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ENERGY EFFICIENCY ASPECTS OF CONDENSING BOILERS USAGE AND APPLICATION FOR LATVIAN RESIDENTIAL SECTOR

KONDENSĀCIJAS KATLU IZMANTOŠANAS ENERGOEFEKTIVITĀTES ASPEKTI UN TO IZMANTOŠANA LATVIJAS DZĪVOJAMAJAM SEKTORAM

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Introduction

Climate change is one of the greatest environmental, social and economical threats the planet faces. Especially, at fault are fossil fuels, the combustion of which gain energy producing a growth of carbon dioxide CO_2 in the atmosphere, making a huge impact on climate change.
There are two ways to minimize the amount of greenhouse gases:

- To switch to fuels, which produce a smaller amount of CO_2;
- To lessen the need for energy, by increasing the effectiveness of heat energy use.

The contraction of energy, respectively the contraction of fuel, is also relevant because of the increasing prices for fuels and combustibles. One of the directions in effective use and energy economy is the maximal usage of heat from combustion products.
A reasonable economy of fuel and CO_2 exhaust reduction can be achieved with condensing technique, which allows releasing the heat of condensation of water vapor in flue gases. The methods and constructions to achieve the water vapor condensing are different. The condensing type boilers are one of the possible constructions, which without additional installations provide the vapor condensation from flue gases. Taking a look at a range of fuels (Fig. 1), we can see that

natural gas as a fuel is the most appropriate one for water vapor condensation process – natural gas does not contain sulfur or ash, which creates problems during the process of condensation.

Appreciating the experience of many European countries, we have to draw the conclusion that, nowadays a big amount of all sold boilers are condensing boilers. Condensing heating boilers have no competitors from the ecological side: high efficiency lessen the usage of fuel, which, at its place lessens the emission amount of harmful substances. The usage of condensing boilers in new buildings has now almost become standard. Already at the design stage, the heating system is coordinated with the capabilities of the boiler because the maximal advantages of it are reached in systems with reduced heat carrier temperature. In older heating systems with a higher working temperature, the boilers work in about 80% of condensing regimen, which provides a certain economy of fuel.

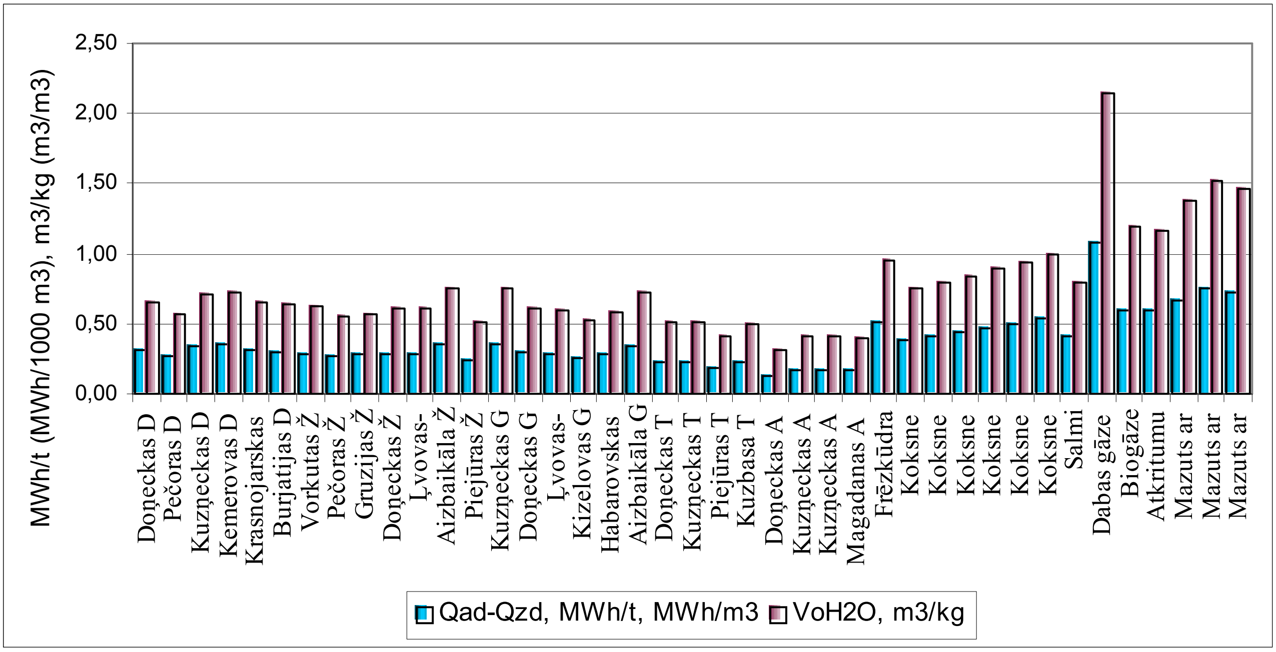

Figure 1. Comparison of fuels by the amount of vapor and their highest and the lowest combustion heat difference

