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Aspects regarding heating and cooling in energy efficient buildings using heat pumps

Aspecte privind încălzirea și răcirea în clădiri eficiente energetic folosind pompe de căldură

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Abstract. *In the current context in which heating and cooling accounts for half of the EU's energy consumption and is responsible for 27% of greenhouse gas (GHG) emissions, reducing the energy demand for heating and cooling and increasing the share of renewable energy represents key elements to fulfill the EU's climate and energy goals.*
The paper presents the potential of the heating and cooling sector to improve energy efficiency and increase the share of energy from renewable sources, focusing on promoting energy efficient buildings and heat pumps. Using Casanova software, the authors have proposed for analysis a passive-green building designed according to passive standard and using environmentally friendly materials, simulating heating and cooling demand in different climate zone in the context of achieving passive house heating and cooling requirements. By comparing different heating systems, for Bucharest city, the simulations highlighted the potential of heat pumps in reducing the final and primary energy consumption.

Keywords: heating, cooling, greenhouse gas, emissions, energy efficiency, heat pump, ecological, passive standard

Rezumat. *În contextul actual în care încălzirea și răcirea reprezintă jumătate din consumul de energie în UE și sunt responsabile pentru 27% din emisiile de gaze cu efect de seră (GES), reducerea cererii de energie pentru încălzire și răcire și creșterea ponderii energiei din surse regenerabile reprezintă elemente-cheie pentru îndeplinirea obiectivelor UE în materie de climă și energie. Lucrarea prezintă potențialul sectorului de încălzire și răcire de a îmbunătăți eficiența energetică și de a crește ponderea energiei din surse regenerabile, concentrându-se pe promovarea clădirilor eficiente energetic și a pompelor de căldură. Folosind software-ul Casanova, autorii au propus pentru analiză o clădire pasivă-verde proiectată în conformitate cu standardul pasiv și folosind materiale* *ecologice, simulând cererea de încălzire și răcire în diferite zone climatice, în contextul limitării necesarului de încălzire și răcire în casele pasive. În comparație cu diferitele sisteme de încălzire, pentru orașul București, simulările evidențiază potențialul pompelor de căldură în reducerea consumului de energie finală și primară.*

Cuvinte cheie: încălzire, răcire, emisii, gaze cu efect de seră, eficiență energetică, pompă de căldură, ecologic, standard pasiv

1. Introduction

At global level, combating climate change is the main challenge for the world's countries, which have committed themselves to a severe limitation of greenhouse gas (GHG) emissions, which are considered the main cause of climate change.

As the energy sector (energy use in industry, energy use in buildings and transport) is responsible for almost three-quarters of world-wide GHG emissions (Figure 1), global actions will be needed to transform the energy sector from fossil-based to zero-carbon until 2050 [1], [2]. Regarding this aspect, the strategies and policies on global scale will focus first on the decarbonization of the energy sector as a key part of the 2050 climate neutrality target. But to reach that target, efficient solutions will be needed across all sectors.

