ENERGETIC REDEVELOPMENT OF THE BUILDINGS: THERMAL AND ECONOMIC COMPARATIVE ANALYSIS BEFORE AND AFTER THE SUBSTITUTION THROUGH CONDENSING BOILER

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Rezumat. Articolul prezintă analiza din punct de vedere termic şi economic pentru două instalaţii de încălzire: prima este o instalaţie tradiţională fară condensare şi cealaltă un sistem modern, modulat cu condensare. Scopul acestei analize este de a demonstra că modernizarea unei instalaţii de încălzire ,pentru căldură şi apă menajeră, se poate face numai prin utilizarea unei instalaţii de ardere cu condensaţie. Această modernizare conduce la o creştere a eficienţei de utilizare a căldurii rezultată prin ardere şi micşorarea consumului de combustibil.
Cuvinte cheie: instalaţii de încălzire, optimizare termică, instalaţii de ardere cu condensarea vaporilor de apă, reabilitarea termică a clădirilor.

Abstract. In this paper, it is presented the comparison of the thermal and economical analysis between two installations: a traditional boiler without condensing and a modern modulated condensing boiler. The aim of this study is to demonstrate the optimization of an existing system used for heating of a building, by the substitution of the old traditional boiler with a premixed burner short flame condensing boiler. The condensing boiler is connected by a middle capacity boiler for the annual heating and annual production of sanitary warm water. We demonstrate through this comparison, that this substitution allows to keep the high annual efficiency, following constantly the thermal load, with an important annual reduction of the fuel consumption.
Keywords: heating installation / thermal optimization / condensing boiler / burn of fuel / redevelopment build.

1. INTRODUCTION

In two flats heated and one buried not heated house with 200 m^2 surface and 600 m^3 volumes, we analyze from thermal and economical point of view the substitution of the existing traditional boiler, with a same power modern condensing boiler.

The traditional boiler is constituted by an open chamber combustion with 31.4 kW useful thermal power. The condensing boiler is constituted by ceramics matrix burner with continuous modulation of the flame from 16 to 100%. Both boilers work with methane fuel. The condensing boiler is constituted by a condenser-exchanger with water-flue gas and with mixing flows in stainless steel.

The fuel enters in the superior part of the condensing boiler and through a venture effect, it aspirates the fuel in the necessary quantity, forming a closed air-fuel mixture. With this type of burner the mixture succeeds to complete the combustion before the impact on the heat exchanger avoiding in this way the inhibition of the flame by contact with the cold walls and the consequent formation of unburnts.

When the combustion is terminated, the gas burned will contain: CO_2, CO, NO_x, but also 2 m^3 water vapour that condenses before going out from the heat exchanger, producing 1.56 litres of the liquid water. During the change of the state from vapour to liquid, the water releases its latent heat to the heat exchanger and therefore to the water of the heating circuit [5].

The saving of the fuel has been valued through the comparison between the consumptions before and after the substitution of the traditional boiler with the condensing boiler.

The figure 1 shows the scheme of an installation with 35 kW burned thermal power traditional boiler constituted by nozzle gas burner and connected to a 120 litres warm water boiler.

The temperature of the going water distributed to the thermo-syphon is regulated by a mixer valve moved by an electric motor that is checked by an electronic regulator with a temperature probe for the going water and another one for the external air. A further probe sets on the return in boiler, acts as anti-condensate, closing partially the mixer valve every time when the temperature of return water goes down under the 323 ÷ 328 K (50 ÷ 55°C). This avoids the inhibition of the flame at contact with the cold heat exchanger and therefore the consequent formation of condenses.

When instead, the anti-condensate probe notices a superior temperature above the 323 ÷ 328 K, the regulator opens the mixer valve to bring the temperature of the thermal fluid to the desired level.

