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# High Efficiency Hybrid Radiant and Heat Pump Heating Plants for Industrial Buildings: An Energy Analysis

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## ABSTRACT

A hybrid condensing radiant tubes system coupled to a heat pump to heat a typical industrial building was modeled in three climatic zones of Italy using dynamic simulation software. The heating system was set up by radiant tubes and an air heating system with terminals placed in the building supplied by hot water produced by the condensation of the exhausted of the radiant tubes and by a heat pump with external air heat source. An optimization of the main parameters (nominal power of the heat pump, bivalent temperature in alternative bivalent operation, and peak power of the photovoltaic system) was carried out on the basis of energy performance of the hybrid heating system. The optimal configuration of the hybrid heating system that minimizes the annual amount of total non-renewable primary energy and maximizes the non-renewable primary energy ratio was compared with traditional heating systems for industrial buildings. The energy savings of this innovative solution vary in the range of 40%-80% depending on the climate and the configuration of the system.

## 1. INTRODUCTION

Traditional climatization plants are not common in industrial buildings due to the particular characteristics of the latter: some equipment could be present on the ceiling or walls (pipes and tubes, bridge cranes, etc.), heights are typically higher (could be more than 8 m), floor areas are very large with different types of occupation by workers, doors can be large and can be often opened, comfort conditions requested are typically different, and thermal insulation of the walls and ceiling is usually scarce [1].

For example, in recent decades, evaporative cooling systems have been used in industrial buildings in northwest area of China, in particular semi-central systems that face the disadvantage of a large duct and difficult control of the temperature in different rooms [2]. More recently, De Angelis et al. [3] simulated different study cases by TRNSYS [4] varying the cooling system in the same reference industrial building, comparing the results in terms of energy savings and thermal comfort. A comprehensive evaluation of different heating, ventilation, and air conditioning (HVAC) systems for an industrial building was provided using the hybrid multicriteria decision making method [5]. Malyavina et al. [6] studied the influence of standard thermal protection of industrial buildings on heating load and seasonal heat consumption for heating in various climatic conditions of the Russian Federation.

Industrial facilities were studied in the case of energy retrofit [7], focusing both on the thermal envelope [8] and on technical building services such as the heating [9] or ventilation [10] plant. Gourlis and Kovacic presented a novel approach to evaluate the potential improvement in energy consumption and indoor climate of historical industrial buildings by dynamic thermal simulation modelling [11], also with regard to passive measures to prevent summer overheating [12]. The same authors also concentrated on developing a decision support tool to analyze the life cycle of facade systems for energy-efficient industrial facilities [13]. Smolek et al. [14] proposed a different modeling approach using cubes to decompose a manufacturing facility into modules such as the building, the energy system, production and logistics. Finally, the use of building information modeling and building energy modelling was explored for the analysis and optimization of two industrial buildings, to highlight the potentials and drawbacks of these methods [15].

In an analysis of the heating plant of an industrial building, traditional systems are not as common. Instead, high temperature radiant heating systems and air heater systems can be used because they are quite easy to install and with relatively low installation costs. Different air systems are available on the market: ground or wall air heaters fueled by natural gas or supplied by hot water and mechanical ventilation plants [16]. More recently, high-temperature radiant systems have been proposed: radiant tubes equipped with small gas burners, or the more traditional types of panels heated by pressurized water or steam, or electrical radiant panels [17, 18]. Such systems feature some positive characteristics: the heat flux can be directed towards the zone of interest, so comfort conditions can be reached with a lower air temperature [19, 20]. In the last decade, low temperature radiant heating floor systems have been installed in new industrial buildings with a higher level of thermal insulation, also due to the large diffusion of condensing boilers [21].

The indoor comfort conditions and energy performance of an innovative condensing radiant tube plant have been studied by the authors [22]. The system has been dynamically simulated by coupling a heat exchanger to condense the exhausted from the tubes. The hot water produced alimented wall-mounted air heaters, which improved the thermal efficiency of the system. The primary energy saving was 7% with respect to a radiant floor coupled to a condensing boiler and could reach 30% compared to a traditional air-heating system. As an additional advantage, better thermal comfort conditions could be allowed in the morning operation of the plant.

In the present study, a further development of the system presented by Noro and Lazzarin [22] is analyzed, that is, a hybrid heating system set up by an air-water heat pump coupled to the condensing radiant tubes plant (condensing radiant tubes + heat pump system, CRT+HP). Heating is provided by the radiant tubes and by the wall-mounted air heaters fed by hot water (40°C) produced by the condensation of the exhausted and by the heat pump. The scope of the study, based on TRNSYS rel. 17 software, is to optimize the hybrid configuration of the system, that is, to determine the values of external air bivalent temperature, heat pump nominal thermal power, and peak power of the photovoltaic plant (if installed on the roof) in order to:

- minimize the $PE_{nren,tot}$ (annual total non-renewable primary energy consumed by the hybrid plant);
- maximize the $PES_{nren,tot}$ (annual total saving of non-renewable primary energy compared to traditional heating systems);
- satisfy the minimum value of the renewable quota ($QR$) according to Italian Legislative Decree 199/2021 (implementation of the Renewable Energy Source II Directive), i.e., at least 60% referring to the considered services (in this work only heating). $QR$ is defined as the ratio between annual quantities of the renewable primary energy used (delivered or produced on site, calculated using the conversion factors ($f_{p,ren}$) for natural gas, electricity from the grid, electricity from the photovoltaic system, thermal energy from the external environment as heat source of the heat pump) and of the total primary energy used (renewable + non-renewable), calculated using the conversion factors ($f_{p,tot} = f_{p,ren} + f_{p,nren}$) for each energy carrier delivered or produced on site.