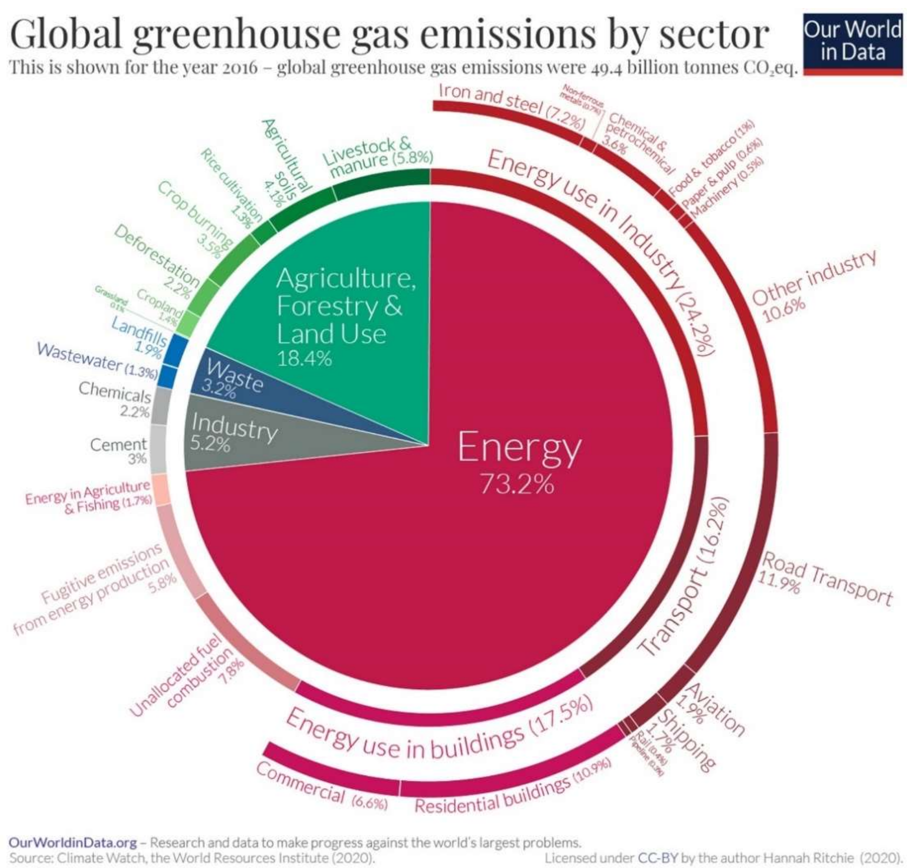

Fig. 1. Global greenhouse gas emissions by sector [1]

To secure the transition to a low-carbon energy sector, while modernizing the economy of European Union and creating opportunities for innovation, investment, jobs and growth for all European citizens [3], [4], energy from renewable energy sources (RES), together with increased energy efficiency, can potentially reach 90% of the required carbon reductions before 2050 [2].

The paper presents the potential of the heating and cooling sector to improve energy efficiency and increase the share of energy from renewable sources, focusing on the potential of energy efficient buildings and heat pumps in reducing GHG emissions and harnessing renewable sources of energy. The authors have proposed for analysis a passive-green building designed according to passive standard, which would use environmentally friendly materials.

2. Heating and cooling

Heating and cooling for residential and commercial buildings (water heating, cooking, ambient heating and cooling, refrigeration) and for industrial purposes (ambient heating and cooling, process heating) accounts for around 50% of global final energy consumption (46% is used in buildings) and more than 40% of global energy-related CO_2 emissions [3], [5], [6].

Given the increasing demand for energy, and the fact that most of this energy comes from fossil fuels (Figure 2), to meet the goal of achieving climate neutrality by 2050, a key role will be played by the decarbonization of the heating and cooling (H&C) sector.

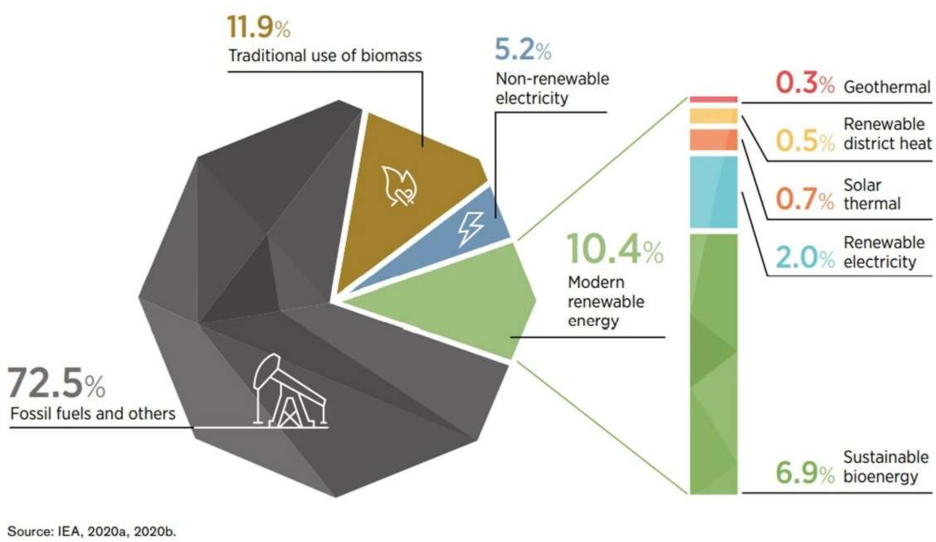

Fig. 2. Share of energy sources in total final energy consumption for H&C, 2019 [6]