Making the calculation of the natural gas used in Latvia, we gain following results (Tab.1).

Table 1.

Values defining the combustion of natural gas.

Theoretically necessary air V^o, m^3/m^3	Dry three atom gases $V_{RO_2} = V_{CO_2}$, m^3/m^3	Theoretical nitrogen volume $V^o_{N_2}$, m^3/m^3	Theoretical water vapor volume $V^o_{H_2O}$, m^3/m^3
9,63	1,01	7,62	2,171
The volumes of components in flue gases if the air excess α>1			
	α=1,03	α=1,05	α=1,07
Water vapor V_{H_2O}, m^3/m^3	2,176	2,179	2,182

Dry gases V_{sg}, m^3/m^3	8,9	9,1	9,3
Total volume of flue gases V_{dg}, m^3/m^3	11,1	11,3	11,5
Mass of dry gases M_{sg}, kg/m^3	12,4	12,1	11,9
Total mass of flue gases M_{dg}, kg/m^3	13,6	13,9	14,1
Mass of water vapor M_{H2O}, kg/m^3	1,740	1,742	1,745
Moisture content d, g/kg dg	146,38	143,59	140,92
Water vapor partial pressure, p_{H2O}, bar	0,198	0,195	0,192
Dew point temperature t_r, ^oC	59,8	59,5	59,1

Let us take a look at the heat balance of the boiler, respectively equation, which connects the heat introduced into the furnace Q_r with the usefully utilized heat Q_1 and the losses of heat ΣQ_{zud}:

$$Q_r = Q_1 + \Sigma Q_{zud} \qquad (1)$$

Accepting that

$$Q_r \approx Q_g, \qquad (2)$$

where Q_g is heat emitted during the combustion of the working mass of fuel, we can gain

$$Q_g \approx Q_1 + \Sigma Q_{zud} \qquad (3)$$

or

$$100 = q_1 + \Sigma q_{zud} = \eta_k + \Sigma q_{zud} \qquad (4)$$

Because of the two combustion heats - highest and the lowest combustion heat, two equations for boiler efficiency are possible.

$$\eta_k^z = q_1 = \frac{Q_1}{Q_z} \cdot 100 \quad \text{and} \quad \eta_k^a = q_1 = \frac{Q_1}{Q_a} \cdot 100 \qquad (5)(6)$$

In the first equation the efficiency coefficient of the boiler is referred to the lowest combustion heat of the fuel, in the second – to the highest combustion heat.

Nowadays in Latvia the lowest combustion heat Q_z of natural gas is approximately 33625 kJ/m^3, which set experimentally at t=20 °C and p=101325 Pa. The highest combustion heat Q_a is relatively equal with $1{,}11\cdot Q_z^d$ - then $Q_a \approx 37320$ kJ/m^3. If we take that $\eta_k^z = 90\%$, then Q$_1$=33625·90/100=30263 kJ/m^3. Using these values we can calculate η_k^a, %,

$$\eta_k^a = \frac{30263}{37320}\cdot 100 = 81{,}09 \tag{7}$$

η_k^z and η_k^a comparison with other values is given in the fig. 2.

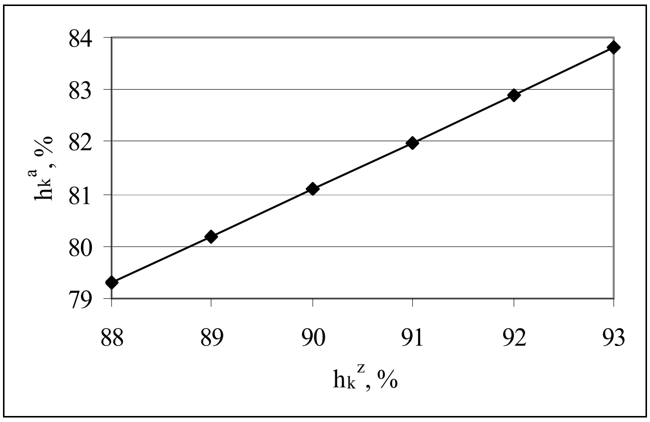

Figure 2. η_k^z and η_k^a comparison for natural gas

Let us value the heat losses Σq_{zud}. Let us assume, that

$$q_3=q_4=q_6=0, \tag{8}$$

where:
q_3 – losses of heat due to chemically incomplete combustion,
q_4 – losses of heat due to mechanically incomplete combustion,
q_6 – losses of heat with the slag and ash.

