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# Efficiency Analysis of Independent and Centralized Heating Systems for Residential Buildings in Northern Italy

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**Abstract:** The primary energy consumption in residential buildings is determined by the envelope thermal characteristics, air change, outside climatic data, users' behaviour and the adopted heating system and its control. The new Italian regulations strongly suggest the installation of centralized boilers in renovated buildings with more than four apartments. This work aims to investigate the differences in primary energy consumption and efficiency among several independent and centralized heating systems installed in Northern Italy. The analysis is carried out through the following approach: firstly building heating loads are evaluated using the software TRNSYS® and, then, heating system performances are estimated through a simplified model based on the European Standard EN 15316. Several heating systems have been analyzed, evaluating: independent and centralized configurations, condensing and traditional boilers, radiator and radiant floor emitters and solar plant integration. The heating systems are applied to four buildings dating back to 2010, 2006, 1960s and 1930s. All the combinations of heating systems and buildings are analyzed in detail, evaluating efficiency and primary energy consumption. In most of the cases the choice between centralized and independent heating systems has minor effects on primary energy consumption, less than 3%: the introduction of condensing technology and the integration with solar heating plant can reduce energy consumption by 11% and 29%, respectively.

**Keywords:** efficiency; primary energy; heating system; residential building; model

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## 1. Introduction

In Europe residential building heating accounts for a considerable part of the primary energy consumption, thus almost every State has defined a regulation to promote energy saving. The Italian current regulation [1] strongly suggests the utilization of centralized systems in renovated buildings with more than four apartments [2]. Exceptions require a suitable technical report based on methodologies reported in national or European standards. The utilized methodologies can be eventually integrated by national research centres or universities [3]. Some Italian regions are also considering extending this recommendation to new residential buildings.

Assotermica, the Italian association of both independent and centralized boiler manufacturers, recorded a strong economic effect of D.P.R. 59/09 [1]: a negative trend in independent boiler sales. To our knowledge there are no papers in which a direct and systematic comparison of several independent and centralized heating systems is reported.

The aim of this study is to compare the efficiency and the primary energy consumption of several independent and centralized heating systems, installed in the typical residential buildings of Northern Italy, utilizing a simple and reliable model based on the European Standard EN 15316 [4].

## 2. Methodology

### *2.1. System Description*

The characteristics of the analyzed heating systems are proposed by Assotermica [5] on the basis of the most widely used heating devices in the Italian territory. All the input data of the heating system layouts arise from an exhaustive statistical market analysis and are accepted by Assotermica as representative of the typical heating systems in the North of Italy.

The reference residential building is composed of 12 apartments, with an average net surface of about 65 $m^2$ each, set out on three floors. The building lies in the Italian climatic zone E, characterized by 2101–3000 degree days. The heating season starts on 15th October and ends on 15th April.

To evaluate the most significant part of existing building stock, four different thermal envelopes have been considered, classified by construction period: new (year 2010), recent (year 2006), 1960s and 1930s. These structures constitute the most of the residential buildings in Northern Italy. The U-values of external structures are reported in Table 1.

**Table 1.** U-values [$W/m^2K$] of external structures for the different construction periods.

| | **2010** | **2006** | **1960** | **1930** |
|---|---|---|---|---|
| Outer Wall | 0.31 | 0.36 | 1.32 | 0.84 |
| Staircase-space wall | 0.33 | 0.37 | 1.25 | 1.17 |
| Floor | 0.31 | 0.47 | 2.37 | 2.01 |
| Roof | 0.30 | 0.43 | 1.49 | 1.46 |
| Door | 0.80 | 0.80 | 1.32 | 1.32 |
| Glass | 1.20 | 1.90 | 5.80 | 5.80 |
| Window | 1.56 | 2.13 | 5.33 | 5.33 |

In the analysis of heating systems in the new building (year 2010) both independent and centralized natural gas fired generators are considered: the first one is installed inside each apartment and satisfies the required heat and DHW; the latter provides heat and DHW to the entire building and is installed in a dedicated room. For each independent and centralized plant, two generator types have been considered: traditional and condensing.

The heating system layouts are reported in Figures 1 and 2. The heating systems are controlled by an external temperature probe; the internal temperature is controlled by a thermostat. In independent systems DHW production is instantaneous; instead in centralized ones there is a storage tank, kept at 60 °C to avoid the proliferation of Legionnaire's bacteria. Integration of DHW production with a centralized solar plant has been considered both in independent and centralized systems coupled just with condensing generators.

