement

The strategies for eco-design are actions that can reduce environmental impact [8]. According to the existing analysis of the boiler's environmental impact the following improvement solutions are offered:

1. To increase durability of the boiler:
   a) heat exchanger can be made of:
      • stainless acid-resistant steel. It would significantly extend the lifetime of the boiler, while the heat exchanger made of plain steel (Steel 3) leaks due to high temperature fluctuation and emissions generated during the burning, and its welding and repair are often ineffective and give a short time guarantee. Though the production of stainless steel heat exchanger

would increase boiler's price and the environmental impact would be significant during the production, but given the fact that the boiler will work longer the environmental impact would be less;
- heat-resistant steel;

b) reusable components should be customized. The boiler is to be produced in such a way that its worn out and unsuitable heat exchanger could be easily replaced by the new one, so that there would be no need to change the whole boiler. The boiler's body would remain the same. Reuse of the same parts leads to reduction in the quantity of inputs that are necessary for production.

2. Re-use of materials:

a) produce as many boiler parts as possible from secondary steel, almost the whole boiler can be made of recycled materials, because about 90% of boiler consists of steel;

b) produce as much as possible packaging from recyclable materials;

c) use recycled paper for installation and use instructions;

d) return a wooden tray back to the supplier so that the customer will not buy unused things and the manufacturer will use the tray several times;

3. Reduction of the total product weight. Compared to the other manufacturers (of other countries) of solid fuel boilers it is fully feasible, because their boilers are lighter, and the efficiency is the same or even higher. This could be achieved by reducing the height of both the boiler and water tank. Recently efficient low water capacity heating systems spread out rapidly, their benefits are low cost, rapid temperature control, etc. Steel can be used for decoration;
   a) Rejection of wheels. As the boiler is transported only during fitting, its location is fixed, its wheels are no longer needed;
   b) Reduction of the environmental impact in the consumption phase. Boiler controls have significant implications on the equipment efficiency, thus the right choice of control devices can increase the total heating product energy efficiency. 10-20% of the boilers do not have any control equipment (only boiler thermostat). In this way one of the solutions should be included into the well-designed system consisting of heat generators, pumps, controls, and in some cases, heat pumps, solar collectors. They should be optimized to work effectively in response to different needs (and the operating conditions). Some of the key factors in achieving this goal are:
   - intelligent control, seeking to ensure that the individual rooms are heated only when needed;
   - hydraulic balance (and control) seeking to reduce the return water temperature;
   - adequate support of renewable energy sources (solar, heat pumps, etc.) [13];
   - installation of microprocessor control system;
   - eautomatic ignition devices.
4. Control panel installation. On the top of the boiler microprocessor the control panel might be fitted which would help control the boiler work.
5. Switch to alternative energy sources.
6. Prevention of condensation in brick chimney. It should be fitted with special stainless acid-resistant steel liner.
7. The change of heat insulation material to more efficient. Reflecting insulation is to be used instead of usual rock wool.
8. The catalyst (firestone bricks) is installed inside the boiler for better products combustion and for maintaining high combustion temperature.
9. Universal design of the boiler. To construct a boiler with an opportunity to burn liquid or gaseous fuels.
10. The increase in boiler load volume. This would allow burning wood or wood briquettes longer. The burning time and the intervals between loads would lengthen;
11. To meet the legislation requirements, the boiler must be made only with the emergency cooling system (AAS). The boiler is equipped with AAS safety heat exchanger, which is fed with cold water when the temperature in the boiler exceeds 95°C. For AAS management it is necessary to obtain additional temperature exceeding safety valve with a temperature sensor.
12. The marking of the boiler's different parts with an indicator showing that WEEE should be disposed of separately (boiler controls, fan, and pump).
13. Information about the liquidation of the boiler when it is stopped being used.
14. For hot water preparation and heating aid the thermal solar heating system equipment could be used.
15. The installation of water treatment devices (water softening) would allow to:
   c) reduce heating costs;
   d) protect the radiator from contaminants;
   e) protect heating devices and system from formation of coal sludge in the boiler;
   f) protect against burst pipes;
   g) assure adequate water circulation in the system (pressure-flow and intensity).

Reducing the environmental impact of alternative selection. Alternatives reducing environmental impact are evaluated under the criteria set out in the company. The scoring system is evaluated from -2 to 2, depending on the benefits of improving the environment, to consumers, enterprises and the improvement of technical feasibility in economic and management sense. Scores are taken into account and alternatives receiving the highest scores are selected for further analysis.