Making the measurements and calculations to define the heat losses in the ambient air q_5, it was obtained that for modern heating boilers with a good heat isolation q_5=0,3%.
The calculations of heat losses with the outgoing flue gases q_2 depending on the temperature of flue gases and air excess and referred to the lowest combustion heat give the following results (Fig. 3).

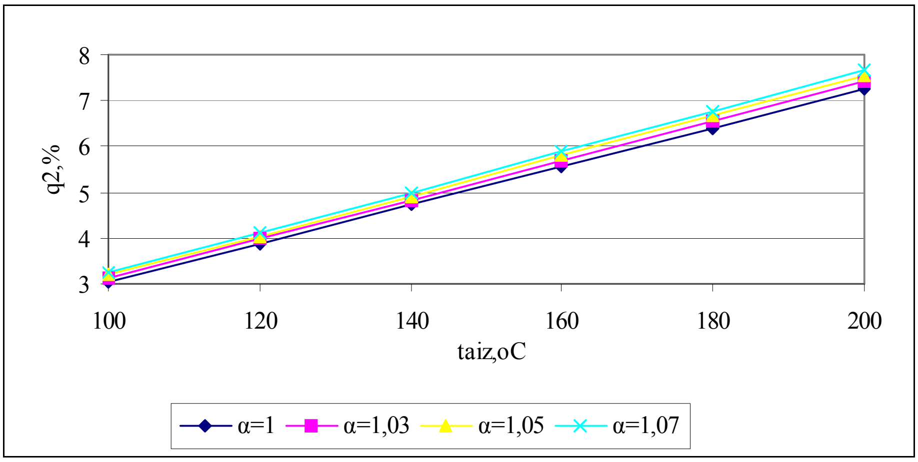

Figure 3. Heat losses with the outgoing flue gases q_2.

The increase of the efficiency by decreasing the temperature of flue gases and, respectively, decrease of the amount of natural gas usage, allows estimating the decrease of CO_2 exhaust:

$$\Delta CO_2 = V_{CO_2}\frac{Q}{Q_z}\left(\frac{1}{\eta_{k1}^{z}}-\frac{1}{\eta_{k2}^{z}}\right), \qquad (9)$$

where Q – the produced heat.
Assuming Q=1 MWh, we gain the ΔCO_2 values, which are given in the table 2.

Table 2.

CO_2 exhaust decrease, minimizing the temperature of flue gases (α=1,05)

	CO_2 exhaust decrease, minimizing the temperature of flue gases			
	from 180 to 160 °C	from 160 to 140 °C	from 140 to 120 °C	from 120 to 100 °C
ΔCO_2, m^3/MWh	1,023	0,999	0,976	0,654

After reaching a temperature lower then the dew point temperature water vapor, which is in the flue gases, condenses, releasing vapor condensing heat. Therefore the efficiency increases not only because of the flue gases cooling down, but also because of the usage of the water vapor condensing heat. Using the data from table 1, we can calculate the efficiency of the boiler, if the temperature of flue gases is lower then the dew point temperature. The efficiency is calculated referring to the lower combustion heat (Fig. 4).