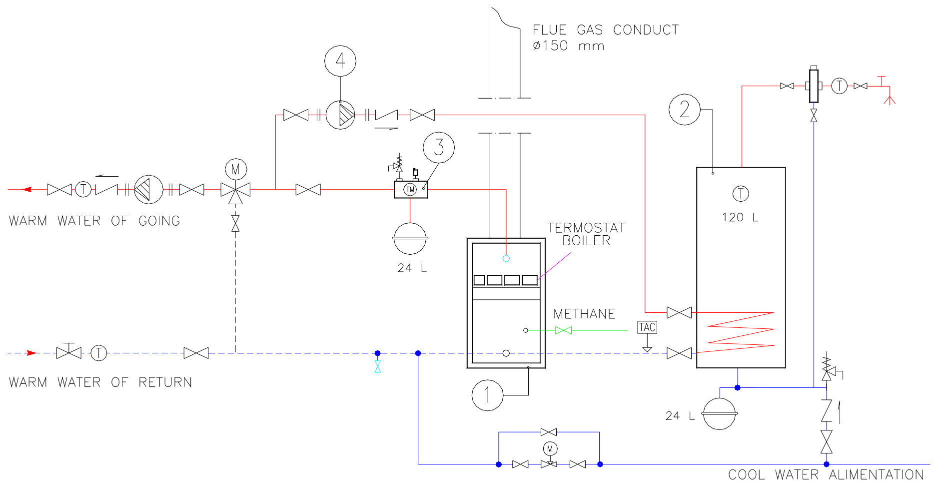

Fig. 1. Scheme of the existing installation:
1 – traditional boiler; *2* – boiler for warm water; *3* – disaerator; *4* – pump anti-condensate.

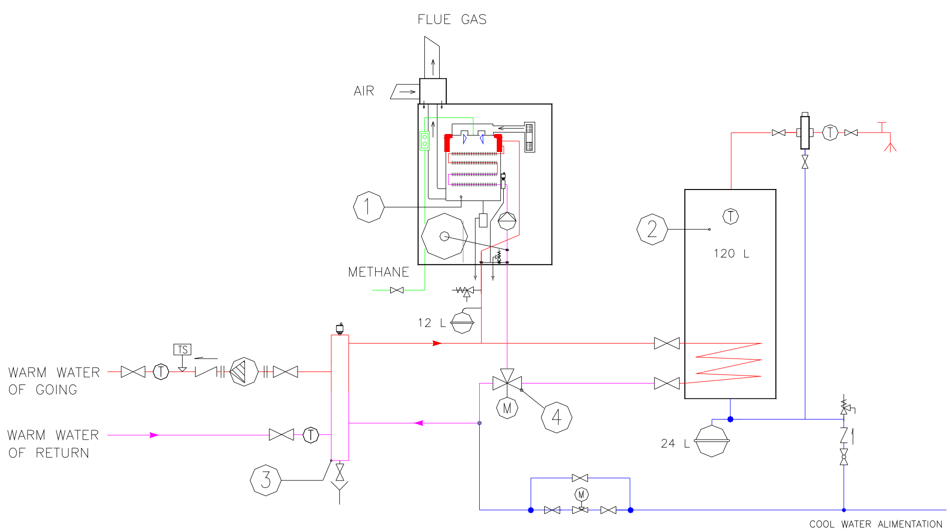

Fig. 2. Scheme of the installation with condensing boiler:
1 – condensing boiler; *2* – boiler for warm water; *3* – vertical separator among hydraulic circuit of condensing boiler and that of users respectively; *4* – three-way valve.

The pump of the warm water boiler circuit, which works as an anti-condensate, maintains also the temperature level of the return water [3].

After the substitution of the traditional boiler with the condensing one, the hydraulic scheme is not conceptually modified, just simplified as it is shown in the fig. 2*,* eliminating some components that are not so essential (probe, anti-condensate pomp and mixer valve).

The anti-condensate pump is not so essential, because in the condensing boiler the flame is able to burn completely the methane even before of the impact on the heat exchanger. Therefore, the problem of the inhibition of the flame doesn't subsist anymore, allowing a performance of combustion (it is consider constant around 98%) for every variation of the heating load [4].

The condense in this case, is formed because the gas burned contains 2 m^3 of water vapour for every m^3 of methane and cross the heat exchanger cooling flue gas below the dew temperature of ~327 K (54°C), where begins the change of the state. It occurs therefore the transfer of the latent heat of condensation on the heat exchanger. The large modulation (from 16 to 100%) of the thermal power of this type of boilers permits to avoid the installation of the pump anti-condensate and of the mixer valve.

