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The importance of the modulation ratio in the boilers installed in refurbished buildings

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ABSTRACT

The refurbishment of a building with better insulation particularly in the walls and in the roof with the windows replacement gives rise to a relevant reduction of the heating load. Then the existing boiler is surely oversized and it must be replaced. The selection of the model is connected to the new design load, but it is also bound to the nominal capacity of the equipment on sale, that is never below about 10 kW. Then it is of paramount importance the modulating ratio that is till which capacity the boiler can operate continuously without working in the inefficient ON–OFF control.

For a typical detached building, first of all the load reductions with common refurbishment is considered for three climates: cold, temperate and mild in Italy. Condensing boiler seasonal performances are then compared with modulating ratio that from the simple ON–OFF arrives till 1:10 for two different nominal capacity.

Finally a further performance improvement can be obtained with variable flow rate pumps, operating with a temperature drop relatively constant between supply and return. Whereas the already high boiler efficiency is not appreciably increased, the electricity saving to drive the pumps can be really outstanding.

1. Introduction

The refurbishment of a building with better insulation particularly in the walls and in the roof with the replacement of the windows with double low emissivity glazing allows a relevant reduction of the heating load. Then the existing boiler is surely oversized and it must be replaced.

Of course the selection of the boiler capacity should consider the new design load, bearing in mind that the nominal capacity of equipment on sale is never below 9 kW. Consequently even the properly selected boilers operate for much of the time at partial load: for a traditional boiler ON–OFF[1] controlled the efficiency can be badly penalised. The energy savings allowed by better boiler control systems were carefully analysed by Liao and Dexter [1] and by Liao et al. [2], but then continuous modulation of the burner was not widespread, even if not available at all on commercial products. If the boiler can be modulated, partial load operation can produce an appreciable efficiency increase.

See in Fig. 1 three possible curves of partial load efficiency as a function of the load factor of the boiler. The lower scale in the abscissa indicates possible outside air temperatures to which boiler load factor corresponds. The lower curve is typical for a traditional boiler. The other two curves are for modulating modern boilers, condensing and not condensing. When the efficiency falls for the traditional device under 50% load factor, it slowly increases for the other two, save that it precipitates even for them for very low load factors. The question is at what load factor takes place this sharp fall. The fall is due to the inability of the burner to be modulated below a given power as the flame becomes unstable. Whereas the devices whose performance is illustrated in Fig. 1 present a very low modulation ratio (the ratio between the minimum modulated capacity and the nominal), the boilers on the market are quite different according to their technology. The cheapest boilers can modulate only to 1:2 (that is till a half of their nominal capacity), when the best models arrive to 1:9.

The importance of the minimum level the modulation can get is often undervalued.

A poor modulation ratio does not allow the boiler to take profit from operative conditions when it might work at very good efficiency, working instead in ON–OFF due to the low load. In fact the hot water temperature control is usually assumed through a compensation curve that requires decreasing temperatures when the outside temperature increases.

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[1] In ON–OFF control a thermostat maintains the supply water temperature at a level usually set by an external temperature compensated alogithm, almost always a straight line.

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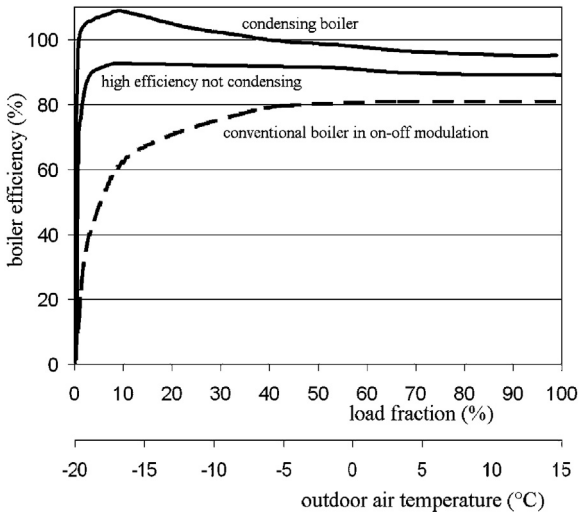

Fig. 1. Boiler efficiency as a function of the load fraction: from the top condensing modulating boiler, modulating not condensing boiler, traditional boiler (doc. Viessman).

To appreciate the influence of the modulation ability of the selected boiler, the annual energy needs of a typical detached dwelling is here studied before and after a refurbishment equipping it with different modulation ratio boilers in three different climates.