This will require strategies to:

- Reduce the use of fossil energy for heating and cooling;
- Increase the share of energy from RES in total final energy consumption for heating and cooling;
- Improve energy efficiency by reducing energy consumption for heating and cooling the buildings.

In the European Union (EU), heating and cooling accounts for half of the EU's energy consumption and mainly relies on fossil fuels [7], [8]. Also, heating and cooling sector is responsible for 27% of GHG emissions [9].

Reducing the energy demand for heating and cooling and increasing the share of renewable energy represents key elements to fulfill the EU's climate and energy targets.

In Romania, the heating and cooling sector accounted for the highest share in the final energy consumption in 2020. According to estimates for 2030, the energy used for H&C will cover half of the total energy consumption (Figure 3).

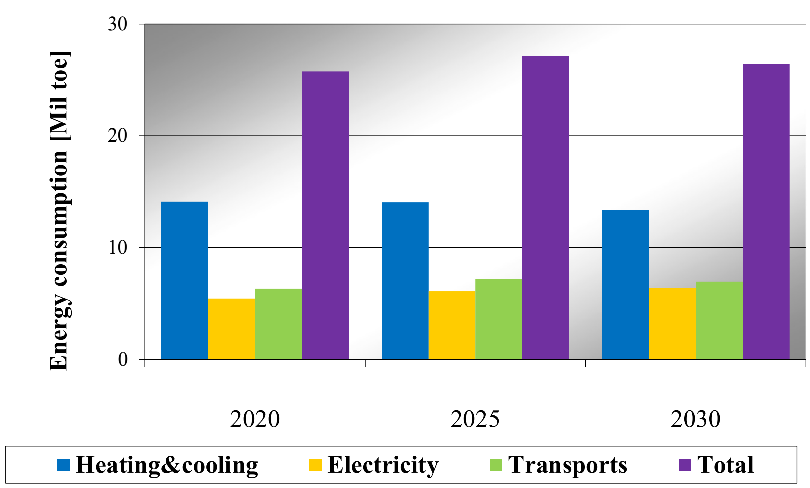

Fig. 3. Estimated trajectory of the final energy consumption by sector [10]

It is obvious that, both at EU and national level, the heating and cooling sector has significant potential to improve energy efficiency and increase the share of energy from renewable sources.

EU member states have committed to improve energy efficiency by at least 32.5% in 2030, to increase the share of energy from renewable energy sources by at least 32% and to reduce GHG emissions by at least 55% compared to 1990 [11].

The share of renewable energy sources in the EU's energy mix has increased from 10.2% in 2005 to 19.7% in 2019, while renewable energy sources accounted for 22.1% of the total energy used for heating and cooling in 2019 (Figure 4).

In Romania, renewable sources of energy contributed 24.3% in gross final energy consumption in 2019. More than a quarter (25.7%) of the energy used for heating and cooling came from renewable energy sources, in 2019 (Figure 5).

In RES used for heating and cooling are also included derived heat and heat energy extracted by heat pumps from air, ground or water, which has contributed more than one quarter of the energy from renewable sources used for heating and cooling [12].