**Figure 1.** Independent heating coupled with a radiant floor system.

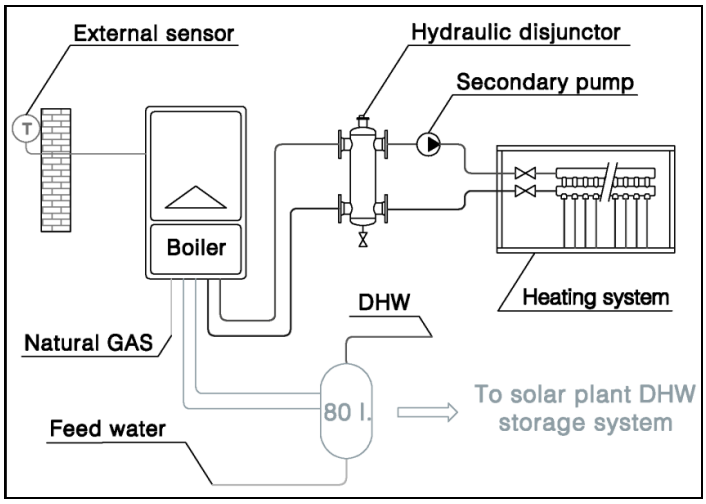
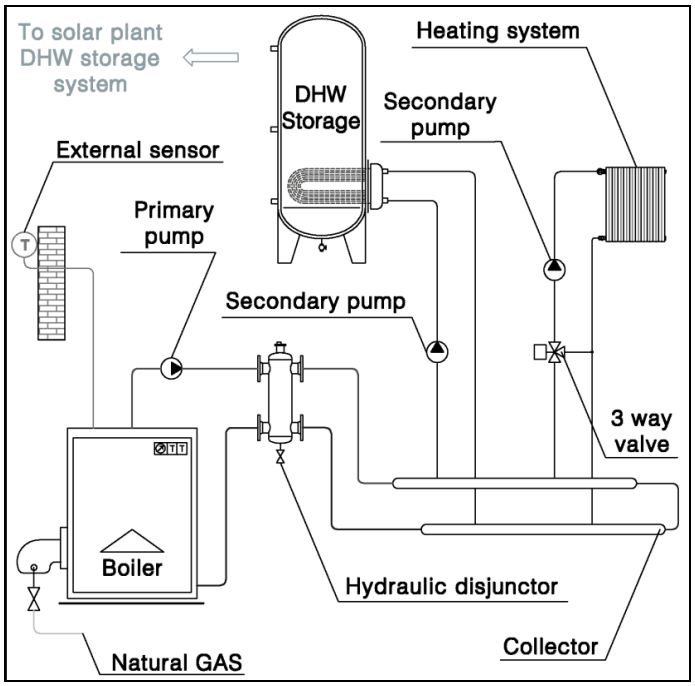



**Figure 2.** Centralized heating system.



The solar plant requires an additional pump (50 W), has an overall area of 20 $m^2$ and produces 60% of the DHW consumption with an efficiency of 48.4 % [6]. In this case a different independent boiler that can be coupled with a storage tank is considered. Table 2 summarizes the main technical data of the boilers: independent traditional (IT), independent condensing (IC), independent condensing with solar plant (IC*), centralized traditional (CT) and centralized condensing (CC).

**Table 2.** Technical data of the considered boilers: independent traditional (IT), independent condensing (IC), independent condensing with solar plant (IC*), centralized traditional (CT) and centralized condensing (CC).

| | IT | IC | IC* | CT | CC |
|---|---|---|---|---|---|
| Maximum nominal heat input [kW] | 25.9 | 24.9 | 12.3 | 69 | 74.6 |
| Maximum nominal heat output [kW] | 24 | 24 | 12 | 62.2 | 72.6 |
| Minimum nominal heat input [kW] | 0.7 | 5 | 2 | 35 | 18.5 |
| Minimum nominal heat output [kW] | 9.3 | 4.7 | 1.9 | 31.6 | 18.1 |
| Fan electric power [W] | 41 | 43 | 28 | 70 | 72 |
| Chimney losses with burner on max [%] | 6.4 | 2 | 2 | 7.8 | 2.3 |
| Chimney losses with burner on min [%] | 12.1 | 1.7 | 2.2 | 11 | 1.7 |
| Chimney losses with burner off [%] | 0.02 | 0.15 | 0.02 | 0.04 | 0.01 |
| Casing losses [%] | 0.7 | 0.7 | 0.89 | 0.7 | 0.4 |

Two types of emitters are considered: high temperature (design temperature 65/55 °C) and low temperature (37.5/32.5 °C). The considered low temperature emitters are radiant floor. The energy consumption of the circulation pumps is also evaluated. In Table 3 pump electrical powers for space heating are reported.

**Table 3.** Analyzed heating systems and electric pumps consumption for space heating.

| Description of Heating System | Nomenclature | Pumps' Electric Power [W] |
|---|---|---|
| 1. Independent traditional gas-fired boiler coupled with radiators | ITR | 40 |
| 2. Centralized traditional gas-fired boiler coupled with radiators | CTR | 248 |
| 3. Independent traditional gas-fired boiler coupled with radiant floor | ITRF | 105 |
| 4. Centralized traditional gas-fired boiler coupled with radiant floor | CTRF | 388 |
| 5. Independent condensing gas-fired boiler coupled with radiators | ICR | 45 |
| 6. Centralized condensing gas-fired boiler coupled with radiators | CCR | 248 |
| 7. Independent condensing gas-fired boiler coupled with radiant floor | ICRF | 115 |
| 8. Centralized condensing gas-fired boiler coupled with radiant floor | CCRF | 388 |
| 9. Independent condensing gas-fired boiler coupled with radiators and solar heating plant for DHW | IC*R+SHP | 45 |
| 10. Centralized condensing gas-fired boiler coupled with radiators and solar heating plant for DHW | CCR+SHP | 248 |
| 11. Independent condensing gas-fired boiler coupled with radiant floor and solar heating plant for DHW | IC*RF+SHP | 115 |
| 12. Centralized condensing gas-fired boiler coupled with radiant floor and solar heating plant for DHW | CCRF+SHP | 388 |

Independent systems, coupled with radiators, have only the built-in circulation pump [7], with a three positions speed control. This type of pump switches off after 15 minutes from burner switch off. In independent systems coupled with low temperature emitters, a hydraulic disjunctor is necessary (Figure 1). For this reason there are two pumps: the built-in generator pump, that works only when the burner is operating, and the secondary circuit pump (three positions speed control), that switches off after 15 minutes from burner switch off. In all centralized systems there is a hydraulic disjunctor: the primary circuit pump (three positions speed control) works only when the burner is operating, the secondary circuit pump has a variable speed control and switches off after 1 hour from burner switch off (Figure 2).

Hereafter the analysis of heating systems in building dates back to 2006, 1960s and 1930s is reported. Effectuating a simple retro-fit, only independent and centralized heating systems with traditional or condensing boiler are considered, discarding radiant floor solution and solar plant integration. In 2006 buildings an increase of radiators surfaces is necessary to operate at the same temperatures of heating systems installed in new buildings (65/55 °C). An increase of emitter surfaces is not sufficient instead in 1960s and 1930s buildings, where is also necessary to increase emitter temperatures, from 65/55 °C to 80/70 °C. The increase of energy demand in 1960s and 1930s buildings requires centralized generators with higher nominal heat output, Table 4; on the contrary the thermal output of independent systems is still sufficient. The pump electric powers for space heating are subsequently modified as reported in Table 5.