The best solution is then compared to benchmark heating systems:

- only condensing radiant tubes (CRT));
- air heater based system (Air);
- radiant floor coupled to condensing boiler (condensing radiant floor, CRF).

For all benchmark systems, energy performances are compared with the innovative hybrid CRT+HP plant. To consider the variety of real situations, both modern and old plants are considered for both Air and CRF by varying the thermal efficiency of the generators in suitable ranges.

The paper is organized as follows: in Section n. 2, the different steps of the modelling and simulations of the building, the hybrid CRT+HP plant, and the benchmark systems are described. In Section n. 3, the results of the simulations are reported first for the cases with the presence of the PV plant and then in the absence of the PV plant. Some remarks on annual energy comparison between the systems are reported as well. Finally, some final conclusions are reported.

## 2. METHODS

The study is conceived by three main steps:

- calculation of the heating load in three different climates by modeling a typical industrial building (based on a real case) [22];
- determination of the best set of bivalent temperature in alternative bivalent operation (the system gives priority to the heat pump, which switches off when the outside air temperature drops below the bivalent temperature and the radiant tubes turn on), HP thermal power and PV peak power installed on the building roof by modelling the hybrid condensing radiant tubes + heat pump system and analyzing the energy performance for each climate;
- modelling of the three benchmark heating systems and comparison of the energy performance with the CRT+HP hybrid system.

### 2.1 Industrial building modelling

The climate conditions of the simulated industrial building are reported in Table 1 for the three climatic zones D, E, and F defined by the Italian Legislative Decree 412/1993on the basis of the heating degree days (zone D: 1401-2100; zone E: 2101-3000; zone F: >3000). The size and characteristics of the opaque and transparent structures are reported in Table 2 and Table 3. Other hypotheses consider an operation heating plant scheduling from 6.00 am to 6.00 pm, a presence of people and lighting scheduling (heating gain fixed at 5 W $m^{-2}$) from 8.00 am to 6.00 pm, and a presence of people and degree of activity and clothing of 40 persons in zone 1, 8 persons in zone 2, 2 met, 1 clo. Air infiltration was supposed to be 0.5 vol $h^{-1}$.

**Table 1.** General climatic data for the heating

| **Type of building use (DPR 412/93)** | **E.8 Building for industrial activity** | | |
|---|---|---|---|
| Climatic zone | D | E | F |
| Resort (Province – State) | Roma (Roma – Italy) | Manta (Cuneo – Italy) | Agordo (Belluno – Italy) |
| Altitude a.s.l. | 20 | 400 | 610 |
| Latitude North | 41° 54’ | 44° 36’ | 46° 17’ |
| Longitude East | 12° 29’ | 7° 29’ | 12° 00’ |
| Degree Days | 1415 | 2814 | 3376 |
| Outdoor design air temperature | 0°C | -9.3°C | -12°C |

**Table 2.** Thermal transmittance of opaque and transparent structures of thermal zones of the building

| **Parameter (unit)** | **Value** |
|---|---|
| Thermal transmittance (W $m^{-2}$ $K^{-1}$) | |
| External wall | 0.389 |
| Door | 3.50 |
| Main door | 3.50 |
| Wall facing offices | 2.954 |
| Base facing wall | 3.220 |
| Floor facing ground | 0.128 |
| Ceiling | 4.086 |
| Ceiling shed | 0.208 |
| Window | 5.0 |
| Thermal bridge wall – floor facing ground (W $m^{-2}$ $K^{-1}$) | 0.353 |
| Thermal bridge wall – ceiling (W $m^{-2}$ $K^{-1}$) | 0.262 |

**Table 3.** Main characteristics of the two thermal zones of the building for TRNSYS simulation

| | Thermal zone 1 | Thermal zone 2 |
|---|---|---|
| Floor area ($m^2$) | 7119 | 716.5 |
| Net height (m) | 8.24 | 8.22 |
| Indoor air temp. (°C) | 18 | 18 |
| Net volume ($m^3$) | 58669 | 5886.2 |

The dynamic simulation of the building with a 0.25 h time step allows to calculate the heating loads (thermal power) and the heating needs (monthly energy, Figure 1). The thermal power of the heating generators is limited to 1200 kW, 1500 kW and 1500 kW for climatic zone D, E and F respectively, to be consistent with the installed power in the real building by the condensing radiant tubes' manufacturer.