The thermal power can be adapted to the contingent requirement in every moment and improves its performances producing more condense, lowering the temperature of return water of the boiler .

A regulator of the condensing boiler allows the variation of the temperature of the working fluid in function of external temperature. The communication between the electronic regulator and an external temperature probe permits continuously the modulation of the burner.

2. THERMAL AND ECONOMICAL ANALYSIS OF A CONCRETE CASE (*)

The *Chart I* and *Chart II* present respectively the specific dates of the two installations with traditional boiler and with condensing boiler: consumptions of methane gas in m^3, the specific costs in €/m^3 respectively €/day, taken from the paid invoices in 5 separate periods.

The thermal and economical analysis has been performed on both installation: with traditional boiler presented in fig. 1 and with condensing boiler presented in fig. 2.

Chart I: **Consumptions of methane and specific costs in the installation with traditional boiler***

Progressive addition days	periodo of two-months utilization	consumption of methane m^3	cost €	days	specific cost of methane €/m^3	specific cost dailing €/day
75	october/november'00	1028	476,17	75	0,46	6,35
137	dicember/january	2192	1051,51	62	0,48	16,96
216	february/march	1307	657,45	79	0,50	8,32
260	april/may	1214	591,86	44	0,49	13,45
365	june/september'01	560	274,75	105	0,49	2,62
	total	**6301**	**3051,74**	**365**	**0,48**	**8,36**

Chart II: **Consumptions of methane and specific costs in the installation with condensing boiler (*)**

Progressive addition days	periodo of two-months utilization	consumption of methane m^3	cost €	days	specific cost of methane €/m^3	specific cost dailing €/day
75	october/november'01	460	230,34	75	0,50	3,07
137	dicember/january	2016	1190,43	62	0,59	19,20
216	february/march	472	240,15	79	0,51	3,04
260	april/may	469	239,12	44	0,51	5,43
365	june/september'02	467	61,46	105	0,13	0,59
	total	**3884**	**1961,50**	**365**	**0,51**	**5,37**

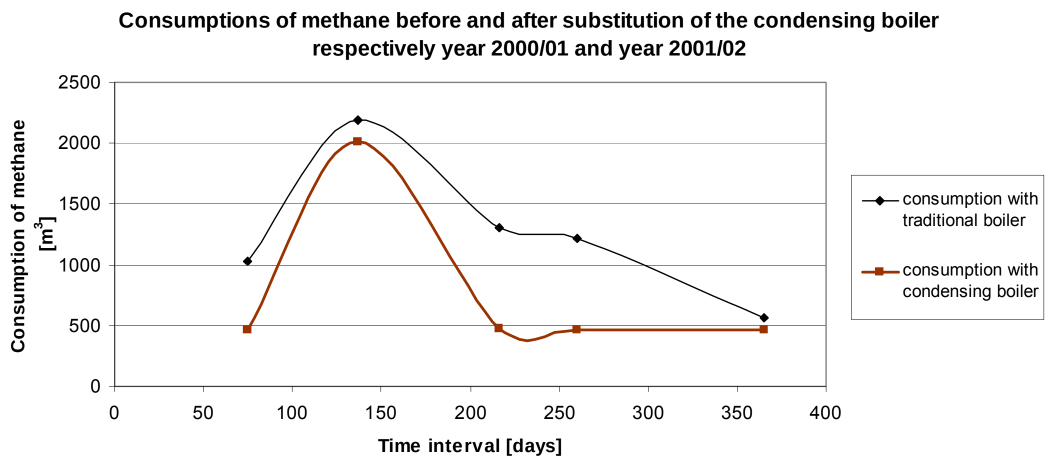

Fig. 3. Comparison of the consumptions with condensing boiler and with traditional boiler.

The *Chart I* and *Chart II* present the real* consumptions taken from the paid real invoices to the public net of methane, before and after the substitution. The measured consumptions for the whole year in the two cases represent the sum of the consumptions for the heating, sanitary warm water and of the use of the kitchen.

The diagram of the consumptions is introduced on the following diagram of fig.3.