**Table 4.** Technical data of the considered boilers: centralized traditional installed in buildings dating back to 1960s and 1930s (CT 1960–1930) and centralized condensing installed in buildings dating back to 1960s and 1930s (CC 1960–1930).

| | **CT 1960–1930** | **CC 1960–1930** |
|---|---|---|
| Maximum nominal heat input [kW] | 165 | 175 |
| Maximum nominal heat output [kW] | 150 | 170 |
| Minimum nominal heat input [kW] | 121 | 44 |
| Minimum nominal heat output [kW] | 110 | 43 |
| Fan electric power [W] | 170 | 229 |
| Chimney losses with burner on max [%] | 7.8 | 2.3 |
| Chimney losses with burner on min [%] | 11 | 1.7 |
| Chimney losses with burner off [%] | 0.04 | 0.01 |
| Casing losses [%] | 0.7 | 0.4 |

**Table 5.** Electric pumps consumption [W] for space heating for the different construction periods.

| **Heating System** | **2006** | **1960** | **1930** |
|---|---|---|---|
| Independent traditional gas-fired boiler coupled with radiators (ITR) | 40 | 90 | 90 |
| Centralized traditional gas-fired boiler coupled with radiators (CTR) | 319 | 583 | 472 |
| Independent condensing gas-fired boiler coupled with radiators (ICR) | 45 | 90 | 90 |
| Centralized condensing gas-fired boiler coupled with radiators (CCR) | 319 | 583 | 472 |

### *2.2. Calculation Method*

The energy analysis is carried out in the following way: firstly the heating demand of the building is calculated through the dynamic simulation software TRNSYS® [8] every 15 minutes, afterwards the primary energy consumption is calculated through a simplified steady-state model based on the EN 15316, considering heat losses of the following different sub-systems: emission, control, storage, distribution and generation. Each subsystem is analysed, taking into account energy inputs, energy outputs, system thermal losses, auxiliary energy consumption and recoverable thermal losses. The motivations to base the method on EN 15316 are: the Italian current regulation requires, for technical analysis, the utilization of a method based on Italian or European Standards; the only officially accepted and widely adopted method in all European countries is the European Standard. The utilization of more sophisticated but less impartial and shared methods would have hindered the acceptance of the results.

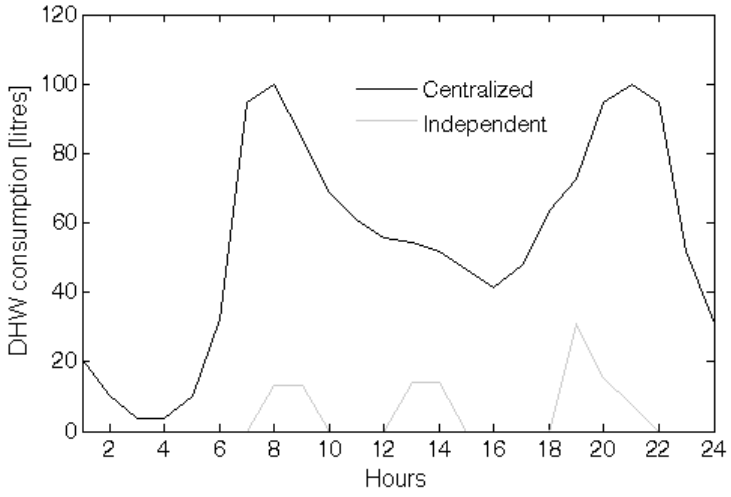
The dynamic behaviour of the system components is not actually modelled, but it is considered as a succession of steady-state conditions, that vary with a quarter-hourly time step. When solar collectors are considered, the heat production of the solar plant is evaluated through the software TSol® [9].

The reference building is composed of apartments with different solar radiation exposures; therefore the comparison of primary energy consumption between independent and centralized systems is carried out considering the sum of each apartment consumptions. The energy demand for space heating depends on energy losses through the building envelope, air infiltration, solar and internal gains. Heat demand is calculated on quarter hourly basis through TRNSYS®.

The internal building temperature is assumed equal to the set-point at 20 °C during the daytime, from 7 a.m. till 9 p.m., while the heating system is switched off during the night, when the internal temperature decreases, depending on building characteristics. The internal gains are considered constant at the value of 5 W/m$^2$, as suggested in EN ISO 13790 [10].

The energy need for domestic hot water is equal to 108 litres per day for every apartment, calculated in accordance with EN 15316, considering appropriate load profiles for independent and centralized heating systems, Figure 3. The former shows peaks in the morning, at midday and in the evening, the latter presents instead a continuous trend.

**Figure 3.** DHW load profile in different heating systems [9].



Thermal losses of emission, control, storage, distribution and generation sub-systems are calculated considering system extensions, duties and loads in accordance with EN 15316 and UNI/TS 11300-2 [11], that is a technical specification for the nationwide application of EN 15316. Thermal losses of each sub-system are calculated every quarter hour as follows:

- Emission thermal losses: efficiency values are taken from Table 17 of UNI TS 11300-2. For radiator, values vary from 0.97 to 0.90, instead for radiant floor, values vary from 0.98 to 0.96. The latter is characterized by further downward heat losses equal to 10% of the heat supplied by the emission sub-system [12,13]. These losses are assumed to contribute to the space heating of the apartment below and for this reason they affect negatively only the energy balance of top floor apartments.
- Control thermal losses: efficiency values are taken from Table 20 of UNI TS 11300-2. For radiators, values vary from 0.98 to 0.96, instead for radiant floor, values vary from 0.97 to 0.95.
- Storage thermal losses are evaluated with [11]:

$$Q_{l,S} = \frac{S_S}{d_S} \cdot (T_S - T_{amb}) \cdot t_S \cdot \lambda_S \quad (1)$$

where:

$Q_{l,S}$ is the thermal energy losses [kWh];
$S_S$ is the external surface of the storage [m$^2$];
$d_S$ is the thickness of storage thermal insulation [m];
$T_S$ is the average temperature of the storage [°C];
$T_{amb}$ is the temperature of the ambient where the storage is installed [°C];
$t_S$ is the operation time of the storage [h];
$\lambda_S$ is the thermal conductivity of storage insulation [W/mK].

