Heat pumps in existing heating and hot water systems: an evaluation of primary energy savings and reduction of CO_2 produced

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Aims of the study

- Replacement of the entire current thermal plant fleet of two different Italian cities with high temperature heat pumps.
- Unobtrusive for citizens since the heat pumps are coupled with current radiators.
- Proposed to improve urban air quality
- Consequences in terms of primary energy savings and CO_2 emissions

Summary

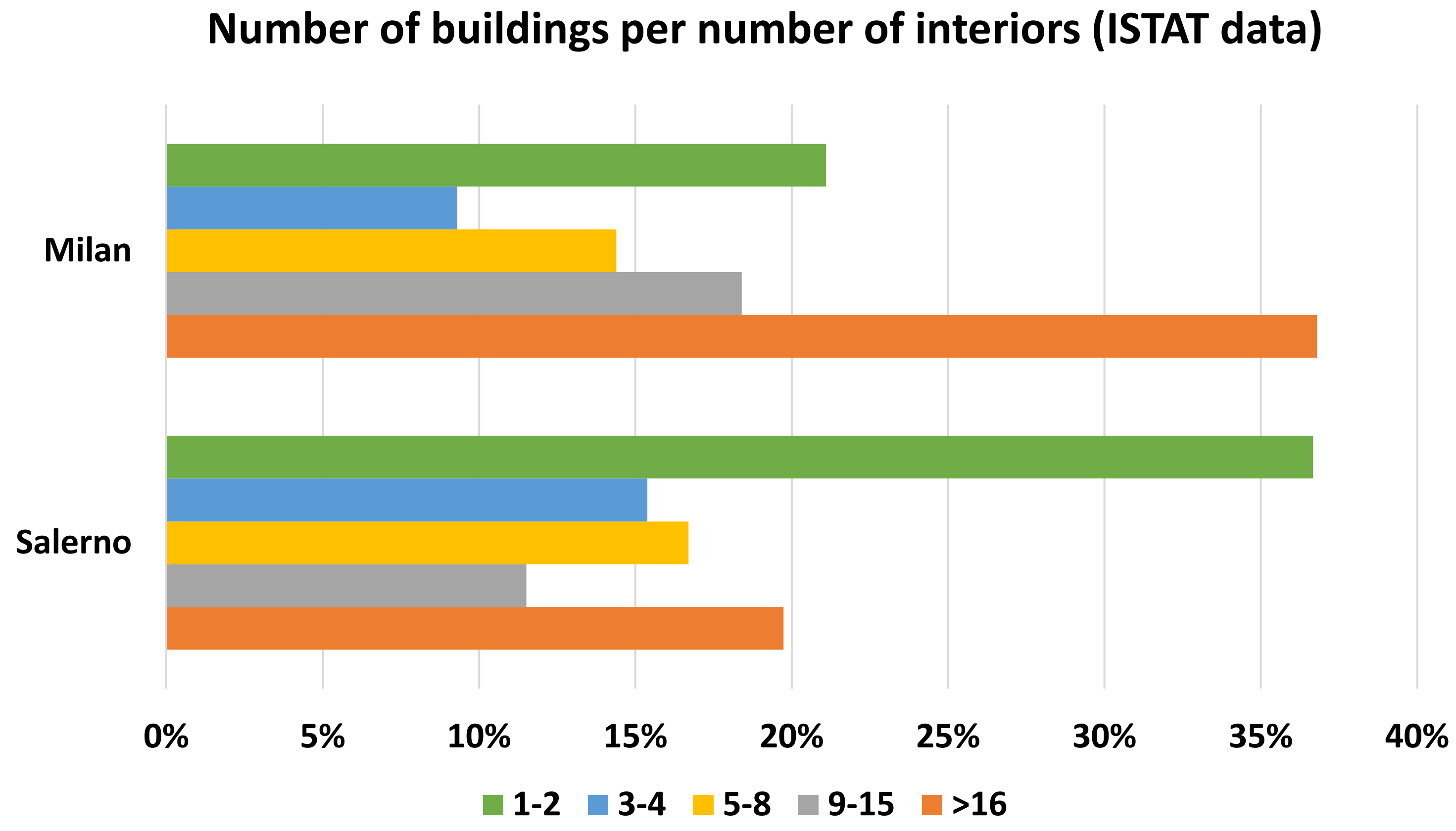
- Climatic description of the two Italian cities
- Thermophysical characterisation of the residential building stock and related thermal energy needs
- Analysis of the existing thermal plants
- Suitable heat pumps
- Evaluation of the impact of the substitution
- Conclusions