According to the companies' results there are showed improvement alternatives (Figure 5). Most of them are important and need to be implemented by the company to increase the boiler's efficiency and reduce environmental impact complying with the legal requirements. Main alternatives reducing the envirnmental impact are: durability of the boiler building, re-use of materials, the total product weight reduction, boiler control equipment installation, fuel switching, which causes less environmental impact.

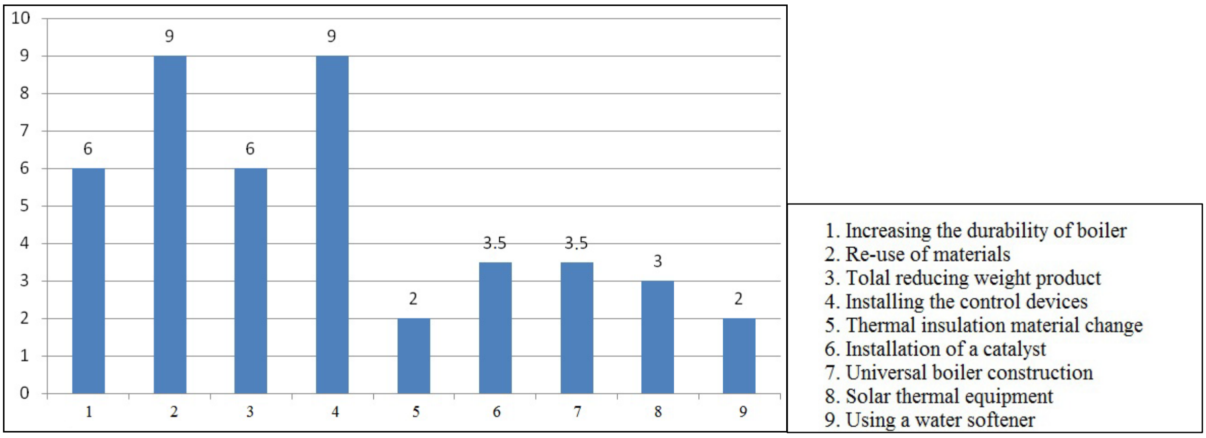

Fig. 5. Assessment of alternatives

9. Description of a new solid fuel boiler

Alternatives have been evaluated according to technical and economic aspects and it is considered that:

- Heat-resistant steel heat exchanger would cause a greater impact on the environment during its production, but given the fact that the boiler will be usable longer, the impact on the environment is more positive (it is accepted that the boiler will serve two-years longer, i.e. 12 years);
- Because of better steel quality (heat resistant) about 7% of steel is saved by reducing the mass of heat exchanger and capacity of water;
- The boiler is manufactured in a way, which would allow to replace only the worn out parts (heat exchanger, and kiln) and its body remains the same, thereby reducing the environmental impact during the production of housing when 23 kg of cast iron, 13.8 kg of steel decoration, 6.9 kg of metal parts and 2.3 kg of insulation material and 0.8 kg of cleaning equipment are saved.
- The whole boiler, except the heat exchanger, is made of recycled metal, thus reducing the environmental impact by 34 times.
- There is no need to produce new pallets, thus it is saved environmental impact of production of a new pallet by returning wooden pallets back to the supplier;
- Because of the comments on the boiler's waste disposal and instructions for WEEE separation, management of different parts of the boiler has become more efficient;
- The wheels are not used in a new boiler;
- Installation and user's manual is produced of recycled paper, and because of the comments about paper recycling, waste management has become more efficient;
- Use of soft water during exploitation extends life of the boiler and reduces heating costs;
- Controlled burning intensity can save up to 40% of fuel [19].
- The environmental impact is reduced twice when using wood instead of coal (Figure. 6).

The eco-design strategy wheel can show solid fuel environmental impact. It reflects best the boiler changes in eco-design, this wheel allows a graphic comparison of an impact on the environment of old and new boilers, taking into account the different environmental criteria. The value is less, the environmental impact is less too (Figure 7).

The main Eco-design boiler production strategies are presented in the scheme of life cycle design.. A conceptual model of eco-design product is presented; it covers eight different life-cycle design strategies. The diagram shows the product life cycle opportunities for improvement, starting from material selection, production and consumption to the final waste clean-up.

After a solid fuel boiler is changed, the environmental impact assessment of a new product done by means of Ecoindicator '99 is given in Figures 8 and 9.