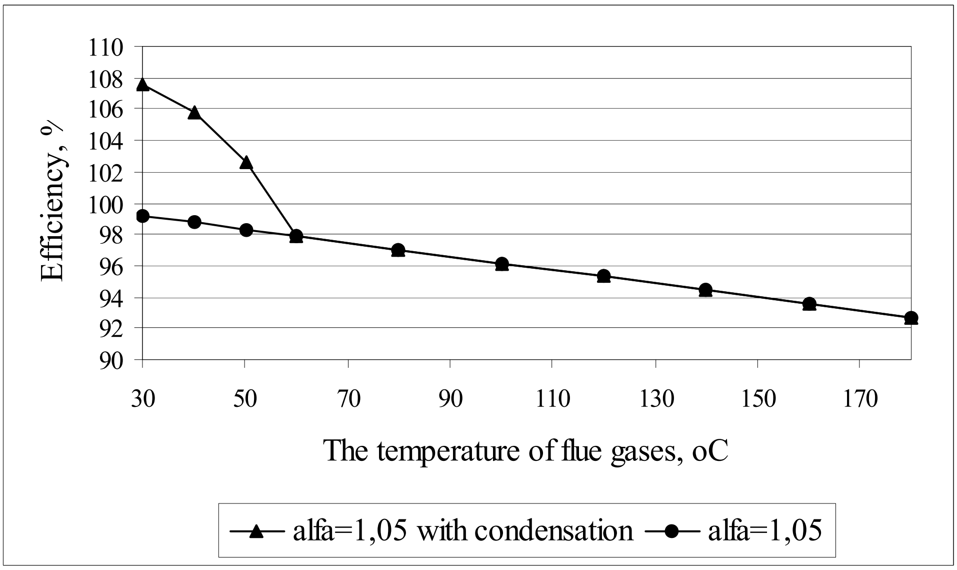

Figure 4. Efficiency of the boiler considering the condensation of water vapor

A line is drawn in fig. 4, showing the changes of boiler efficiency if conditionally accept that there is no water vapor condensation and the increase of the efficiency coefficient is the result of only of the cooling down of flue gases.

To estimate the applicability for typical buildings, which are about thirty or forty years old, we need to know the parameters of the building, the corresponding water, especially return, temperatures for the heating system, which are defined by the outdoor air temperature.

Knowing that condensing boilers are capable to work in the condensing regimen only in the case when heating system's water return temperature is lower then the dew point temperature, let us analyze the duration of heating season and the outdoor air temperature in three cities of Latvia with different climatic conditions, assuming that the water temperature for heating corresponds to the curve 95/70 °C.

Table 3 and fig. 5 give the outdoor air temperature allocation by intervals and the design temperature for heating for the chosen cities of Latvia.

Table 3

The allocation of outdoor air temperatures by intervals

Outdoor temperature intervals, ^{o}C	The duration of separate outdoor temperature intervals, h		
	Riga	Daugavpils	Liepaja
-20 and lower	14	53	3
-20...-15	77	168	33
-15...-10	260	339	155
-10...-5	553	652	402
-5...0	1202	1018	1035
0...5	1816	1708	2255
5...8	998	934	965
total:	4920	4872	4848
Design temperature for heating	-20	-26	-17

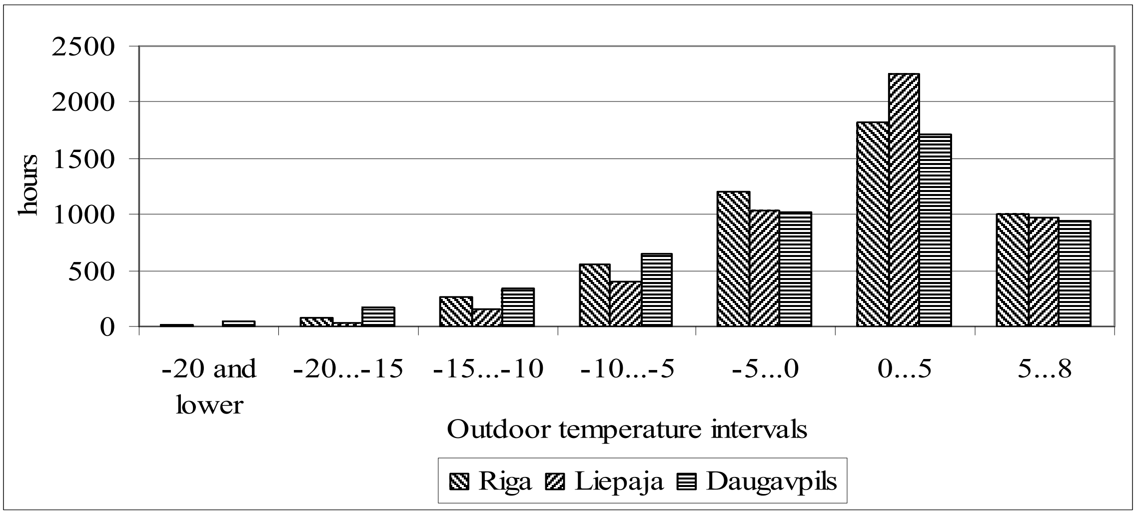

Figure 5. Outdoor temperature allocation by intervals

Forward and return water temperature depending on the outdoor temperature is given in the fig.6.