Climatic description of the two Italian cities

Milan and Salerno

City	Location	Climatic zone	External Design temperature
Milan	Lombardy, north-west Italy	Cold-temperate zone E	-5°C
Salerno	Central-southern Italy	Mid-temperate zone C	2°C

Building stock



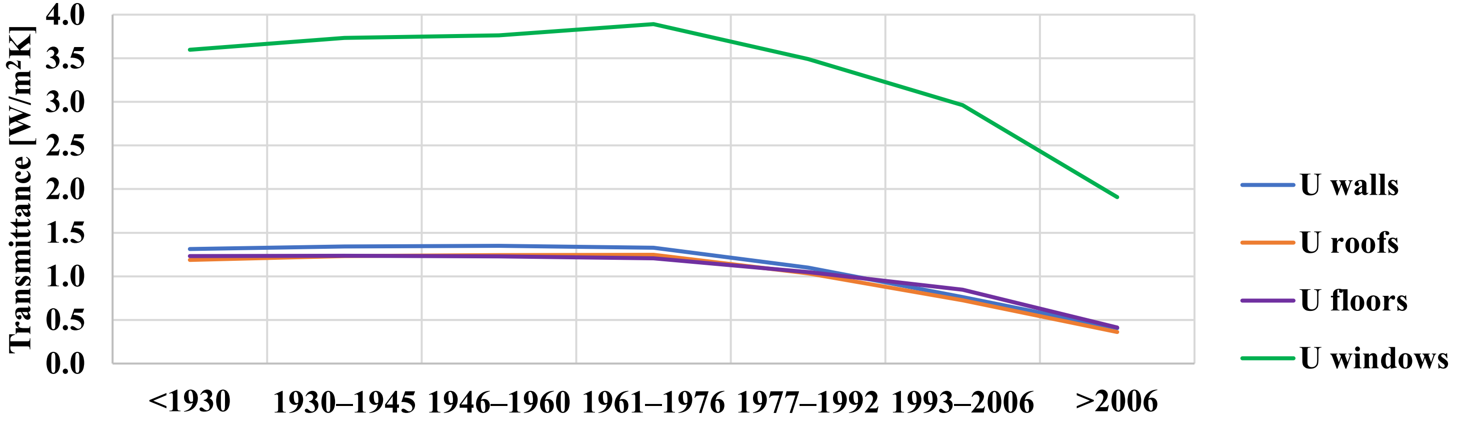
Milan:

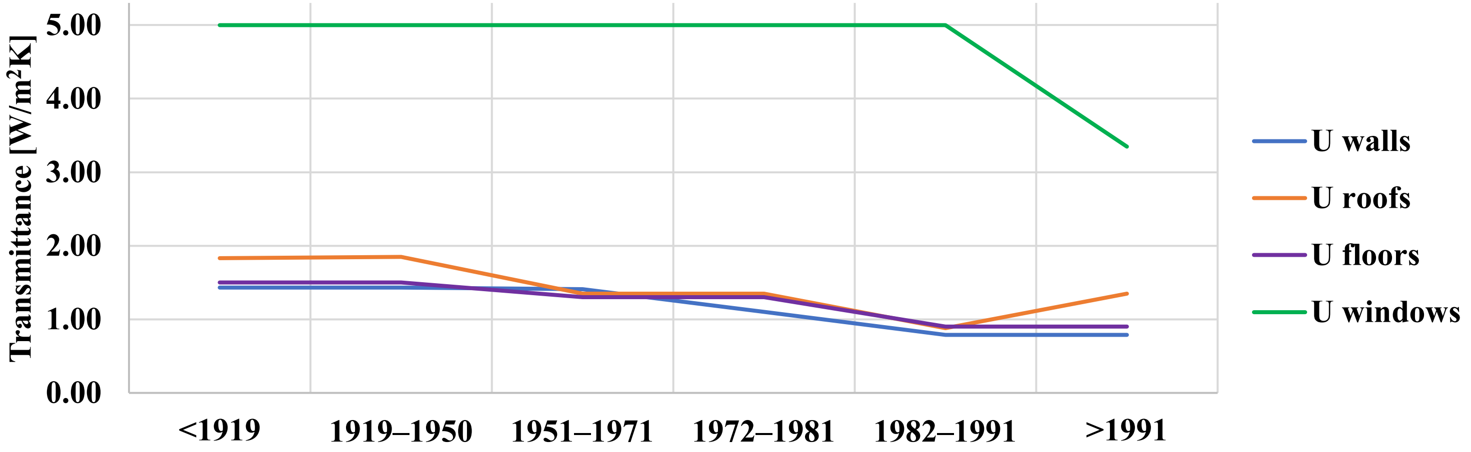
- 70% constructed between 1919 and 1970, only 5% after 1990
- 66% are four or more stories above ground, only 7% are one story
- 55% have more than eight interiors

Salerno:

- 55% built between 1919 and 1970, only 7.5% after 1990
- 46% are two or three stories above ground
- 37% consisting of one or two interiors

Average thermal transmittances





Thermal energy needs - Milan

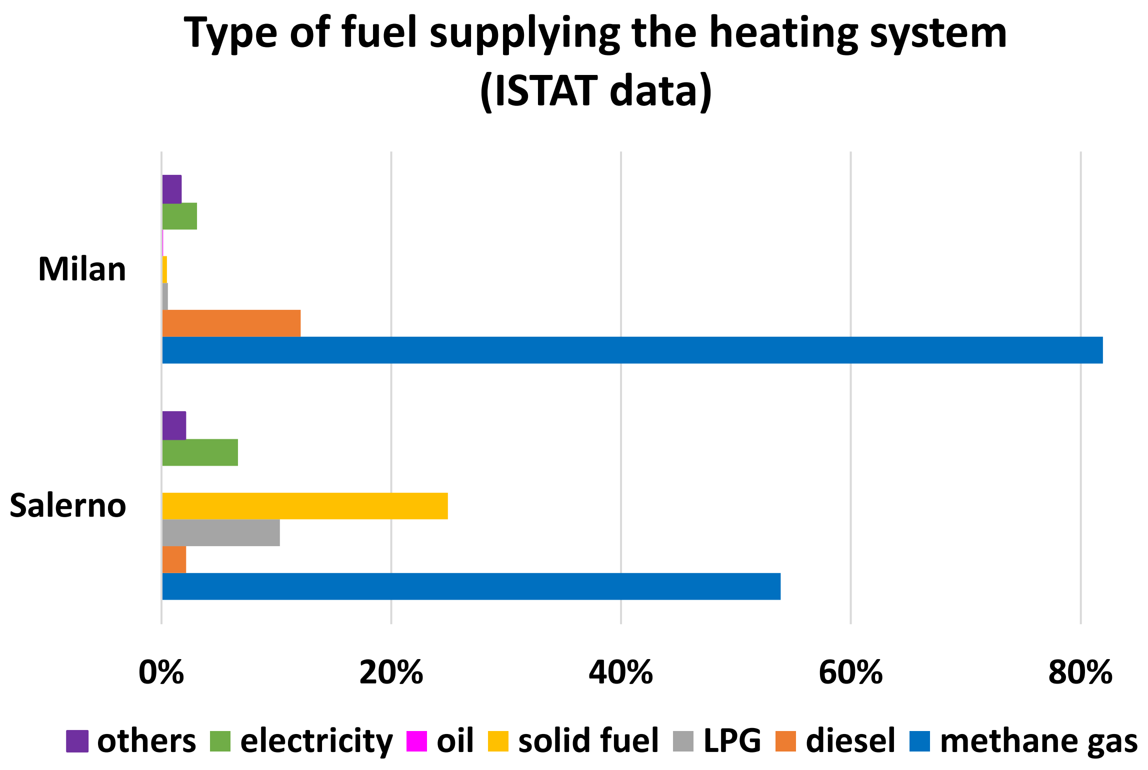
CY	%BS	Thermal energy needs in kWh_t/year		
		Heating	DHW	Heating and DHW
<1919	8.8%	7744	1140	8883
1919–1945	16.3%	7733	1130	8863
1946–1960	25.0%	7933	1151	9084
1961–1970	28.1%	8709	1209	9919
1971–1980	11.2%	8564	1233	9797
1981–1990	4.2%	8346	1269	9615
>1990	6.3%	5791	1159	6950