The data to our disposition are:

$N = 6$ people	$P_{elpc} = P_{elp2} = 100$ W
$V_k = 150$ m^3	$t_{eb} = 288$ K
$V_{cte} = 560$ m^3	$t_{ac} = 313$ K
$P_c' = 31.4$ kW	c_c (2000/01) = 0.48 €·m^{-3}
$P_c'' = 33.6$ kW	c_c (2001/02) = 0.51 €·m^{-3}
$H_i = 34.4$ MJ·m^{-3}	$c_{el} = 0.085$ €·kWh^{-1}
$\eta_g' = 0.6$	$i = 2.64$ %
$\eta_g'' = 0.79$	$n = 10$ years
$P_{elp1} = 150$ W	$C_i'' = 3{,}700.00$ €

* Installation of heating with condensing boiler of the house in via Pasubio, 31 - Novara – Italy.

Chart III: **Numerical values for both the cases with traditional boiler and with condensing boiler**

Amortization for condensing boiler

ΔC_i =	$C_i' - C_i''$ =	-3700 €			
ΔC_g =	$C_g' - C_g''$ =	**1059,10 €**	⇒	**36,5**	**%**
i =		2,64 %			
PVa		12,29			
NPV =	ΔC_i + PVa(n,i%) · ΔC_g =	**9316,31 €**			
for NPV = 0	**it is obtained:**				
PVa(n, 2,64%) =	$-\Delta C_i/\Delta C_g$ =	3,49	⇒	**3 < n < 4 years**	
PVa(15, i%) =	$-\Delta C_i/\Delta C_g$ =	3,49	⇒	**i*=IRR =25,6%**	

a)

Traditional boiler	***Summer period from april 2000 to september 2000***		***Condensing boiler***	***Summer period from april 2001 to september 2001***	
Consumption of fuel due to the consumption of sanitary warm water					
V_{cse} =	$V_{cte}/4*6-V_k$ =	690,00 m^3	V_{cse} =	$V_{cte}/4*6-V_k$ =	549,90 m^3
Q_s' =	$V_{cse} \cdot H_i \cdot \eta_g$ =	14478,96 MJ	Q_s' =	$V_{cse} \cdot H_i \cdot \eta_g$ =	14944,08 MJ
Q_{ts}' =	$2Q_s'$ =	28957,92 MJ	Q_{ts}' =	$2Q_s'$ =	29888,16 MJ
t_{summer} =	Q_s'/P_c =	128,13 h	t_{summer} =	Q_s'/P_c =	123,50 h
$t_{summer/day}$ =	t_{summer}/T =	0,71 h/g	$t_{summer/day}$ =	t_{summer}/T =	0,69 h/g
m_{water}' =	$Q_s'/c_p(t_{ac}-t_{fsc})$ =	**138554,64 l**	**m_{water}'' =**	$Q_s'/c_p(t_{ac}-t_{fcc})$ =	**143005,57 l**
$m_{water/day}'$ =	$Q_s'/c_p(t_{ac}-t_{fsc})/180$ =	**769,75 l/g**	**$m_{water/day}''$ =**	$Q_s'/c_p(t_{ac}-t_{fcc})/180$ =	**794,48 l/g**
C_{se}' =	$V_{cse} \cdot C_c$ =	331,20 €	C_{se}' =	$V_{cse} \cdot C_c$ =	280,45 €
C_{si}' =	$V_{csi} \cdot C_c$ =	331,20 €	C_{si}' =	$V_{csi} \cdot C_c$ =	280,45 €
C_r' =	$(V_{ct}-V_{cse}-V_{csi}-2V_k) \cdot C_c$ =	2218,08 €	C_r' =	$(V_{ct}-V_{cse}-V_{csi}-2V_k) \cdot C_c$ =	1266,94 €
C_t' =	$C_{si}'+C_{se}'+C_r'$ =	**2880,48 €**	**C_t' =**	$C_{si}'+C_{se}'+C_r'$ =	**1827,84 €**
Electric energy consumption of the pomp winter+summer for the production of sanitary warm water					
P_{els}' =	$2 \cdot t_{summer} \cdot P_{elpc}$ =	25,63 kWh	P_{els}' =	$2 \cdot t_{summer} \cdot P_{elpc}$ =	24,70 kWh
C_{els}' =	$P_{els}' \cdot C_{el}$ =	**2,18** €	**C_{els}' =**	$P_{els}' \cdot C_{el}$ =	**2,10** €
Electric energy consumption of the pomp in winter for the period of heating					
Q_r' =	$(V_{ct}-V_{cse}-V_{csi}-2V_k) \cdot H_i \cdot \eta_g$ =	96967,06 MJ	Q_r' =	$(V_{ct}-V_{cse}-V_{csi}-2V_k) \cdot H_i \cdot \eta_g$ =	67510,62 MJ
t_{winter} =	Q_r'/P_c =	858,12 h	t_{winter} =	Q_r'/P_c =	557,94 h
$t_{winter/day}$ =	t_{winter}/T =	4,77 h/g	$t_{winter/day}$ =	t_{winter}/T =	3,10 h/g
P_{elr}' =	$t_{winter} \cdot (P_{p1}+P_{pc})/1000$ =	214,53 kWh	P_{elr}' =	$t_{winter} \cdot (P_{p1}+P_{pc})/1000$ =	139,48 kWh
C_{elr}' =	$P_{elr}' \cdot C_{el}$ =	**18,23** €	**C_{elr}' =**	$P_{elr}' \cdot C_{el}$ =	**11,86** €
C_{elt}' =	$C_{els}'+C_{elr}'$ =	**20,41** €	**C_{elt}' =**	$C_{els}'+C_{elr}'$ =	**13,96** €
C_g' =	$C_t'+C_{elt}'$ =	**2900,89 €**	**C_g' =**	$C_t'+C_{elt}'$ =	**1841,80 €**