- Distribution thermal losses are evaluated with [4]:

$$Q_{l,d} = U \cdot L \cdot (T_w - T_{amb}) \cdot t \quad (2)$$

where:

$U$ is the linear thermal transmittance of considered pipe section [W/mK];
$L$ is the length of considered pipe section [m];
$T_w$ is the average hot water temperature of considered pipe section [°C];
$T_{amb}$ is the average ambient temperature around considered pipe section [°C];
$t$ is the operation time at the corresponding temperatures [h].

The linear thermal transmittance of the different pipe sections is calculated in accordance with [14]. Thickness of pipes thermal insulation (thermal conductivity of 0.04 W/mK) has been chosen in accordance with [15].

The average hot water temperature of pipe section for space heating, considering constant flow rate and supply temperature control depending on the outdoor temperature, is calculated with the following [4]:

$$T_w = \Delta T_{des} \cdot \beta_{dis}^{\frac{1}{n}} + T_{amb} \quad (3)$$

where:

$\Delta T_{des}$ is the temperature difference between mean emission system design temperature and room temperature [°C];
$\beta_{dis}$ is the partial load of the distribution system;
$n$ is the exponent of the emission system;
$T_{amb}$ is the room temperature [°C].

- Generation thermal losses are evaluated with boiler cycling method [16]. The input data to the method has been evaluated from experimental results [5].

### *2.3. Energy Performance Indexes*

The analysis is carried out considering the following energy quantities:

- $E_{b,sh}$ boiler primary energy need for space heating, based on natural gas low heating value (LHV);
- $E_{b,DHW}$ boiler primary energy need for domestic hot water, based on natural gas LHV;
- $E_b$ boiler primary energy need for space heating and domestic hot water, based on natural gas LHV:

$$E_b = E_{b,sh} + E_{b,DHW} \tag{4}$$

- $W_{aux}$ electrical energy consumption for operation of auxiliaries;
- $E_{aux}$ primary energy need for the operation of auxiliaries [17]:

$$E_{aux} = W_{aux} / 0.41 \tag{5}$$

- $E_{tot}$ total primary energy need (solar radiation does not have an economic cost and is wasted if not utilized, thus the associated primary energy is considered a free gain):

$$E_{tot} = E_b + E_{aux} \tag{6}$$

- $Q_p$ thermal energy supplied by the heating system (boiler and auxiliaries);
- $Q_h$ energy demand of the building (space heating and DHW);
- $W_{aux,rh}$ thermal energy recovered from operation of auxiliaries.

The energy performances of heating systems are evaluated with the following indexes:

- boiler efficiency:

$$\eta_b = \left(Q_p - W_{aux,rh}\right) / E_b \tag{7}$$

- boiler and auxiliaries efficiency:

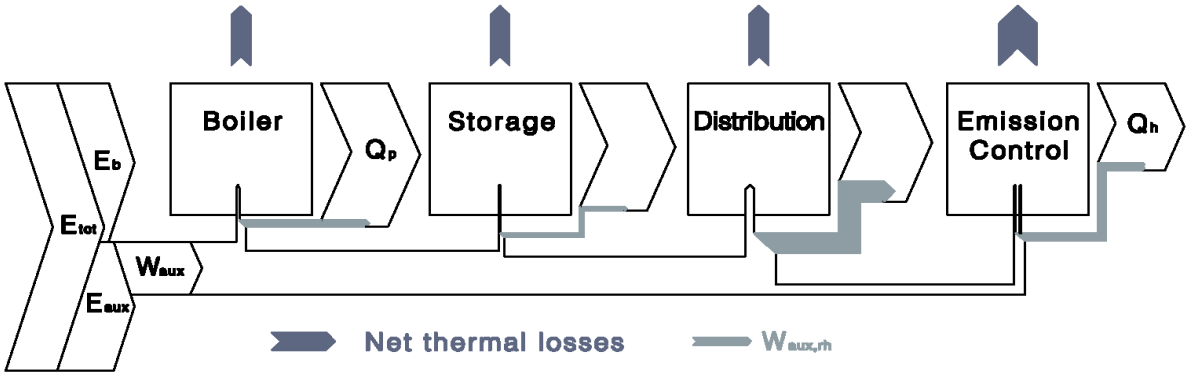
$$\eta_{b-a} = Q_p / \left(E_b + E_{aux}\right) \tag{8}$$

- global efficiency of heating system:

$$\eta_g = Q_h / \left(E_b + E_{aux}\right) \tag{9}$$

Figure 4 shows the energy flow directions and the subsystems consumption steps.