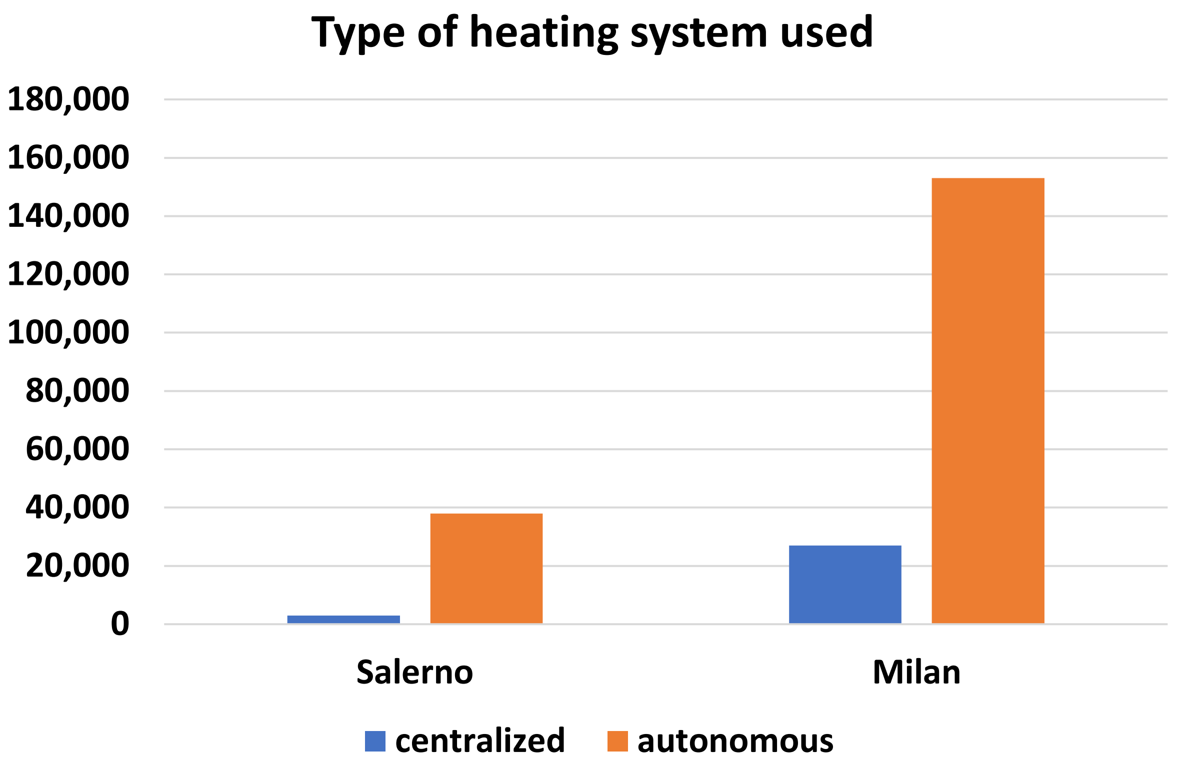
Thermal energy needs - Salerno

CY	%BS	Thermal energy needs in kWh_t/year		
		Heating	DHW	Heating and DHW
<1919	8.1%	4778	1239	6017
1919–1945	9.8%	4782	1239	6022
1946–1960	24.1%	4205	1375	5580
1961–1970	31.4%	3916	1443	5359
1971–1980	12.9%	3304	1443	4746
1981–1990	9.4%	2774	1443	4217
>1990	4.3%	2525	1443	3968

Analysis of the existing thermal plants

Milan and Salerno





Selection

- High temperature air-to-water heat pumps; terminals: radiators (70°C)
- Suitable size from a manufacturer’s catalogue
- Sizing based on winter heat load at the outdoor design temperature
- Power supply: national grid (35% renewable fraction, 65% fuel fraction)

Characteristics of selected heat pumps

Compressor	scroll compressor with inverter
Refrigerant	R32
Operating logic	prioritizing DHW production

Performance

Milan

CY	%BS	NP kW	PP kW	COP (–5 °C/70 °C)
<1919	8.8%	3.35	8.73	1.78
1919–1945	16.3%	3.34	8.73	1.78
1946–1960	25.0%	3.43	8.73	1.78
1961–1970	28.1%	3.76	8.73	1.78
1971–1980	11.2%	3.70	8.73	1.78
1981–1990	4.2%	3.61	8.73	1.78
>1990	6.3%	2.50	8.73	1.78

Salerno

CY	%BS	NP kW	PP kW	COP (2° C/70 °C)
<1919	8.1%	3.40	9.13	2.00
1919–1945	9.8%	3.41	9.13	2.00
1946–1960	24.1%	3.03	9.13	2.00
1961–1970	31.4%	2.85	9.13	2.00
1971–1980	12.9%	2.68	9.13	2.00
1981–1990	9.4%	2.53	9.13	2.00