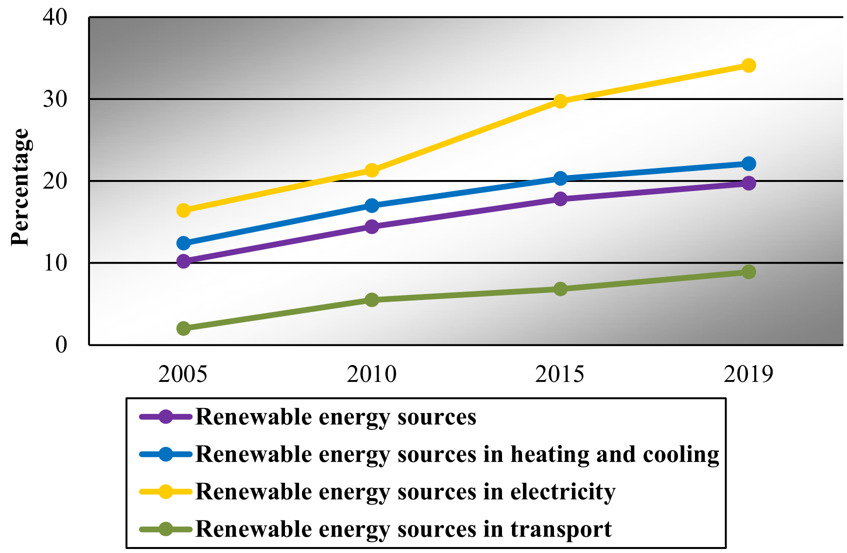

Fig. 4. Share of energy from renewable energy sources, at EU level [13]

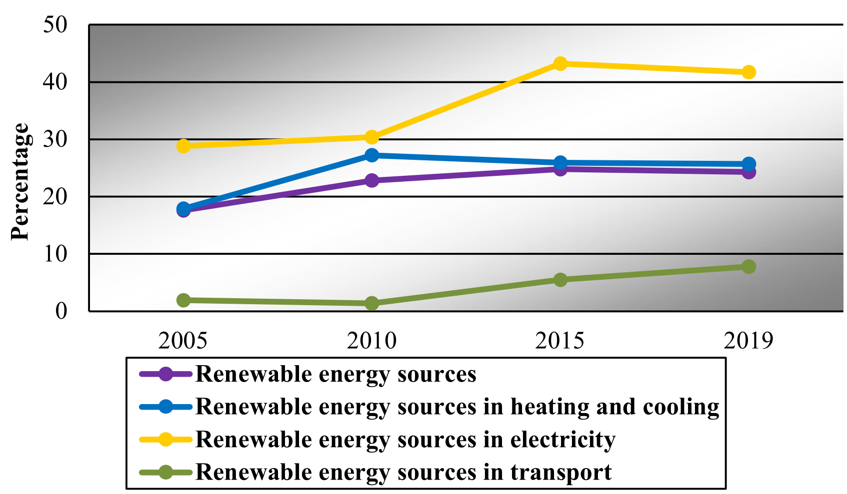

Fig. 5. Share of energy from renewable energy sources, in Romania [13]

Considering that at EU level buildings cover 40% of energy consumption and 36% of greenhouse gas emissions (emissions largely from construction, usage, renovation and demolition of buildings) [14], the heating and cooling sector has significant potential to improve energy efficiency and increase the share of energy from renewable sources.

Heat pumps use about 75% of energy from renewable sources and the remaining 25% from other sources (electricity). If electricity is generated from renewable sources (photovoltaic, wind, hydro) then the heat pumps are fully renewable and CO_2-neutral [15]. According to the International Energy Agency, heat pumps could save 50% of the building sector's CO_2 emissions, being one of the most promising solutions for decarbonizing the heating and cooling sector [15], [16].

3. Case study and simulation results

Energy and environmental strategies to reduce energy consumption and pollutant emissions of GHG have raised concerns for the development of energy efficient and environmentally friendly buildings. These buildings must be designed and built to ensure optimum comfort, energy efficiency and the lowest possible environmental impact.

Passive buildings represent a top standard in the current context of energy efficient buildings, with the aim of ensuring the highest indoor comfort conditions at low cost. The standard of passive building focuses mainly on the comfort of the occupants of the building, indoor air quality requirements and the reduction of energy consumption: energy demand for heating and cooling of spaces ≤15 kWh/m^2·year, primary energy demand ≤120 kWh/m^2·year [17].