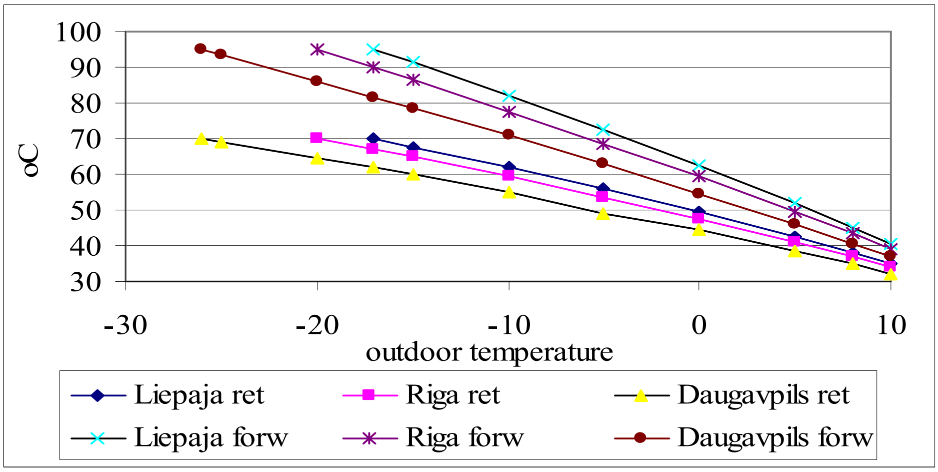

Figure 6. Forward and return water temperature depending on outdoor temperature

Combining the fig. 5 and 6 we gain coherence between the water return temperature from heating system and separate outdoor temperature durations (Fig. 7).

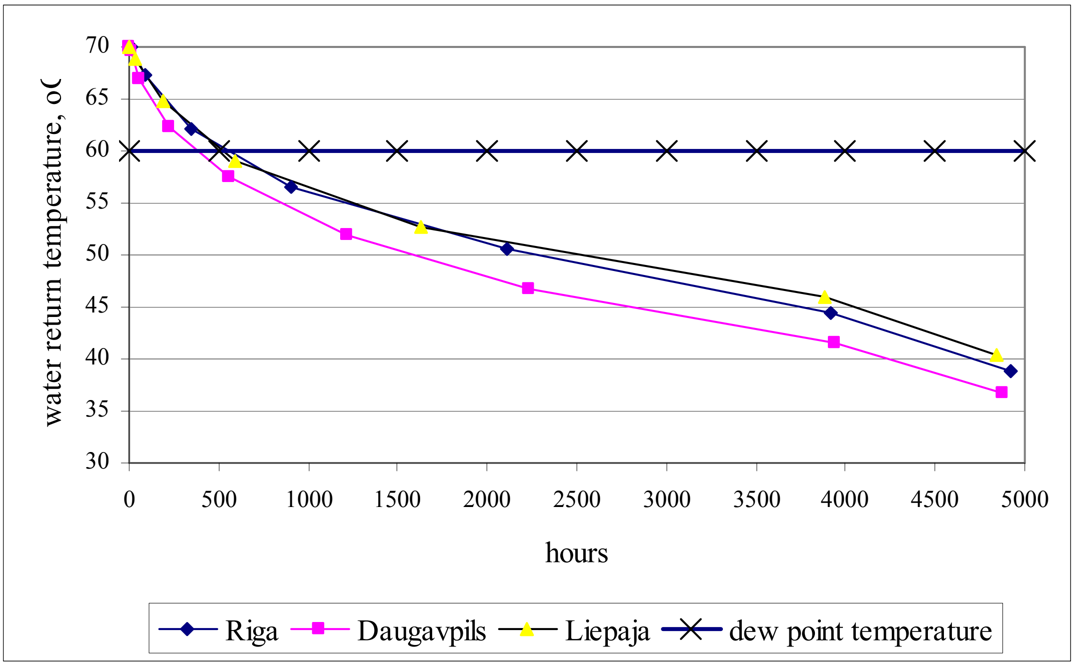

Figure 7. Water return temperature coherence with separate outdoor temperature durations.