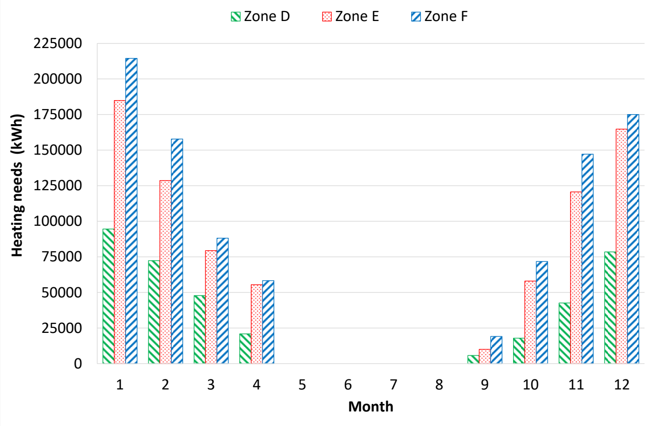


**Figure 1.** Monthly heating needs for the industrial building in three thermal zones

### 2.2 CRT+HP, CRT, Air, and CRF systems modelling

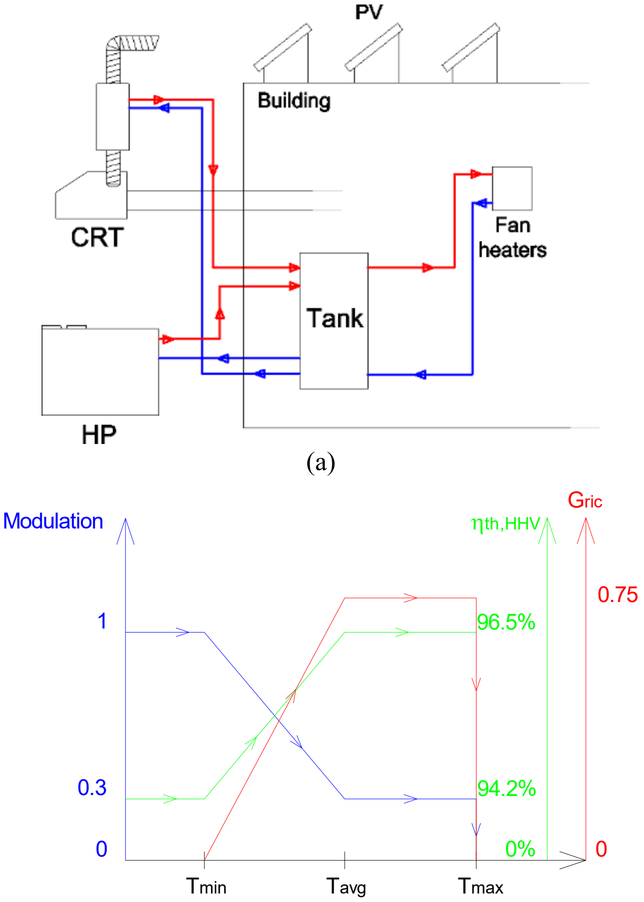
In the hybrid configuration (CRT+HP), an air-water heat pump is coupled to condensing radiant tubes to increase the utilization of renewable energy. A suitable thermal energy storage (1000 L) decouples wall-mounted air heaters from the hot water produced at 40°C by the condensing heat exchanger and the heat pump (Figure 2a).

The combustion air flow rate is controlled by an exhausted tab that recirculates part of the exhausted to keep the excess air at the minimum value at part load operation (that is, when natural gas fuel is regulated by a proportional valve).

The dynamic operation of the system is simulated in TRNSYS by coupling types 607 and 659. The former has been modified in order to simulate the behavior of the high temperature radiant tube system. At the start of operation, the CRT burner is turned on at maximum power to obtain the maximum exhausted temperature. When the temperature of the indoor air increases near the set point, the thermal power of the CRT burner is modulated by controlling the proportional valve of natural gas to have the fuel mass flow rate that is necessary to produce the heating load requested at that time step. Fuel modulation decreases the exhausted temperature and the exhausted tab is regulated to have the correct minimum air excess in the burner (Figure 2b) [22].

The heat pump, whose nominal data are reported in Table 4, is simulated by means of type 941.

The heat pump has priority operation, providing the thermal power to face the heating load according to the external air temperature $T_{ext}$. It operates in an alternative bivalent mode, i.e. its shutdown is when $T_{ext} < T_{biv}$, where the bivalent temperature $T_{biv}$ has to be optimized. In each time step, the radiant tubes cover the heating load that is not satisfied by the heat pump. A minimum load factor of 30% for the radiant tubes is considered. Thermal storage can compensate for an eventual surplus or deficit in thermal energy. Finally, the photovoltaic field, if present, can cover (partially or in excess, depending on the peak power installed) the electric consumption of the heat pump. The values of some parameters used in the energy analysis are reported in Table 5.