An ecological or "green" building can be more than a passive house, a building constructed and used in a responsible way with respect to the environment, throughout their entire life cycle [18].

While limiting energy consumption, these "green" buildings also aim to reduce the negative ecological impact using environmentally friendly materials and renewable sources of energy.

The authors propose for analysis a family house with a useable area of 175 m^2 built on wooden structure and thermal insulation from wood. The choice of materials was made based on energy and environmental performance: thermal conductivity as low as possible and as little environmental impact as possible (kg CO_2 eq).

Based on the two principles on which the construction of passive houses is focused, namely the optimization of its components and the reduction of losses, we start from the following passive designing strategies:

- A compact form of the building with a Surface/Volume ratio S/V=0.75;
- Most of the windows oriented towards south;
- External shading systems;
- A high degree of thermal insulation and tightness;
- Heat recovery.

In order to limit the global heat transfer coefficients (U-values) at envelope level according to the passive standard (U≤0.15 W/m^2·K for external walls/roof/floor slab and U≤0.8 W/ m^2·K for windows), the following solutions were chosen:

- Exterior walls from wood, flexible wood fiber insulation (360 mm), clay board, rear ventilated cladding, the global heat transfer coefficient U=0.11 $W/m^2 \cdot K$;
- Floor slab from wood, rigid wood fiber insulation (300 mm), clay screed, the global heat transfer coefficient U=0.12 $W/m^2 \cdot K$;
- Upper floor ceiling from wood, rigid wood fiber insulation (320 mm), clay plaster, the global heat transfer coefficient U=0.12 $W/m^2 \cdot K$;
- Triple glazing windows with low emissivity (Low-e) and highly insulated wood window frames, the global heat transfer coefficient U=0.7 W/ $W/m^2 \cdot K$.

Due to good insulation and sealing, to ensure conditions of thermal comfort and indoor air quality, it will be necessary to provide a domestic mechanical ventilation system with heat recovery from the exhaust air.

The simulations were made with the Casanova software [19] for different climate zones: Bucharest (Romania), London (United Kingdom), Lisbon (Portugal), Barcelona (Spain), Helsinki (Finland) and two cases: Case no. 1 - without mechanical ventilation system, Case no. 2 - with mechanical ventilation system and heat recovery (88% efficiency).

The results obtained for all analyzed cities are summarized in the following table (Table 1).

Table 1

Heating and cooling demand for all analyzed cities

City	Minimum temperature of the year [^{0}C]	Maximum temperature of the year [^{0}C]	Mean temperature of the year [^{0}C]	Case no. 1		Case no. 2	
				Heating [kWh/ $m^2 \cdot$year]	Cooling [kWh/ $m^2 \cdot$year]	Heating [kWh/ $m^2 \cdot$year]	Cooling [kWh/ $m^2 \cdot$year]
Helsinki	–20.7	26.5	4.8	105.1	-	23.7	2.2
Bucharest	–16.3	35.9	10.9	61.3	5.3	11.5	11.8
London	–6.7	28.8	10.7	52.3	0.4	6.9	2.3
Lisbon	–0.8	38.2	16.5	14.2	12.6	0.3	17.3
Barcelona	0.2	37.7	15.7	20.9	12.3	0.8	15.9

As a result of the simulations, we notice that:

- For the city with the lowest minimum temperature of the year i.e., Helsinki (–20.7 ^{0}C) the energy demand for heating exceeds 100 $kWh/m^2 \cdot$year (case no. 1) and 15 $kWh/m^2 \cdot$year (case no. 2), but the cooling demand meets passive standard for both cases;

- For cities with a minimum temperature of the year of -16.3^0C (Bucharest), -6.7^0C (London) and 0.2^0C (Barcelona) the energy demand for heating (case no. 1) matches the energy efficient buildings.
  In accordance to the Romanian certifying system, these buildings are in type A class of energetic efficiency;
- For Lisbon (-0.8^0C minimum temperature of the year) the energy demand for heating fulfills the passive requirement;
- For all analyzed cities, the cooling demand in case no. 1 is below 15 kWh/m^2·year;
- Providing a domestic mechanical ventilation system with heat recovery (case no. 2) the energy demand for heating decreased below 15 kWh/m^2·year (except for Helsinki) and the cooling demand increased to maximum 15 kWh/m^2·year for the coldest cities (Helsinki, Bucharest, London) and over 15 kWh/m^2·year for the hottest cities (Lisbon and Barcelona).