b)

In the *Charts III a, b* there are underlined the economical analysis and the numerical values of comparison calculated in the two cases with traditional boiler and with conditioning boiler.

It is necessary to specify that, during the months from April 2000 to September 2000, the consumptions indicated in the *Chart I* and *Chart II* contains the values due to the production of sanitary warm water and to the use of the kitchen. The consumption of the kitchen is generally estimated around 25 m^3/months for 6 persons with a total summer consumption of $V_k = 150\ m^3$.

The consumption of the sanitary water is obtained subtracting such value from the data presented in the *Chart I* and *Chart II*. The *Chart III* contains the cost of the condensing boiler which includes the skilled labour for the assemblage regarding the installation with traditional boiler. Subsequently, in the same chart they underline that:

• the real saving of fuel is equal to **36,5%**;

• the number of years of amortization "n", in hypothesis that the investment is sustained with own funds and that the cost of the money is maintained constant in the time and equal to $i = 2.64\%$, is obtained calculating at first the NPV, then the value of the parameter PVa in hypothesis that the duration of the condensing boiler is $n = 10$ years with $i = 2.64\%$, data taken from literature [1]. The pay back time of the investment corresponds at the year when the NPV annuls itself;

• the intern rate of efficiency i* = IRR

The figure 4 presents in detail the sectioned view side of the condenser-exchanger, to underline better the form, the route of the fluid and the flue gas into its internal.

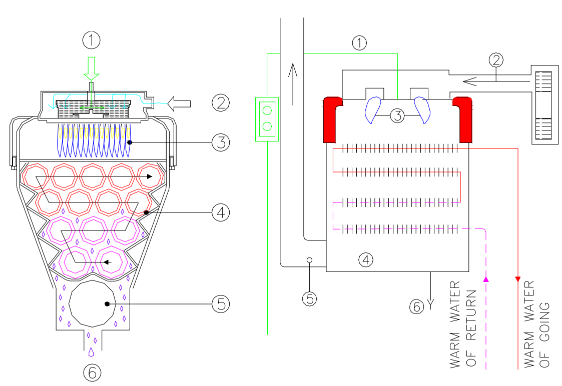

Fig. 4. View side of the condensor-exchanger: *1* – methane; *2* – atmospheric air; *3* – flame; *4* – condensator – exchanger; *5* – flue gas; *6* – condensate.

3. CONCLUSIONS

The value of the actualized cash flows to the useful life of the condensing boiler, named also Net Present Value or NPV it has turned out positive.

The maximum value of the interest that assures us the possibility to take in loan money, without going to lose it corresponds to what annuls NPV. Such interest is named IRR = i (**) and it has turned out of 25,6%.