**Figure 4.** Energy flows direction.

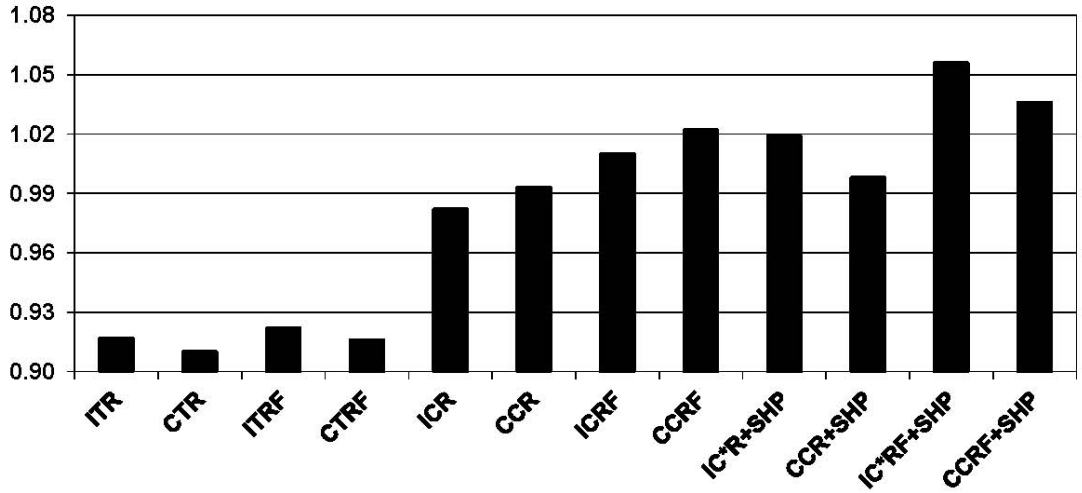



## 3. Results

### *3.1. New Buildings*

In the following section the simulation results for the 2010 building are reported. The boiler efficiency calculation results are reported in Figure 5, where the influence of four system features (independent/centralized, condensing/traditional boiler, high/low temperature emitters, solar DHW integration) can be compared. Note that the boiler efficiency does not take into account the heat supplied by solar heating plant, it refers only to the heat effectively supplied by the boiler, see Equation (7).

**Figure 5.** Boiler efficiency of heating systems.

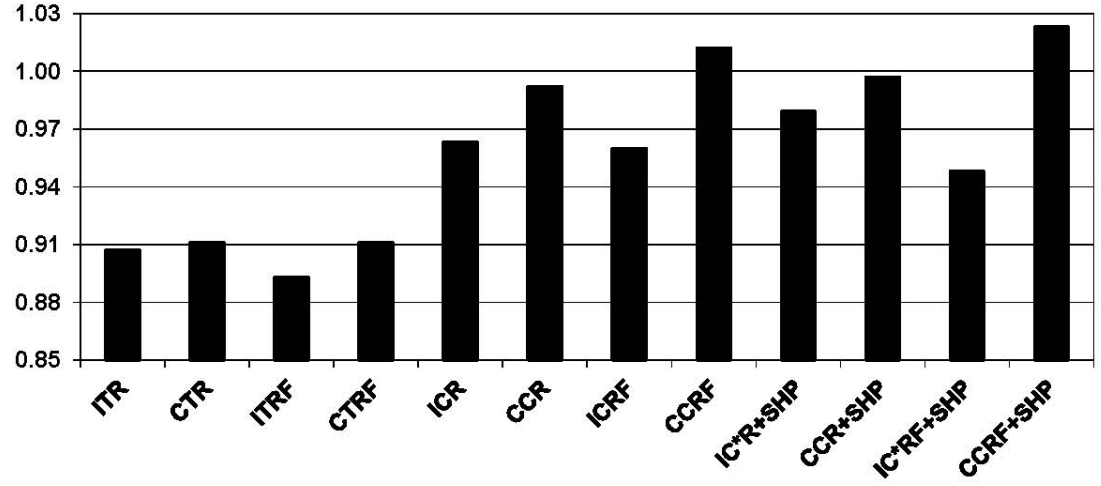



Among the analyzed aspects the major influence on boiler efficiency is given by the choice between traditional or condensing technology: the latter increases this index by 6–10%. Solar heating plant integration gives the second contribution in improving boiler efficiency, up to 5%. While the differences between independent and centralized systems are much less important (<3%). Independent generators have higher boiler efficiency than centralized boilers in the case of traditional technology; vice versa for condensing technology. Centralized systems with solar plant have lower boiler efficiency than independent ones. The influence of emitter typology is minor, comparable with

independent/centralized system one. The boilers coupled with low temperature emitters have higher efficiency than boilers with high temperature emitters.

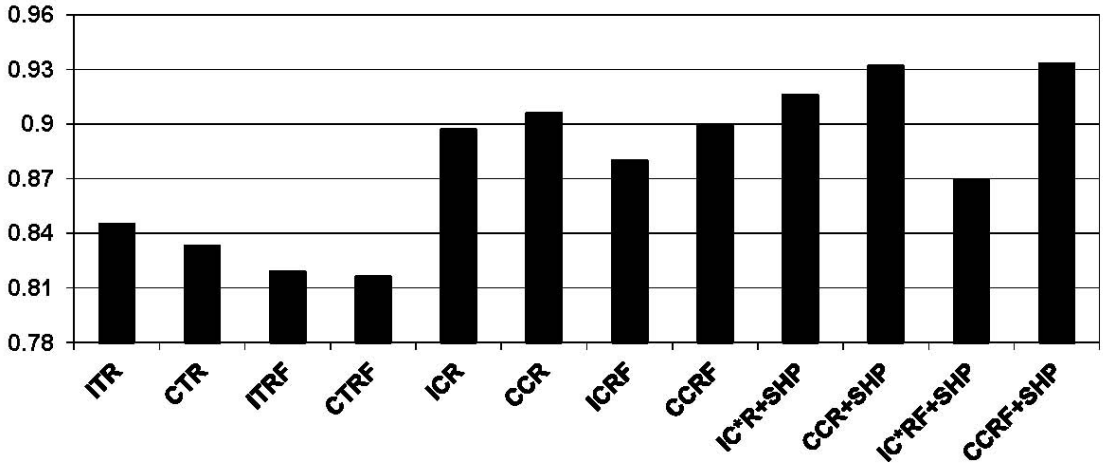
Boiler and auxiliaries efficiencies are reported in Figure 6. Again the most influential system feature is the boiler technology: the installation of condensing boiler increases boiler efficiency by 5–11%. The second contribution in improving this index is given by the choice between independent and centralized heating systems: the latter have always a better efficiency, up to 7% higher. The differences between high and low temperature emission sub systems are much less important, about 3%. Independent heating systems are better if coupled with radiators, whereas centralized ones are better if coupled with radiant floors. The influence of DHW solar integration is limited, less than 2%.