(a)

(b)

**Figure 2.** (a) Schematic of the CRT+HP plant; (b) Control logic of the proportional valve of natural gas (blue) and the exhausted tab (red). $G_{ric}$ (recirculated exhausted mass flow rate) is expressed in terms of the fraction of the return flow of the radiant tubes. Thermal efficiency (on HHV) versus modulation is also reported (green). In the simulations, the hypotheses are $T_{min}$=17°C, $T_{avg}$=17.5°C, $T_{max}$=18°C

**Table 4.** Nominal data of the air-water heat pump (mod. Clivet Spinchiller WSAN-XSC3 90.4) (D.B.=dry bulb temperature; W.B.=wet bulb temperature)

| $T_{ext}$ (°C) | | $T_{out,cond}$ (°C) | | | | | |
|---|---|---|---|---|---|---|---|
| D.B. | W.B. | 35 | | | 40 | | |
| | | $kW_{th}$ | $kW_{el}$ | COP | $kW_{th}$ | $kW_{el}$ | COP |
| -7 | -8 | 205.0 | 60.8 | 3.37 | 203.0 | 67.8 | 2.99 |
| -5 | -6 | 216.0 | 61.2 | 3.53 | 214.0 | 68.0 | 3.15 |
| 0 | -1 | 245.0 | 62.4 | 3.93 | 243.0 | 68.9 | 3.53 |
| 2 | 1 | 260.0 | 62.8 | 4.14 | 256.0 | 69.4 | 3.69 |
| 7 | 6 | 297.0 | 64.1 | 4.63 | 290.0 | 70.7 | 4.10 |
| 12 | 11 | 344.0 | 65.7 | 5.24 | 336.0 | 72.1 | 4.66 |

**Table 5.** Main parameters for energy and economic analysis (following the Italian Legislative Decree 199/2021)

| Symbol | Meaning | Value |
|---|---|---|
| $f_{p,nren,NG}$ | Non-renewable primary energy conversion factor for natural gas | 1.05 |
| $f_{p,nren,el}$ | Non-renewable primary energy conversion factor for electricity from the grid | 1.95 |
| $f_{p,ren,el}$ | Renewable primary energy conversion factor for electricity from the grid | 0.47 |
| $f_{p,ren,PV}$ | Renewable primary energy conversion factor for electricity from the PV field | 1 |
| $f_{p,ren,heat\_source\_HP}$ | Renewable primary energy conversion factor for external air thermal energy | 1 |
| *QR* | Minimum renewable ratio for new buildings | 60% |
| PV ($kW_p$) | (Reference) peak power of the PV field | 200 |
| PV ($\eta_{nom}$) | (Reference) peak efficiency of the PV field | 16.0% |
| PV ($m^2\ kW_p^{-1}$) | (Reference) specific area of the PV field | 6.3 |

## 3. RESULTS AND DISCUSSION

The results of the simulations refer to the annual energy performance of the CRT+HP system in the three climatic zones (D, E, F) in terms of sensitivity analysis: it is presented how the values of the main indices ($PE_{nren,tot}$, *PER*, $CO_2$ specific emission, *QR*) vary with the nominal power of the heat pump, with the peak power of the photovoltaic system (if present) and with the bivalent external air temperature. The main scope is to choose the best values of these three variables with respect to the reference values shown in Table 4 and Table 5. On the basis of such results, energy performances of the optimal configuration of the CRT+HP system are compared with the three benchmark heating systems (CRT, CRF, Air) in terms of non-renewable primary energy saving ($PES_{nren,tot}$).

### 3.1 Energy analysis with PV

Figure 3 reveals that in climatic zone D the most advantageous configuration is set up by $T_{biv}$ = 0°C; nominal output of the heat pump (Pth_HP) = 493 $kW_{th}$ (170% of the nominal output of Table 4, equal to approximately 41% of the nominal power of the radiant tubes, which is 1200 kW in climatic zone D); peak power of the photovoltaic system (PPV) = 340 $kW_p$ (170% of the nominal peak power of Table 5). This is the configuration that simultaneously minimizes the consumption of non-renewable primary energy $PE_{nren,tot}$ and allows for a high renewable ratio *QR*.

In both climatic zones E and F, the most advantageous configuration is set up by: $T_{biv}$ = 0°C; Pth_HP = 392 $kW_{th}$ (135% of the nominal output of Table 4, equal to approximately 25% of the installed nominal power of the radiant tubes (1500 $kW_{th}$)); PPV = 270 $kW_p$ (135% of the nominal peak power of Table 5).