The indicative NPV and IRR point out both that the investment is convenient. The time of return or pay-back of the investment represents the year when the condensing boiler is amortized and it is that whom corresponds the annulment of the NPV. The condensation boiler is amortized from 3^o to 4^o year.

It can't be neglected the climatic variation from year to year. In fact the values of the degrees day in the heating period 2000/01 and 2001/02 are respectively 2150 DD and 2296 DD [2]. The percentage difference between these two values is 7%. This shows, that the period 2001/02 has middle been colder of the precedent and it has influenced the major consumption of 4%. So, the energetic saving calculated of 36,5% must be increased with this percentage becoming 40,5%. The condensing boiler demonstrates efficacy during into the whole year.

The results of this study could be more accurate, if in the future the consumptions of fuel are valued in a wide time interval, considering the rate of inflation of the energetic products.

Nomenclatures

V_{ct} – total volume of methane consumed for the whole year for production sanitary warm water and heating recorded to the paid invoices .... [m^3]
V_{cse} – volume of methane consumed for production warm water in summer period recorded to the paid invoices .... [m^3]
V_{csi} – volume of methane consumed for production sanitary warm water in winter period recorded to the paid invoices .... [m^3]
V_k – volume of methane consumed for utilizing kitcken .... [m^3]
P_c'– thermal power of a traditional boiler .... [W]
P_c'' – thermal power of a condensing boiler........................ [W]
P_{elp1} – electric power of the pomp of the thermo–syphons circuit ....
P_{elp2} – electric power of the anti–condensate pump .... [W]
P_{elpc} – electric power of the boiler pump............................. [W]
P_{els}' – electric power consumption of the pump of boiler for production warm water with traditional boiler .... [W]
P_{elr}' – electric power consumption of the pumps for production heating with traditional boiler .... [W]
P_{els}'' – electric power consumption of the pump of boiler for production warm water with condensing boiler .... [W]
P_{elr}'' – electric power consumption of the pumps for production heating with condensing boiler .... [W]
H_i – net heat value of fuel .... [MJ·m^{-3}]
t_{eb} – temperature of the warm water of entrance in the boiler .... [K]
t_{ac} – temperature of the warm water in exit of the boiler .... [K]
c_p – specific heat of the thermovector fluid ....[MJ·kg^{-1}K^{-1}]
c_c – specific cost of fuel .... [€·m^{-3}]
c_{el} – specific cost of electric energy...........................[€·kWh^{-1}]
Q_s' – heating quantity needed for production of warm water with traditional boiler .... [MJ]
Q_s'' – heating quantity needed for production of warm water with condensing boiler .... [MJ]
Q_{ts}' – heating quantity for whole year necessary for production of warm water with traditional boiler...... [MJ]
Q_{ts}'' – heating quantity for whole year necessary for production of warm water with condense boiler .... [MJ]
Q_{tr}' – heating quantity for whole year necessary for heating production with traditional boiler................. [MJ]
Q_{tr}'' – heating quantity for whole year necessary for heating production with condensing boiler................ [MJ]
t_{summer} – operating time of the boilers in summer period .... [h]
$t_{summer/day}$ – operating daily time of the boilers in summer period .... [h]
t_{winter} – operating time of the boilers in winter period .... [h]
$t_{winter/day}$ – operating daily time of the condensing boiler in winter period .... [h]
T – operating summer period of the boilers....................... [day]
m_{H_2O}' – mass of warm water utilized in the case with traditional boiler .... [l]
m_{H_2O}'' – mass of warm water utilized in the case with condensing boiler .... [l]
C_{elr}' – cost of electric energy of heating period with traditional boiler .... [€]
C_{els}' – cost of electric energy of summer or winter period expense for utilizing warm water with traditional boiler .... [€]
C_{elr}'' – cost of electric energy of heating period with condensing boiler .... [€]
C_{els}'' – cost of electric energy of summer or winter period expense for utilizing warm water with condensing boiler .... [€]
C_g' – global cost of electric and thermal energy for case with traditional boiler .... [€]
C_g'' – global cost of electric and thermal energy for case with condensing boiler .... [€]
$PV_a(n, i)$ – annual factor..[%]
NPV – net present value .... [€]
$IRR = i$ (**) – intern rate of efficiency.................................[%]
η_g – season efficiency of the condensing boiler [W]

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