**Figure 6.** Boiler and auxiliaries efficiency of heating systems.




Global efficiency results for the analyzed systems are reported in Figure 7. This energy index takes into account all the thermal losses of each subsystem, including storage, distribution, emission and control.

**Figure 7.** Global efficiency of heating systems.

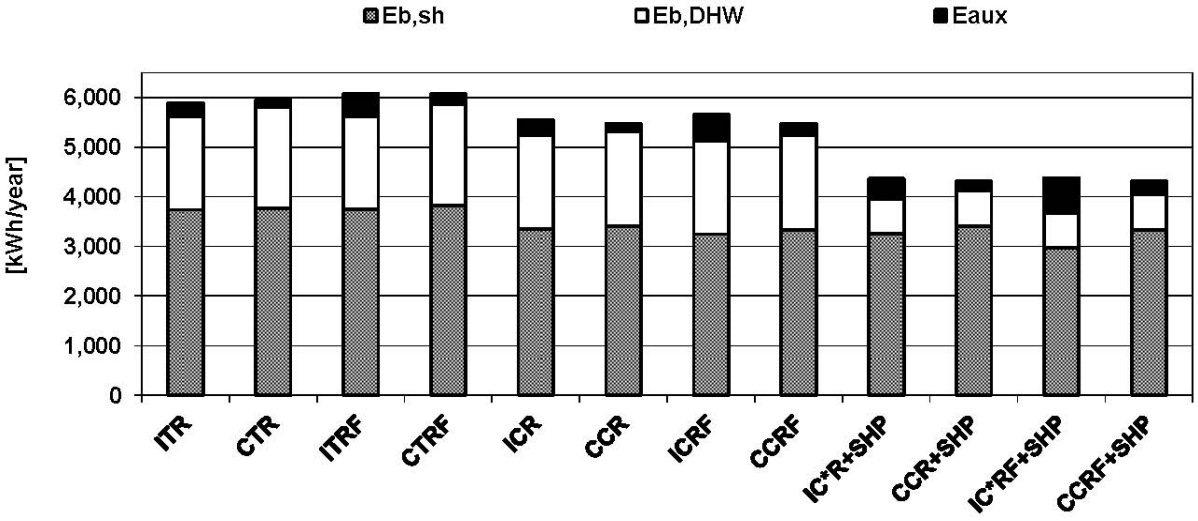



Among all the analyzed aspects the most influential one is again the choice between traditional and condensing boiler: the latter permits to increase global efficiency up to 9%. The second important system feature is the DHW solar heating integration. Generally it increases the efficiency by 3%, the

only exception is the case IC*RF+SHP, where a negative effect is observed. The option between independent and centralized configuration has generally minor influence, comparable with high/low temperature emitters one: the differences are generally less than 2%, again excluding the case IC*RF+SHP.

Analyzing the primary energy need [18], DHW solar heating integration becomes the most influential heating system feature (Figure 8). The positive contribution of solar plant to DHW production is evident: the primary energy saving is more than one fourth. The energy indexes previously analyzed do not take into account the heat supplied by solar heating plant: for this reason its contribution is underestimated.

**Figure 8.** Primary energy needs of heating systems.




On the contrary the differences among systems without solar plant are coherent with global efficiency analysis. Therefore the aspect that mainly contributes to primary energy saving is the choice between traditional and condensing boilers, instead the options high/low temperature emitters and independent/centralized layout have minor influence.

The primary energy need analysis emphasizes the share of auxiliaries consumption: considerable values are evident in the cases of independent systems coupled with radiant floor and/or DHW solar integration (Figure 8).

In Table 6 the effects of the considered heating system features on primary energy consumption are summarized. The introduction of DHW solar heating entails always a positive effect, included between 26.9% and 29.1%. The installation of condensing technology reduces the primary energy consumption by 6.1–11%, instead the influence of emitter typology is minor: the utilization of high temperature emitters decreases primary energy consumption to nearly 3%. Introducing centralized heating systems does not determine always a positive effect: energy consumption is decreased by 3.3% in some cases, while is increased by 1% in other cases.

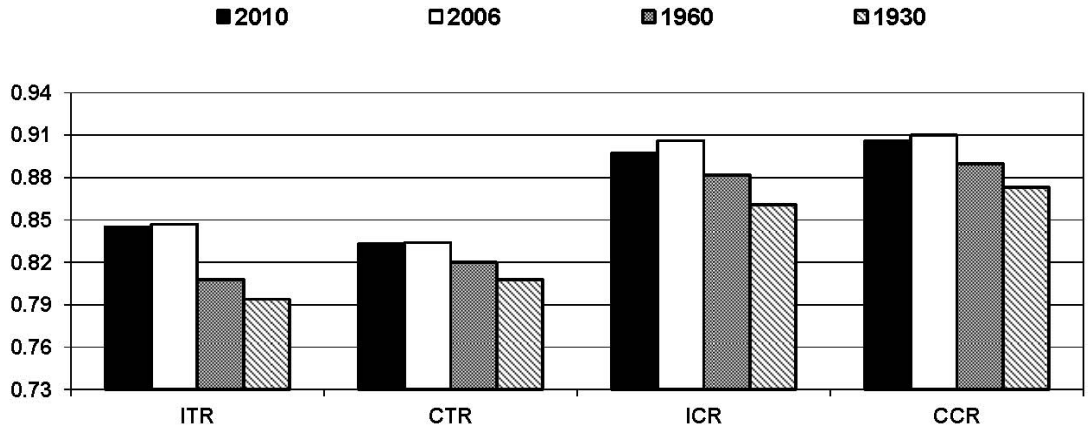
**Table 6.** Reduction of primary energy consumption due to heating system features.