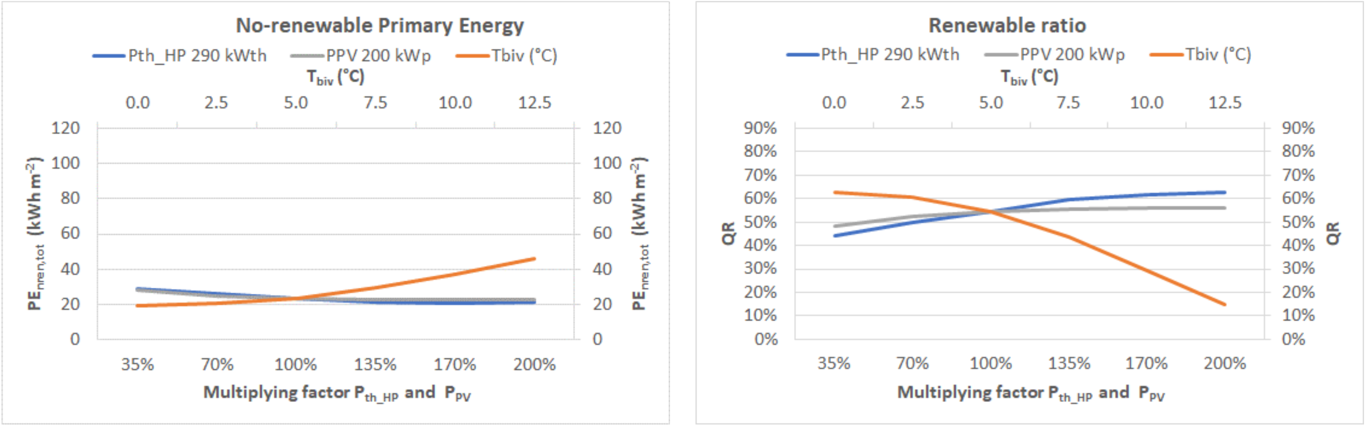
Table 6 shows the annual values of energy performance indices of the CRT+HP system in the optimal configuration. *PER* decreases in colder climates mainly due to the greater use of radiant tubes (i.e., natural gas) and to a lower use of renewable energy by the heat pump. In fact, there is a lower use of both thermal energy (as a heat source at the evaporator due to lower *COP*) and electrical energy powering the compressor (due to lower production of the photovoltaic field). For the same reasons, the *QR* renewable ratio decreases in colder climates. Note that the 60% value required by Legislative Decree 199/2021 is exceeded only in climatic zone D.

The self-consumed (by heat pump) electricity quota of photovoltaic production is higher in colder climates (15% in zone D, 24% in zone F). Table 6 reports the annual value of the *PER*, which is quite high in general, and extremely high in milder climates.

Figure 4 reports the comparison in terms of annual non-renewable primary energy between the hybrid CRT+HP system and the benchmark plants. The hybrid system allows extremely high non-renewable primary energy savings ($PES_{nren,tot}$) compared to the other solutions, especially in milder climates (zone D). In this case, there is a greater contribution from renewable sources in input to the heat pump, both the aeraulic one to the evaporator (higher *COP* due to higher external temperatures) and the electric one from photovoltaics.

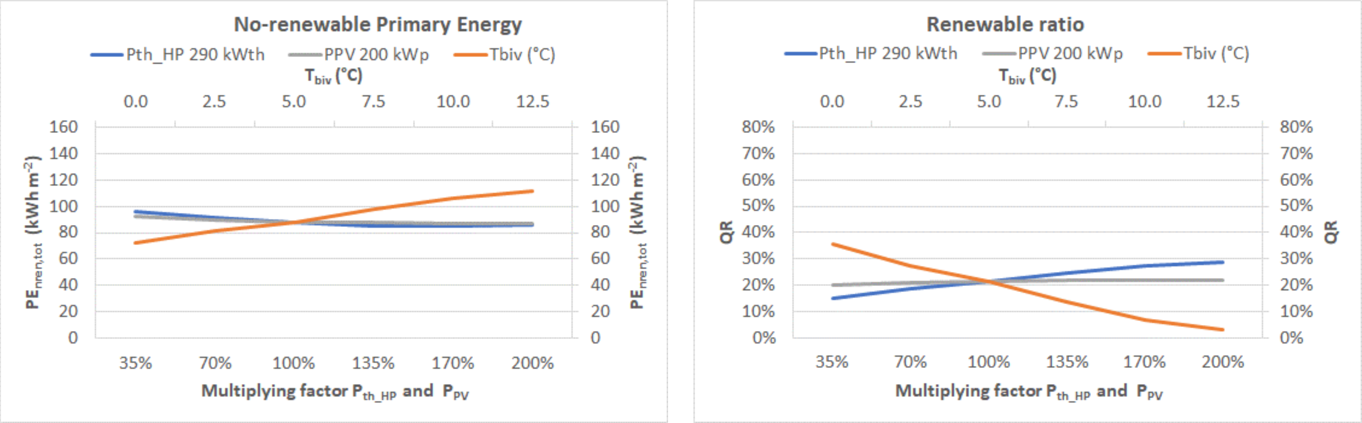
As a final remark, note that, even with respect to the efficient condensing radiant tubes plant (CRT), the hybrid configuration allows for very high $PES_{nren,tot}$ ranging from 40% to 82%.