In order to meet the requirements of the passive standard, for limiting heating and cooling demand to 15 kWh/m^2·year, while preserving the shape and dimensions of the building, it will be necessary to adapt the orientation of the building and windows, shading systems and the degree of thermal insulation (global heat transfer coefficient or U-value) according to the climate zone.

It is known that heat pumps can play an important role in decarbonizing the heating and cooling of building sector by reducing the dependency of fossil fuels, promoting renewable sources of energy and reducing finally and primary energy demand. To highlight the potential of heat pumps we analyze, for Bucharest (case no. 1 and case no. 2), the influence of different heating systems on primary and final energy demand (Figure 6 and Figure 7).

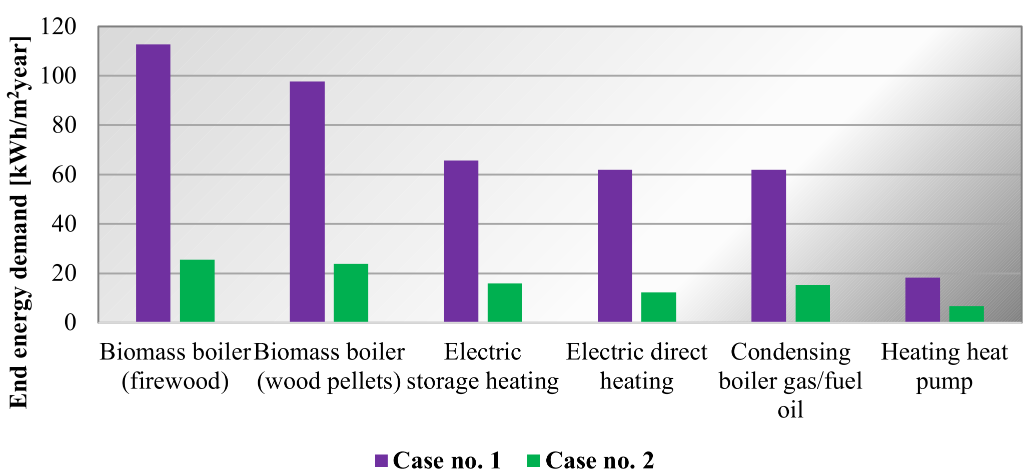

Fig. 6. Final energy demand for different heating systems

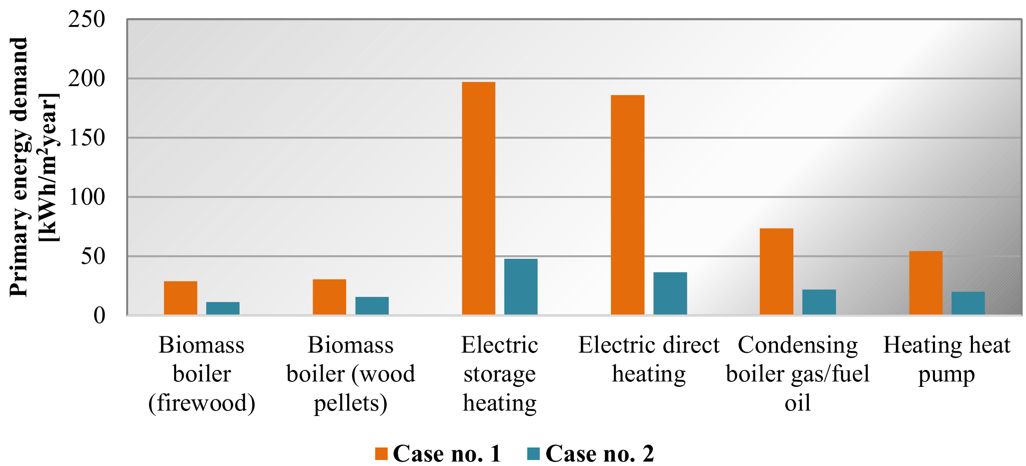

Fig. 7. Primary energy demand for different heating systems

From the results obtained, we noted that:

- Heat pumps record the lowest end energy consumptions for heating, delivering energy savings compared to other heating systems analyzed between 45…73% in case no. 2 and 70…83% in case no. 1;
- In terms of primary energy consumptions for heating, taking into account the following primary energy factor:
  - Electricity 3,
  - Oil, gas 1.1,
  - Biomass wood pellets/firewood 0.2,

  the lowest values of primary energy demand were obtained when using biomass boiler with firewood and wood pellets, and compared to the other heating systems heat pump achieved energy savings of 8…57% in case no. 2 and 25…72% in case no. 1.

Unlike other heating systems, heat pumps can also provide cooling of the building by reversing the operating cycle.

As a result of high performance and energy extracted from the environment, heat pumps reduce energy consumption for heating and cooling buildings and thus contribute to reducing GHG emissions.

4. Conclusions

Due to the fact that buildings in EU cover 40% of energy consumption and 36% of greenhouse (GHG) gas emissions, the heating and cooling sector has significant potential to improve energy efficiency and increase the share of energy from renewable sources, by promoting energy efficient and ecological buildings and heat pumps.

The authors have proposed for analysis a passive-green building designed according to passive standard, using environmentally friendly materials: a family house built on wooden structure and thermal insulation from wood, triple glazing windows with low emissivity (Low-e) and highly insulated wood window frames, most of the windows oriented southward, external shading systems, a high degree of thermal insulation and tightness and domestic heat recovery.

From the simulations carried out using the Casanova software, for different cities and two cases: with or without a domestic mechanical ventilation system with heat recovery (Table 1), we notice that:

- For Helsinki, the city with the lowest minimum temperature of the year (–20.7^{0}C), the energy demand for heating exceeds 100 kWh/m^2·year in case no. 1 and 15 kWh/m^2·year in case no. 2. However, the cooling demand meets the passive standard requirements for both cases;
- For the following cities with a minimum temperature of the year: Bucharest (–16.3^{0}C), London (–6.7^{0}C) and Barcelona (0.20^{0}C), the energy demand for heating in case no. 1 matches the energy efficient buildings;
- For Lisbon with –0.8^{0}C minimum temperature of the year, the energy demand for heating fulfills the passive requirement;
- For all analyzed cities: Helsinki, Bucharest, London, Lisbon and Barcelona, the cooling demand in case no. 1 is below 15 kWh/m^2·year;
- For case no. 2, by using a domestic mechanical ventilation system with heat recovery, the energy demand for heating decreased below 15 kWh/m^2·year (with except of Helsinki).
  The cooling demand increased to maximum 15 kWh/m^2·year for the coldest cities: Helsinki, Bucharest, and London and over 15 kWh/m^2·year for the hottest cities (Lisbon and Barcelona).

In order to meet the requirements of the passive standard (H&C demand up to 15 kWh/m^2·year), while preserving the dimensions and shape of the building, it will be mandatory to change and adjust: the orientation of the building and/or windows, the thickness of thermal insulation, the shading systems etc. according to the climate zone of interest.

By reducing the actual dependency of fossil fuels, by promoting renewable energy sources (RES) and lowering down the finally and primary energy demand, nowadays heat pumps (HP) can play a significant role in decarbonizing the H&C of building sector.

From the simulations we carried out using the Casanova software, with different heating systems for Bucharest city, we noticed the followings:

- Compared to other heating systems analyzed, HP record the lowest end energy consumptions for heating, also delivering important energy savings;
- With respect to the primary energy consumptions for heating, HP achieved important energy savings compared to condensing boiler gas/fuel oil, electric storage heating or electric direct heating.

By using for buildings ecologically materials with high energy performance and ensuring heating and cooling with HP, we will achieve much more significant contributions to decarbonize the heating and cooling sector.

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