| Heating System Features | Min [%] | Max [%] |
|---|---|---|
| DHW solar heating integration | 26.9 | 29.1 |
| Traditional → Condensing | 6.1 | 11 |
| Low → High Temperature | 0 | 3.17 |
| Independent → Centralized | −1 | 3.3 |

### *3.2. Old Buildings*

The global efficiency for each of the different building structures is reported in Figure 9. Heating systems installed in 2006 buildings have generally higher global efficiency than in 2010 ones: this is particularly evident in the independent condensing heating systems. Heating systems in the 1960s and 1930s buildings have lower global efficiency than 2010 and 2006 buildings: the reduction is in the range of 3–4%, with the exception of independent traditional systems, with a 6–7% reduction. The results in Figure 9 emphasize that the global efficiency is more affected by adopting different envelop insulation, than choosing between independent or centralized layout.

**Figure 9.** Heating systems global efficiency as the year change.



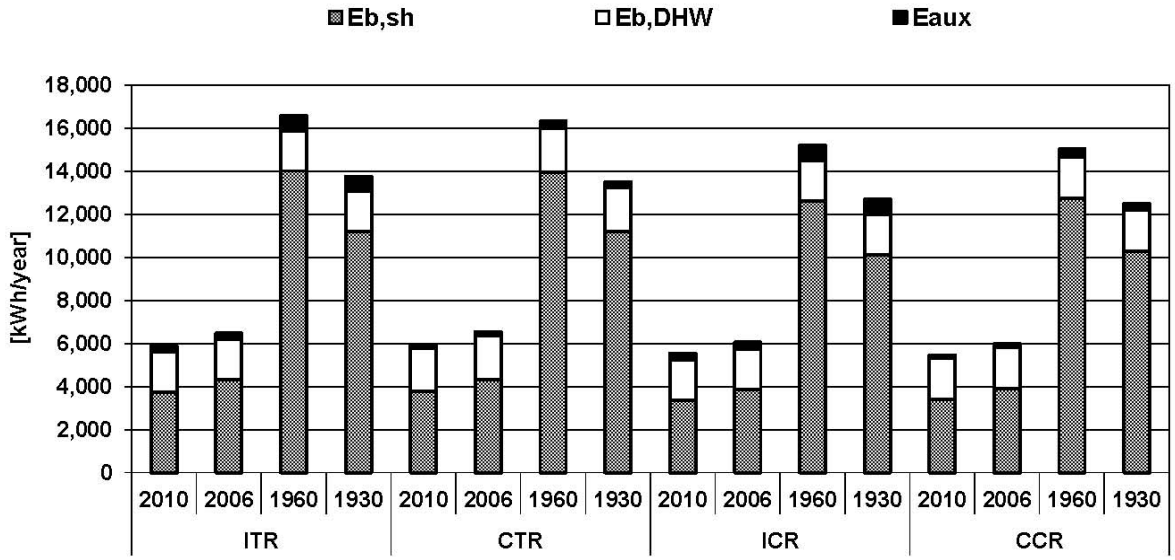

Comparisons of primary energy needs are reported in Figure 10. The primary energy consumption for DHW production remains constant: it does not depend on building thermal insulation. Comparing 2006 and 2010 buildings a slight increase in boiler primary energy for heating and auxiliaries is evident. Instead in 1960s buildings boiler primary energy for heating rises considerably, approximately four times, while the auxiliaries consumption just increases 2.5 times. Similar considerations are valid also for 1930s buildings.

## 4. Discussion

### *4.1. Influence of Heating System Features*

In the following section the influence of the four system features (independent/centralized, condensing/traditional boiler, high/low temperature emitters, solar DHW integration) on the reported results is analyzed and discussed.

**Figure 10.** Primary energy needs of ITR, CTR, ICR and CCR heating systems.




Among all the analyzed aspects the choice between condensing/traditional boilers has a significant influence on system performance: this is due to boiler technical characteristics, peculiar of the two different technologies. As expected this consideration is evident in all the investigated energy indexes.

The introduction of solar plant has both a positive effect on boiler efficiency (Figure 5) and a negative effect on boiler and auxiliaries efficiency (Figure 6). The first one is due to the more continuous boiler load profile assured by DHW solar production: this determines fewer burner switches on/off (less intermittent operation), implying less thermal losses, thus higher boiler efficiency. The second one is due to the additional consumption of the circulating pump of the solar system. A further positive effect, evident analyzing global efficiency, Figure 7, is due to a reduction of storage and distribution thermal losses, that are partially covered by the solar plant. The resulting overall effect on global efficiency is positive. The only exception is the IC*RF+SHP case: the negative contribution of auxiliaries' consumption is even higher than the two positive effects. This result could be misleading: even though the lower global efficiency, compared to ICRF, the primary energy saving is considerable, approximately 29%. Therefore solar plant integration has always a significant positive influence on system performance. These considerations are in agreement with other studies in literature, for example very similar contributions of DHW solar plants, installed in Northern Italy, are reported in [19].

The choice between high/low temperature emitters has minor influence compared to the previously discussed aspects. Radiant floor installation determines: a positive effect on boiler efficiency, due to lower operating temperature; a negative effect on boiler and auxiliaries efficiency, caused by the higher flow rate and circulation pump consumption. A third effect influences negatively global efficiency: radiant floors have an additional downward thermal losses equal to approximately 10% of the supplied heat. The resulting overall effect of radiant floor installation is negative in all the investigated cases.

The differences between centralized and independent systems are minor, comparable to high/low temperature emitters effect. Centralized heating systems have always a better boiler and auxiliaries efficiency than independent ones, because of reduced circulation pump consumption for space heating.