>1990	4.3%	2.46	9.13	2.00

- Choice of oversizing
- Full load performance at design conditions
- COP computed by interpolation of the second efficiency values η_{II} (UNI EN 14825)

Primary energy needs

Milan

CY	Thermal energy needs for heating and DHW preparation, kWh_t/year	Primary energy needs single boiler, kWh_t/year	Primary energy needs HP ($COP_{-5\,°C/70\,°C}$), kWh_t/year
<1919	8883	11,307	7434
1919–1945	8863	11,281	7417
1946–1960	9084	11,560	7602
1961–1970	9919	12,614	8300
1971–1980	9797	12,467	8199
1981–1990	9615	12,245	8046
>1990	6950	8894	5816

Salerno

CY	Thermal energy needs for heating and DHW preparation, kWh_t/year	Primary energy needs single boiler, kWh_t/year	Primary energy needs HP ($COP_{2\,°C/70\,°C}$), kWh_t/year
<1919	6017	7743	4482
1919–1945	6022	7748	4485
1946–1960	5580	7220	4156
1961–1970	5359	6957	3991
1971–1980	4746	6190	3535
1981–1990	4217	5529	3141
>1990	3968	5218	2955

CO_2 emissions

14th IEA HEAT PUMP CONFERENCE

Milan

CY	Thermal energy needs for heating and DHW preparation, kWh_t/year	CO_2 emissions single boiler, $kgCO_2$/year	CO_2 emissions HP ($COP_{-5\,°C/70\,°C}$), $kgCO_2$/year
<1919	8883	2288	1602
1919–1945	8863	2283	1599
1946–1960	9084	2339	1639
1961–1970	9919	2552	1789
1971–1980	9797	2523	1767
1981–1990	9615	2478	1735
>1990	6950	1800	1254