Climatic zone D



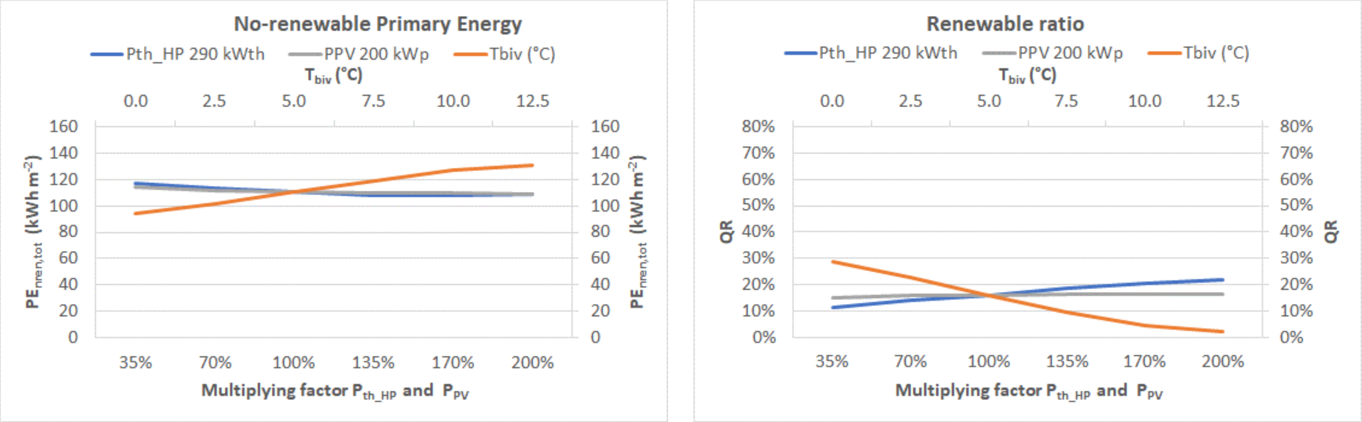
(a) (b)

Climatic zone E



(a) (b)

Climatic zone F

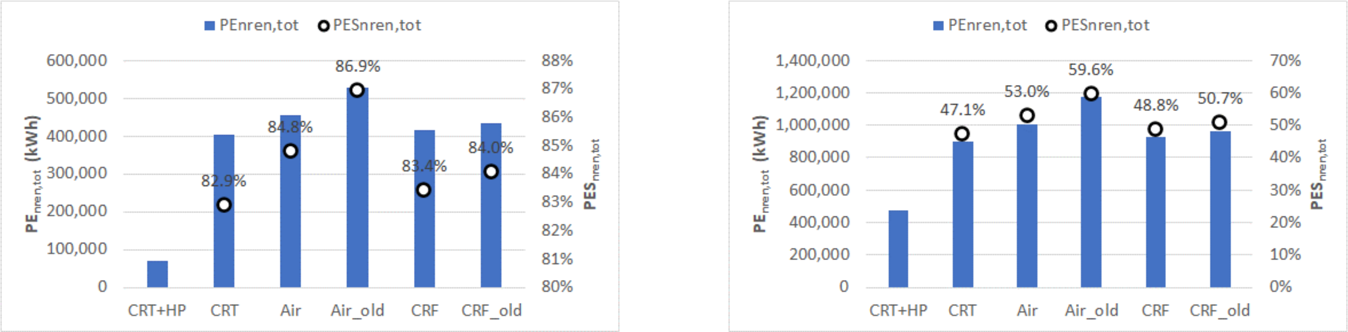


(a) (b)

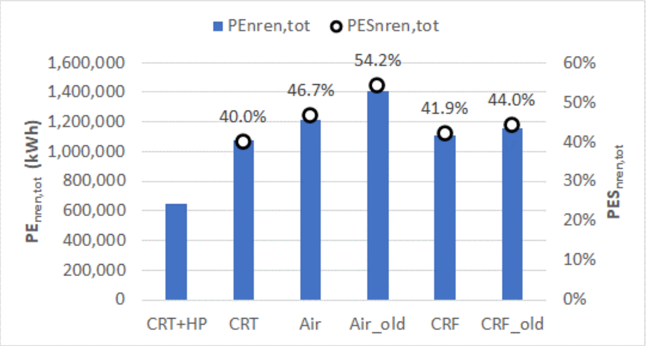
**Figure 3.** Annual values of $PE_{nren,tot}$ and $QR$ of the hybrid CRT+HP system varying the multiplication factor of the nominal output of the heat pump (Pth_HP) and the peak power of the photovoltaic system (PPV) (lower abscissa, left ordinate) and varying the bivalent temperature (upper abscissa, right ordinate) (with PV, bivalent alternative operation)