The three-speed pump, installed in the independent systems, has a lower efficiency than the variable speed pump of centralized systems. Instead an extended distribution sub-system and a storage tank are present in centralized systems, implying higher thermal losses than in independent systems. Therefore considering global efficiency, the centralized systems perform better than the independent ones only in certain cases, *i.e.*, with condensing boilers. For these reasons the recommendation of D.P.R. 59/09 [2], that strongly suggests the utilization of centralized heating systems regardless of heating system peculiarities (DHW integration, emitters and boiler typologies), has to be considered only as a general suggestion. The most efficient layout between independent and centralized cannot be established *a priori*.

Note that the differences between high/low temperature emitters and independent/centralized layout cases are so limited that they can be considerably affected by a slight variation of auxiliaries' consumption or operating temperatures. The sensitivity analysis reported in the next section evaluates these influences. These considerations are also valid comparing global efficiency and primary energy need values for different construction periods. The higher values of global efficiency in 2006 buildings are due to the less relevant weight of auxiliary consumption: the latter keeps almost constant while primary energy need slightly increases, Figure 10. Instead in 1960s and 1930s buildings the lower values of global efficiency are due to higher thermal losses, mainly caused by higher operating temperature.

In our opinion the choice between independent and centralized heating system should not be based on the evaluation of primary energy consumption, but rather on other technical and economical aspects. A relevant aspect can also be the reliability of system characteristics during the whole lifetime. In practice, continuous maintenance and correct operation of centralized heating systems are assured by a responsible technician, allowing generally both stable and high performance and controlled pollutant emissions during system lifetime. Instead the independent systems operation and maintenance are not guaranteed to be optimal, because strongly affected by user behavior.

### *4.2. Results Reliability*

The results reported in this work are obtained from a calculation method based on European Standard. The consistency of the developed method with the EN 15316 allows utilizing available parameters, permitting reliable comparisons. This simple and flexible method has a high computational speed and can be easily applied to different cases and situations by changing a limited number of parameters. Despite these considerations the results are affected by a non-negligible uncertainty, mainly due to climatic data variability and user behaviour, that cannot be predicted. More accurate results are necessarily related to real cases and could be obtained measuring and billing for existing apartments.

For this reason, a sensitivity analysis has been carried out in order to appraise the influence of a variation in the most significant system characteristics. From the consideration of previous sections, the primary energy need is evident to be significantly affected by auxiliaries consumption and thermal losses, that depend on different heating system peculiarities.

In the sensitivity analysis, the effects of auxiliary consumption and operating temperatures variations are evaluated. Considering 2010 buildings, the auxiliary consumption has been modified by ±20%, instead the operating temperature has been modified by ±5 °C in the case of radiators and by ±2.5 °C in the case of radiant floor.

The results reported in Table 7 show a little variation of primary energy consumption, on the order of magnitude of the influence of independent/centralized and high/low temperature emitters features (Table 6). Therefore the significant influences of boiler typology and DHW solar production are robust to variations in auxiliaries' consumption and operating temperature; instead the considerations on emitter typology and independent/centralized layout are less reliable. For example a reduction of auxiliary consumption mainly diminishes the primary energy consumption of independent heating system, rather than centralized one. Also the variation of operating temperature affects differently the primary energy consumption in the analyzed heating systems; however the influence is limited. Therefore the result that emitter typology and independent/centralized layout have a minor influence in determining primary energy consumption is confirmed to be reliable.

**Table 7.** Influence of auxiliaries and operating temperature on primary energy consumption.

| | Primary Energy Variation [%] | | | |
|---|---|---|---|---|
| **Heating System** | **Aux +20%** | **Aux −20%** | **T +2.5/5 °C** | **T −2.5/5 °C** |
| ITR | 0.6 | −0.6 | 0.2 | −0.2 |
| CTR | 0.4 | −0.4 | 0.2 | −0.2 |
| ITRF | 1.0 | −1.0 | 0.1 | −0.1 |
| CTRF | 0.5 | −0.5 | 0.1 | −0.1 |
| ICR | 0.8 | −0.8 | 0.7 | −0.8 |
| CCR | 0.5 | −0.4 | 0.6 | −0.7 |
| ICRF | 1.4 | −1.4 | 0.4 | −0.4 |
| CCRF | 0.7 | −0.6 | 0.4 | −0.4 |
| IC*R+SHP | 1.4 | −1.4 | 1.0 | −1.1 |
| CCR+SHP | 0.8 | −0.7 | 0.7 | −0.8 |
| IC*RF+SHP | 2.5 | −2.5 | 0.3 | −0.3 |
| CCRF+SHP | 1.0 | −1.0~0.99 | 0.5 | −0.5 |

## 5. Conclusions

A systematic and encompassing analysis of several independent and centralized heating systems has been carried out. The conclusions that can be drawn are the following:

- The installation of condensing technology rather than traditional ones has a considerable influence on heating system performance: it reduces energy consumption by 6.1–11%.
- Solar DHW production in new buildings is the most relevant feature in primary energy saving, about 27–29%. Its installation should be promoted especially in centralized heating systems.
- Emitter typology has minor influence on primary energy consumption: the utilization of high temperature emitters can reduce primary energy consumption to 3%.
- The choice between independent and centralized layout is not the main heating system feature that affects energy consumption: the choice of traditional/condensing boiler, DHW solar heating integration and envelope thermal characteristics are more influential in the investigated cases. Therefore the recommendation of the Italian current regulation [2] has to be considered as a general suggestion to be verified case by case.

- In new buildings the energy input of auxiliaries gives a considerable contribution to primary energy consumption of independent systems: this is their main drawback.
- The primary energy need is strongly affected by building thermal insulation: it triples comparing 2010 buildings with 1960s ones. In renovation of old buildings, to make the most of an enhancement of heating system efficiency, a suitable envelop improvement should be coupled.

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