Salerno

CY	Thermal energy needs for heating and DHW preparation, kWh_t/year	CO_2 emissions single boiler, $kgCO_2$/year	CO_2 emissions HP ($COP_{2\,°C/70\,°C}$), $kgCO_2$/year
<1919	6017	1567	966
1919–1945	6022	1568	967
1946–1960	5580	1461	896
1961–1970	5359	1408	860
1971–1980	4746	1253	762
1981–1990	4217	1119	677
>1990	3968	1056	637

Reduction of primary energy consumption and CO_2 emissions - Milan

CY	%BS	Number of HPs	Global primary energy HPs / global primary energy boilers	CO_2 HPs/CO_2 boilers
<1919	8.8%	42,328	66%	70%
1919–1945	16.3%	78,379	66%	70%
1946–1960	25.0%	119,867	66%	70%
1961–1970	28.1%	134,816	66%	70%
1971–1980	11.2%	53,821	66%	70%
1981–1990	4.2%	20,379	66%	70%
>1990	6.3%	30,410	65%	70%
TOTAL		480,000	66%	70%

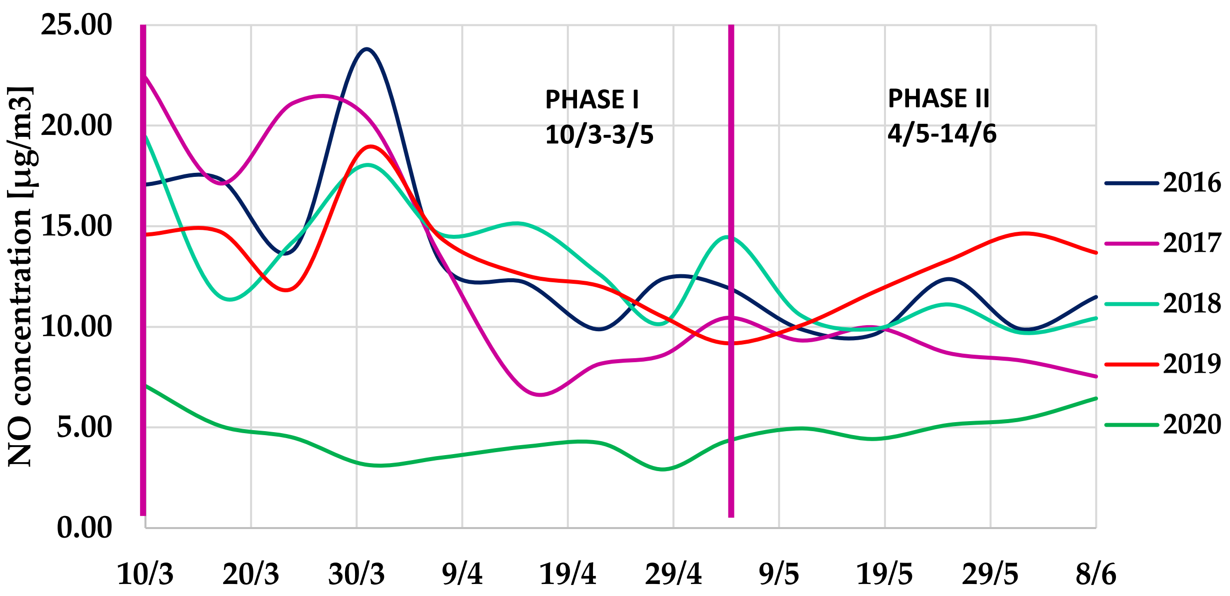
Reduction of primary energy consumption and CO_2 emissions - Salerno