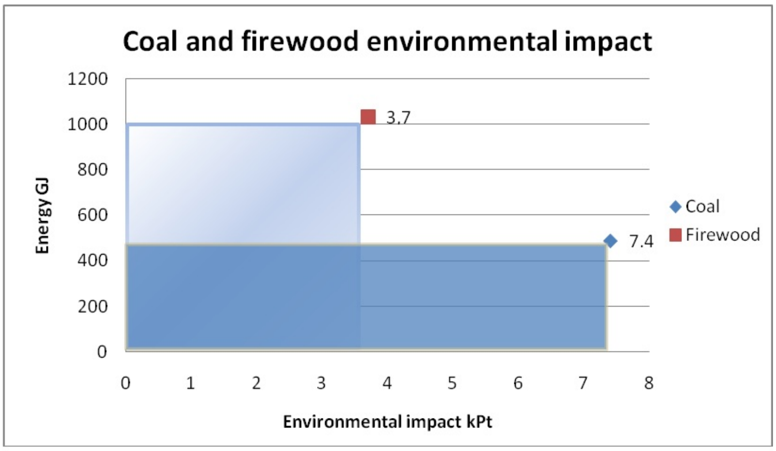

Fig. 6. Energy realease from the solid fuel and environmental impact

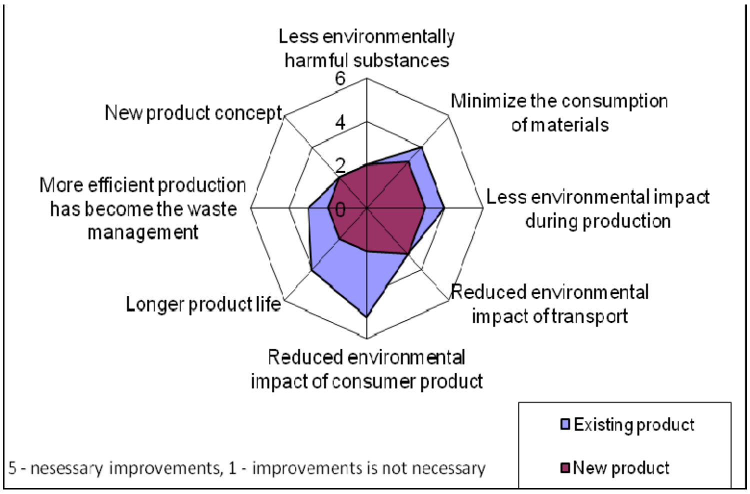

Fig. 7. Solid fuel boiler eco-design strategy wheel

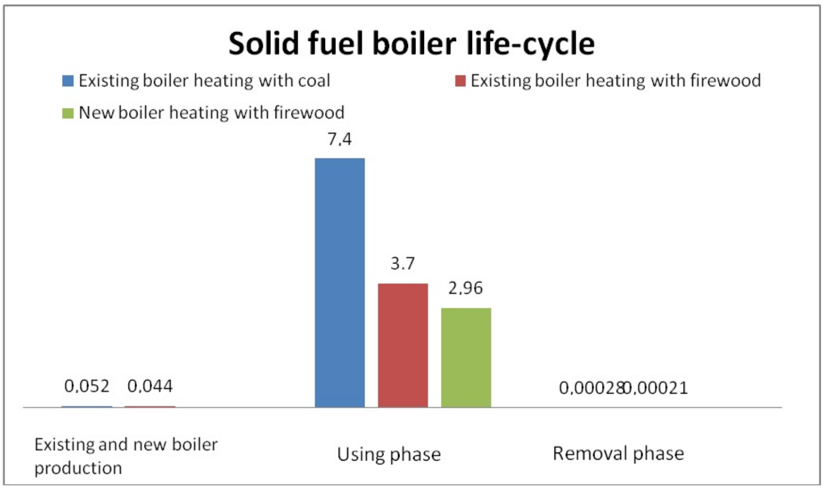

Fig. 8. Existing and new boiler environmental impact

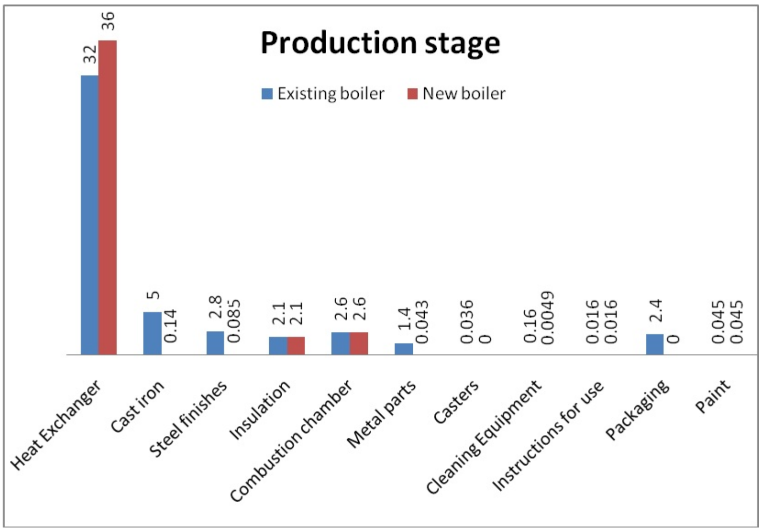

Fig 9. Existing and new solid fuel boiler environmental impact during production

10. Conclusions

1. Boiler controls have a significant effect on the equipment efficiency, the proper choice of control devices helps manufacturers increase the total heating energy efficiency. In addition to the energy efficiency they may bring real and achievable savings and economic benefits.
2. The study on manufacture of solid fuel boilers has revealed that 65% of boilers have no management software that would make it possible to reduce the environmental impact. It also became clear that 70% of companies seeking to increase the energy efficiency have no knowledge about the environmental impact during the boiler's entire life cycle.
3. ECO IT program has found that the greatest negative impact on the environment is caused by the boilers using phases 489 GJ (burning coal) and GJ 1031 (burning wood). It is also found that coal has twice greater impact on the environment than wood. (coal 7.4 kPt, wood 3.7 kPt). 1 GJ energy of wood content makes 3.6 Pt, and 1 GJ coal content makes 15.1 Pt.
4. The following improvements can be achieved in manufacture of solid fuel boilers: their lifetime extension, control panel installation, use of re-use materials, reduction of the total product weight, installation of thermal solar heating equipment, boiler parts marking, and several other means which reduce a negative impact on the environment.
5. According to the studies of new solid fuel boiler life-cycle assessment, it is estimated that during the manufacturing process 15% of reduction of environment impact has been achieved (Eco-indicator'99 value changed from 0.052 to 0.044 kPt), the environmental impact during removal is reduced by about 8% (from 0.28 to 0.21 Pt), and by using the environmental impact is reduced by 20% (from 3.7 to 2.96 kPt).