2. The reduction of the loads

The studied building is a semi-detached house, built up according to the standards of the seventies. The external walls are realised with blocks of hollow bricks dual course (12 cm thickness, total thickness of the wall 28 cm). Windows are single glazed, wood frame. Horizontal floors are not insulated; the ground floor stays on an unheated basement, whereas the first floor ceiling finds an unheated and not insulated attic above. The roof is made of hollow flat blocks with roof tiles.

See plans and section in Fig. 2(a)–(c). The total floor area is 146 m^2 with a heated volume of 394 m^3, while the total gross volume is 567 m^3.

The existing heating plant is equipped with a gas boiler whose burner is atmospheric and ON–OFF controlled. The supply temperature is 75 °C and the nominal capacity is 24 kW. The load heat exchangers are cast iron radiators, sized at a temperature difference of 50 K (average radiator – ambient).

The refurbishment provided:

- an external thermal insulation of 10 cm expanded polystyrene foam ($k = 0.031\ W\ m^{-1}\ K^{-1}$);
- attic insulation with 20 cm glass wool ($k = 0.040\ W\ m^{-1}\ K^{-1}$);
- replacement of windows with double low emissivity glazed thermal break ($U = 1.5\ W\ m^{-1}\ K^{-2}$).

The analysis was carried out in three different climates, considering the resorts of Belluno (cold), Milan (temperate) and Rome (mild). The outdoor design temperature is respectively of −10 °C, −5 °C and 0 °C with annual degree days of 3043, 2404 and 1415.

The evaluations of the thermal loads was obtained by sorting the hourly weather data of the Test Reference Year into discrete groups at intervals of 1 °C (bins) so that temperature cumulative curves were produced (bin method [3]). Fig. 3 reports the three cumulative curves. As for every bin can be associated the building thermal load (in winter mainly dependent on the outside temperature), a load cumulative curve can be drawn where each bin gives a load and the time length in hours of it.

The free heat inputs could be related to the outside air temperature, so that the load curve takes it into account. The Domestic Hot Water (DHW) loads were instead not considered as the focus of this study is the building heating and the DHW loads are strongly connected to the different habits of the inhabitants.

The comparison in the three resorts with the starting condition regards:

- the refurbished building keeping the existing boiler;
- the refurbished building with a new condensing boiler, nominal capacity 24 kW and low modulation ratio (1:3);
- the refurbished building with a new condensing boiler, nominal capacity 9.1 kW and high modulation ratio (1:9).

The results regarding the boiler replacement are presented after some insights on the efficiency of the boilers at partial loads.

The comparison of the energy savings due to the refurbishment of the building envelope is summarised in Fig. 4 where energy requirements are represented for the three considered resorts before and after refurbishment. A graphical view of the results for a single resort (Belluno) as a function of the outside temperature is given in Fig. 5.

Energy requirements undergo a sharp reduction, arriving around at 40% of the previous demand. A reduction of similar order regards also the peak power. Consequently the operation of the same nominal capacity boiler is deeply partialized. The resulting penalty can limit the benefits just presented.

3. The efficiency of the boilers at partial loads

In Italy the replacement of the existing boiler with a condensing boiler together with a building refurbishment can receive a financial reward of 55% of the expenditure as a tax deduction in ten years. In addition in the last years the price gaps between traditional and condensing boilers greatly reduced thanks to the spreading of condensing technology in North Europe countries [4]. No particular features are requested on the condensing boiler and nothing is said on the modulation ratio.

Condensing boiler efficiency is the higher the lower the return water temperature from the plant [5–7]. When the burner can be continuously modulated, the efficiency is increasing at the lowering of the load factor. This behaviour is illustrated in Fig. 6 where the efficiency is represented at nominal capacity and at minimum capacity as a function of the average temperature of the water inside the boiler.

The efficiency improvement at low capacity can be explained considering that the combustion product residence time in the boiler is roughly proportional to the instantaneous capacity, whereas the reduction in the convection coefficient reduces with the velocity ratio raised at 0.8. For example for half capacity, the residence time doubles and the convection coefficient is at 57% ($0.5^{0.8}$): consequently the temperature of the exhaust is lower than before and the efficiency increases.

Condensation does not appear for an average temperature of the water above 60 °C and no appreciable differences exist at nominal and minimum capacity [8]. For temperatures lower than that the efficiency gains are relevant particularly for minimum capacity operation.

Apart that many condensing boilers do not include modulation at all, the modulating appliances on the market allow modulation ratios from only 50% to a 10% of the best models.

To understand the importance of the modulation ratio, let us consider a plant with an outdoor temperature compensated control. The water temperature supplied to radiators increases or