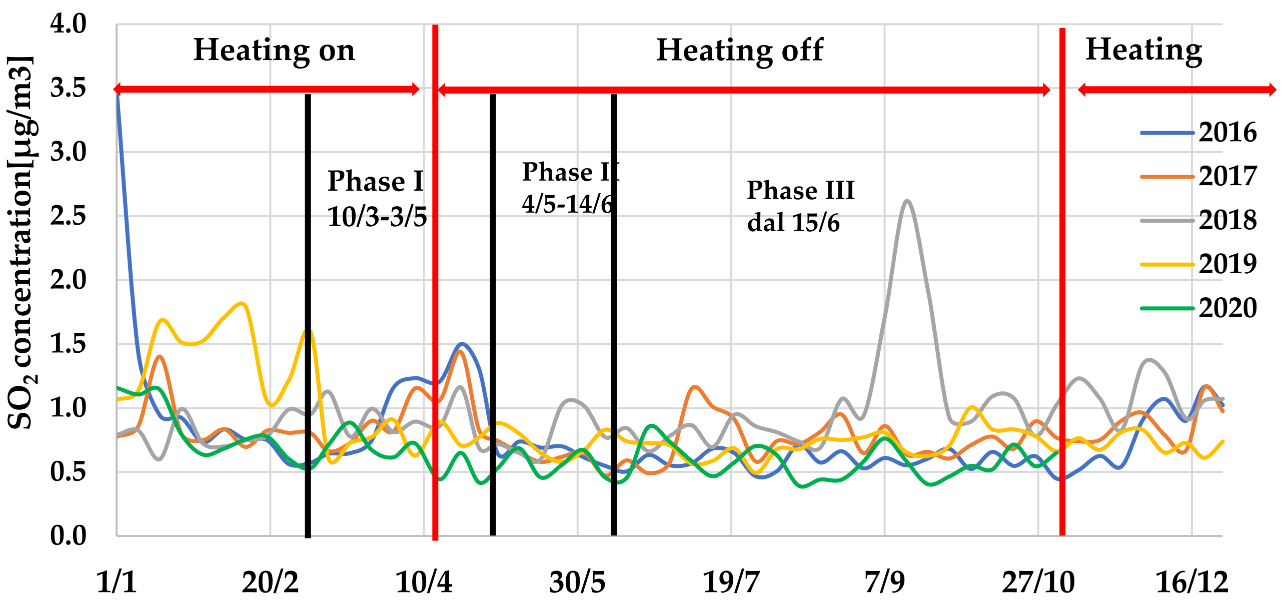
CY	%BS	Number of HPs	Global primary energy HPs / global primary energy boilers	CO_2 HPs/CO_2 Boilers
<1919	8.1%	6022	58%	62%
1919–1945	9.8%	7255	58%	62%
1946–1960	24.1%	17,860	58%	61%
1961–1970	31.4%	23,226	57%	61%
1971–1980	12.9%	9546	57%	61%
1981–1990	9.4%	6934	57%	61%
>1990	4.3%	3158	57%	60%
TOTAL		74,000	57%	61%

Heating systems as an emissive source

This study underlines the important role of heat pumps for sustainability and electrification targets to achieve energy transition.
The choice of the present evaluation starts from a previous work on the analysis of pollutant concentrations and from the identification of the weight of heating systems as an emissive source.

LOCKDOWN EFFECT





Results and limits of the work

- Proposed replacement of boilers with HPs would be a viable solution in terms of:
  - reduction of primary energy needs
  - reduction of CO_2 emissions

- Analysis carried out with some approximations:
  - average efficiency of boilers
  - selection performed of the machines
  - design conditions

Future analyses

- Future evaluations:
  - real operating conditions: SCOP at partial load related to external temperature profiles
  - different Italian and European cities
  - residential sector: individual dwelling and centralized heat pumps systems
  - replacement scenarios of boilers with heat pumps in the industrial sector