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Lietuvoje gaminamų kieto kuro katilų poveikio aplinkai mažinimas taikant būvio ciklo įvertinimo metodiką

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Lietuvoje dar nėra tirta buitinių kieto kuro katilų pagerinimo galimybės taikant būvio ciklo įvertinimo metodiką. Tyrimo metu išanalizuota buitinių kieto kuro katilų poveikis aplinkai – gaminimo, vartojimo bei šalinimo fazėje. Ištyrus, kad didžiausias poveikis aplinkai daromas gaminimo bei eksploatavimo metu, yra pateikti ekologinio projektavimo siūlymai, kurie leidžia sumažinti gaminimo bei vartojimo fazės metu daromą poveikį aplinkai.

Tad šiame straipsnyje analizuojamas buitinio kieto kuro katilo efektyvumo didinimas taikant būvio ciklo priemones. Būvio ciklo įvertinimas (BCĮ) – visuminis požiūris į gaminį, kai vertinamas gaminio poveikis aplinkai per visą jo būvio ciklą, pradedant žaliavų išgavimu, transportavimu, perdirbimu ir baigiant atliekų surinkimu.

Straipsnyje pateikiama kieto kuro katlių poveikio aplinkai analizė, ES energiją vartojančių gaminių politika, yra išanalizuota šildymo katilų gamybos situacija Lietuvoje, katilo gamybos grandinėje pagrindini aplinkos apsaugos aspektai (gaminio vartojimo fazės, gamybos fazės ir šalinimo poveikiai aplinkai). Kieto kuro katilo poveikio aplinkai nustatymui pasirinkta naudoti Ekoindikatorių '99 metodika – tai supaprastinta būvio ciklo įvertinimo metodika, specialiai pritaikyta naudoti gaminių projektavimo metu. Šią metodiką parengė būvio ciklo įvertinimo ekspertų grupė, sudaryta iš įvairių Europos mokslinių tyrimų institucijų atstovų. Taip pat šia programa įvertintas dviejų skirtingų kuro rušių (medienos ir anglių) poveikis aplinkai, pateikti ekologinio projektavimo pasiūlymai šildymo katilams.

Atlikus kokybinį tyrimą nustatyta, kad 65 % Lietuvoje gaminamų katilų neturi įdiegtos valdymo įrangos. Taip pat šio darbo metu buvo nustatyta, kad anglių poveikis aplinkai yra du kartus didesnis nei malkų (7,4 kPt ir 3,7 kPt), o katilo poveikis aplinkai po įdiegtų pagerinimo alternatyvų, sumažėtų 20 %.