**Table 6.** Annual values of the energy performance indices of the CRT+HP system in the optimal configuration for the three climatic zones (*PE*=primary energy) (with photovoltaic)

| Symbol | Description | Unit | Zone D | Zone E | Zone F |
|---|---|---|---|---|---|
| $PE_{ren,el}$ | Renewable quota of electricity from the grid | kWh | 3,272 | 4,545 | 8,840 |
| $PE_{nren,el}$ | Non-renewable quota of electricity from the grid | kWh | 13,575 | 18,857 | 36,675 |
| $PE_{ren,PV}$ | Renewable quota of electricity from the PV self-consumed | kWh | 77,435 | 99,845 | 89,512 |
| $PE_{ren,PV,exp}$ | Renewable quota of electricity from the PV exported to the grid | kWh | 431,252 | 367,027 | 284,480 |
| $PE_{ren,heat\_source\_HP}$ | Thermal energy as heat source of the HP | kWh | 246,289 | 287,078 | 281,042 |
| $PE_{ren,tot}$ | Total renewable | kWh | 326,996 | 391,468 | 379,393 |
| $PE_{nren,NG}$ | Non-renewable as natural gas | kWh | 57,464 | 454,312 | 608,957 |
| $PE_{nren,tot}$ | Total no-renewable | kWh | 71,039 | 473,168 | 645,632 |
| $PER$ | Primary energy ratio | | 5.35 | 1.69 | 1.44 |
| $QR$ | Renewable ratio | | 82.2% | 45.3% | 37.0% |
| $PE_{nren,tot}$ | Specific total non-renewable | kWh m$^{-2}$ y$^{-1}$ | 9.1 | 60.4 | 82.4 |
| $CO_2$ | | kg$_{CO2}$ m$^{-2}$ | 1.8 | 11.5 | 15.8 |



(a) Zone D (b) Zone E

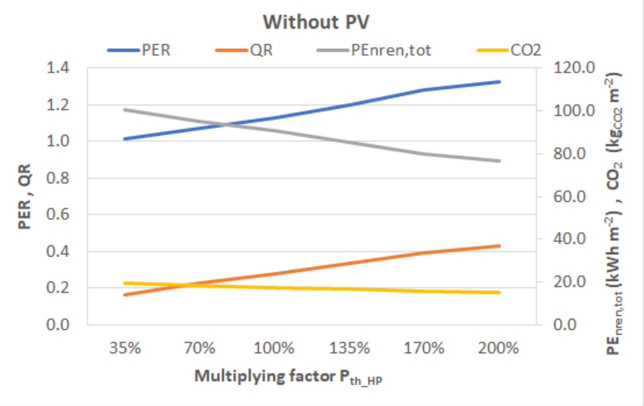


(c) Zone F

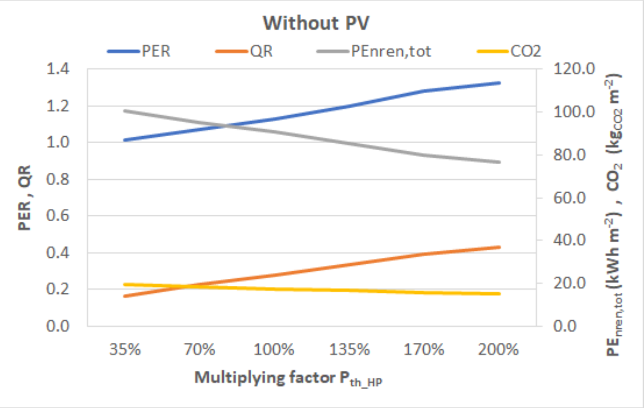
**Figure 4.** Total annual non-renewable primary energy consumption ($PE_{n,ren,tot}$) and savings of the same energy ($PES_{nren,tot}$) of the hybrid CRT+HP system in the optimal configuration (with photovoltaic)

### 3.2 Energy analysis without photovoltaics

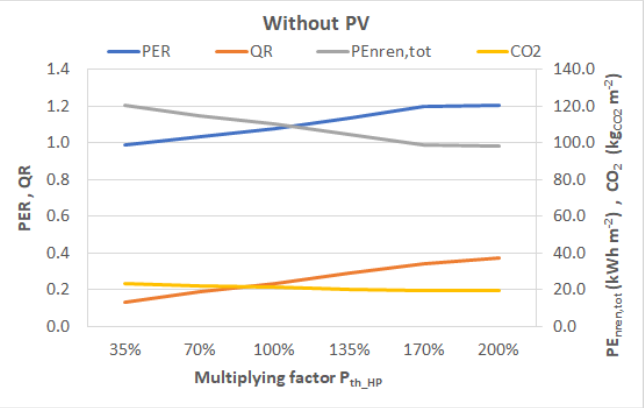
In case of no economic investment in the photovoltaic plant, the optimal size of the heat pump (Pth_HP) with alternative operation decreases from climatic zone D to F: it is 200% of the value in Table 4 in zones D and E (i.e. 580 $kW_{th}$, 48% and 39% of the nominal installed power of the radiant tubes, respectively), while it decreases to 170% in zone F (i.e. 493 $kW_{th}$, 33% of the nominal installed power of the radiant tubes) (Figure 5) (with $T_{biv}$ = 5°C). In addition to the fact that the *PES* is lower than in the case with a PV plant, primary energy savings are still very interesting, especially in milder climates (from 30% with respect to CRT to 47% with respect to Air_old system in zone D) due to the high contribution of renewables in the HP evaporator (i.e. higher *COP*).