The obtained results allow estimating economical characteristics of condensing boilers usage.

Conclusions:

1. The considerable growth of prices for natural gas makes one of the economy directions the maximal usage of the heat from combustion products, using condensing boilers.
2. Condensing technique allows using the heat of condensation, which is lost with outgoing flue gases in simple gas boilers. As a result the highest natural gas combustion heat is used.
3. Analyzing the possibilities to use condensing boilers for residential buildings in Latvian cities with already existing heating systems and water temperature curve 95/70 °C it was

stated that the work of the boiler in condensing regimen is possible for the most part of the heating season.

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Arajeva A., Gedrovičs M. Kondensācijas katlu izmantošanas energoefektivitātes aspekti un to izmantošana Latvijas dzīvojamajam sektoram.
Balstoties uz mūsdienu nepieciešamību efektīvi izmantot gāzes kurināmo un tiekties pēc CO_2 *izmešu samazināšanas un ņemot vērā gāzes kurināmā cenu ievērojamu pieaugumu, rakstā parādīti kondensācijas tehnikas izmantošanas energoefektivitātes aspekti - iespēja izmantot dabasgāzes augstāko sadegšanas siltumu, tādējādi samazinot kurināmā patēriņu un izmešu daudzumu. Zinot Latvijā izmantojamās dabasgāzes sastāvu, ir veikti siltumtehniskie aprēķini un atrasti degšanas produktu tilpumi, to parciālie spiedieni un attiecīgi izskaitļotas rasas punkta temperatūras, kas atbilst noteiktajām gaisa patēriņa koeficienta vērtībām. Ir salīdzināti katlu lietderības koeficienti, attiecinot uz augstāko un zemāko sadegšanas siltumu, un siltuma zudumu apmēri dažādu faktoru ietekmē. Ir analizēta iespēja efektīvi izmantot kondensācijas katlus Latvijas dzīvojamajam sektoram uz esošo apkures sistēmu bāzes. Atbilstoši Latvijas pilsētu klimatiskajiem apstākļiem, izvēlēto pilsētu aprēķinu temperatūrām, apkures sezonas ilgumam un dinamikai ir prognozētas apkures sistēmas tīkla ūdens atgaitas temperatūras, kas ļauj secināt par katla darbības kondensācijas režīmā iespējamību. Iegūtie rezultāti ļauj novērtēt kondensācijas katlu izmantošanas ekonomiskos rādītājus.*

Arajeva A.,Gedrovičs M., Energy efficiency aspects of condensing boilers usage and application for Latvian residential sector.
The considerable growth of prices for natural gas makes one of the economy directions the maximal usage of the heat from combustion products and reasonable economy of fuel and CO_2 *exhaust reduction can be achieved with condensing technique, which allows releasing the heat of condensation of water vapor in flue gases. The energy efficiency aspects of condensing technique - the possibility to use the highest combustion heat of natural gas to reduce the usage of the fuel and to decrease the volume of flue gases are shown in the article. Knowing the composition of natural gas used in Latvia, the thermo technical calculations were made as well as calculations of volumes of combustion products, their partial pressures and accordingly, the temperatures of dew points corresponding to particular air excess values. The possibility to use the condensing boilers was analyzed for the residential sector on the base of the existing heating system. According to the climate, duration and dynamics of the heating season of cities of Latvia the water return temperature was forecasted, which allows to conclude about the*

working ability of condensing boiler regimen. The gained results give the opportunity to estimate the condensing boilers economical value.

Араева А., Гедрович М., Аспекты энергоэффективности использования конденсационных котлов и их применение в жилом секторе Латвии.

В статье представлены аспекты энергоэффективности использования конденсационной техники – возможность применения высшей теплоты сгорания природного газа, снижая, таким образом, потребление топлива и количество выбросов. При наличии информации о составе используемого в Латвии природного газа были проведены теплотехнические расчёты и найдены объёмы продуктов сгорания, их парциальные давления и соответствующие коэффициенту избытка воздуха температуры точек росы. Была проанализирована потенциальная возможность использовать конденсационные котлы в жилом секторе Латвии на базе уже существующих отопительных систем. В соответствии с климатическими условиями, длительностью отопительного сезона и его динамикой в Латвийских городах, была спрогнозирована температура обратной воды в системе отопления, что позволяет делать выводы о возможностях работы котла в конденсационном режиме. Полученные результаты, кроме того, дают возможность оценить экономические показатели конденсационных котлов.