(a) Zone D



(b) Zone E



(c) Zone F

**Figure 5.** $PE_{n,ren,tot}$, *PER*, *QR*, and specific $CO_2$ emission varying the Pth_HP multiplying factor (without PV)

Based on previous results, the *PER* of the hybrid system is very high, especially in milder climates (in zone D it exceeds the value of 5 with the presence of the PV field). It decreases in colder climates mainly due to more extended use of radiant tubes (and therefore of natural gas) and to lower use of renewable energy by the heat pump (Table 7). Without the PV plant the *PER* cannot reach such values, even if very interesting in any case. Consequently, both the non-renewable specific primary energy consumption and the $CO_2$ specific emissions with the PV plant are definitely higher than in the case of absence.

The *QR* renewable ratio decreases substantially in colder climates for the same reasons as above. The value of 60% is exceeded only in the presence of the photovoltaic system (Table 7).

**Table 7.** Energy performance of the CRT+HP system in optimal configuration

| | | | Zone D | Zone E | Zone F |
|---|---|---|---|---|---|
| WITH PV – BIVALENT ALTERNATIVE | *PER* | | 5.35 | 1.69 | 1.44 |
| | *QR* | | 82.2% | 45.3% | 37.0% |
| | $PE_{nren,tot}$ | kWh m$^{-2}$ | 9.1 | 60.4 | 82.4 |
| | $CO_2$ | $kg_{CO2}$ m$^{-2}$ | 1.8 | 11.5 | 15.8 |
| WITHOUT PV – BIVALENT ALTERNATIVE | *PER* | | 1.73 | 1.33 | 1.21 |
| | *QR* | | 56.5% | 43.2% | 37.1% |
| | $PE_{nren,tot}$ | kWh m$^{-2}$ | 28.1 | 76.9 | 98.5 |
| | $CO_2$ | $kg_{CO2}$ m$^{-2}$ | 5.7 | 15.2 | 19.3 |

## 4. CONCLUSIONS

From the energy point of view, in the presence of the photovoltaic system it is not advantageous to size the heat pump of the CRT+HP system more than 40% of the installed power of the radiant tubes in climatic zone D, and 25% in zones E and F.

The most suitable values of bivalent temperature in alternative operation are equal, respectively, to 0°C in zone D, 0°C in zone E, 0°C in zone F. Concerning the optimal peak PV power to be installed, it is between 5.5 and 7.5 m$^2$ $kW_p^{-1}$ depending on the nominal peak efficiency of the panels (in the range of 14%-19%).

In the optimized configuration, the hybrid CRT+HP heating system allows very high *PER* especially in milder climates: in zone D it exceeds the value of 5 in the presence of the photovoltaic system, and it decreases in the colder zones E and

F. The value of 60% for *QR* is exceeded only in the presence of the photovoltaic system.

The energy performance of the hybrid system allows for very high primary energy savings with respect to the benchmark plants: in the presence of the photovoltaic system, the *PES* varies from 40% (climatic zone F) to values greater than 80% (climatic zone D). In case of no investment in PV, the values are lower, but still interesting.

As a further development of this work, the effects on the energy performance of a different control logic of the hybrid configuration (such as the bivalent parallel one) could be analyzed. Furthermore, an economic analysis could be implemented to assess the economic viability of the hybrid system in comparison to the benchmark heating plants. The economic analysis could also be useful to highlight that installation of the PV field could make the hybrid solution less sensitive to the increase of the cost of electricity from the grid, which otherwise would heavily affect the actual economic viability of the investment.

## ACKNOWLEDGMENT

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## NOMENCLATURE

### Acronym

| | |
|---|---|
| Air | Air heating system |
| CRF | Condensing Radiant Floor |
| CRT | Condensing Radiant Tube |
| HHV | High Heating Value, MJ Sm$^{-3}$ |
| HP | Heat Pump |
| HVAC | Heating, Ventilation, Air Conditioning |
| NG | Natural Gas |
| PV | PhotoVoltaic |

### Symbol

| | |
|---|---|
| $COP$ | Coefficient Of Performance |
| $f_p$ | Primary energy factor |
| $P$ | Power, kW |
| $PE$ | Primary Energy, kWh |
| $PER$ | Primary Energy Ratio |
| $PES$ | Primary Energy Saving |
| $QR$ | Renewable Ratio |
| | Efficiency |

### Subscripts

| | |
|---|---|
| *biv* | Bivalent |
| *cond* | Condenser |
| *el* | Electricity from the grid |
| *exp* | Electricity exported to the grid |
| *ext* | External |
| *fuel* | Fuel |
| *heat_source* | Heat source of the heat pump (at the evaporator) |
| *nren* | Non-renewable |
| *out* | Outlet |
| *ren* | Renewable |
| *th* | Thermal |
| *tot* | Total |