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RENEWABLE HYBRID SYSTEMS FOR SPACE HEATING AND COOLING BIBLIOGRAPHIC REVIEW

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Environmental sustainability has become one of the biggest problems facing the energy sector today. In developed countries, the building sector represents 40% of the total primary energy demand which in most cases is still supplied mainly with conventional energy sources. Therefore, implementing energy efficiency measures combined with energy systems renewable is a major priority to decarbonize the economy. Interest in air conditioning systems has increased globally, as such systems have the potential to reduce greenhouse gas emissions, use fossil fuels, and improve energy security. Hybrid systems composed of renewable sources plus conventional systems focused on air conditioning, do not provide sufficient benefits. However, 100% renewable hybrid systems that replace traditional air conditioning systems have great environmental, social, and economic advantages and also overcome the barrier of intermittence of renewable energy sources. In this area, this work presents a review of the state of the art of specific renewable hybrid systems for air conditioning. It analyses the sources of renewable origin that are most used, the optimization models, storage methods, and type of systems: isolated or connected to the network.

Keywords: Hybrid systems; Renewable energy; Decarbonization; space heating and cooling.

REVISIÓN BIBLIOGRÁFICA DE SISTEMAS RENOVABLES HÍBRIDOS PARA CLIMATIZACIÓN

La sostenibilidad medioambiental se ha convertido en uno de los mayores problemas a los que se enfrenta el sector energético en la actualidad. El sector residencial consume el 40 % de la demanda total de energía primaria, por lo que un objetivo prioritario es implementar medidas de eficiencia energética combinadas con sistemas de energía renovables. El interés en los sistemas de climatización se ha incrementado a nivel global, ya que dichos sistemas tienen el potencial de reducir las emisiones de gases de efecto invernadero, el uso de combustibles fósiles y mejorar la seguridad energética. Los sistemas híbridos compuestos por fuentes renovables más sistemas convencionales enfocados a la climatización no aportan los beneficios suficientes. Sin embargo, los sistemas híbridos 100% renovables que sustituyen los sistemas de climatización tradicionales, tienen grandes ventajas medioambientales, sociales y económicas y, además, superan la barrera de la intermitencia de las fuentes de energía renovables. En este ámbito, este trabajo presenta una revisión del estado del arte de los sistemas híbridos renovables específicos para climatización. Analiza las fuentes de origen renovable que más se emplean, los modelos de optimización, métodos de almacenamiento y tipo de sistemas: aislados o conectados a red.

Palabras clave: Sistemas híbridos; Energías Renovables; Descarbonización; Climatización

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1. Introduction

Energy sector is responsible for most of greenhouse gas emission in the world. Heating and Cooling (H&C) production energy-related for housing and industry has become more relevant over the last decades, and now represents a considerable field. Worldwide, 50% of the energy used is for heat production, accounting for 40% of energy-related greenhouse gas emissions (IRENA, IEA, and REN21, 2018). In Europe, H&C plays a crucial role in the transition into clean and carbon neutral economy by 2050. In the EU households, 79% of the final energy is used for heating and domestic hot water. Cooling, however, accounts for a small share, but demand is increasing mainly due to the climate change and the raising of the temperatures. Regarding the industry sector, around 70% of the final energy is used for space and industrial process heating, and only 3% is used to produce cooling (Fraunhofer ISI, Fraunhofer ISE, TU Wien, TEP Energy, IREES 2016). Nowadays, and despite the efforts promoted by the different national administrations, the production of H&C is mainly provided by fossil fuels in most European countries (Fraunhofer ISI, Fraunhofer ISE, TU Wien, TEP Energy, IREES 2016). Renewable energy (RE) for H&C ranges between 66% in Sweden to only 6% in Ireland, with an average of 23% for the European Stated Members in 2020. Although the participation of RE in H&C has increased over the last decades (from 12% in 2004 to 22% in 2019) one third of the world´s population still relies on the use of conventional biomass, kerosene, or coal with many negative socio-economic consequences.

By considering the specific literature, the combined potential among the main RE sources —biomass, solar thermal, geothermal and aerothermal— is enough to satisfy the total expected demand for heating and cooling in the EU before 2050, which, at the same time, it is expected to be reduced by 20% as average with respect to the demand on 2006 (Renewable heating a& cooling European Technology Platform 2011). By 2050 the technologies that combine energy supply of Renewable Heating and Cooling (RHC) could reach up to 600 Mtoe, which is more than the total demand for H&C. Biomass could account for 231 Mtoe, geothermal 150 Mtoe, solar thermal 133 Mtoe, and Aerothermal and hydrothermal count contribute to 75 Mtoe (European Technology Platform on Rebewable heating and Cooling 2013). Nevertheless, this objective can only be achieved with a better use of these resources. Even though Renewable Energy Systems (RES) for heating and cooling generally have very limited environmental impact, efficiency gains are crucial for renewables to fulfill their potential in the next decades. Energy efficiency thus means achieving synergies among the renewable energy production, distribution, and consumption sectors.

Likewise, the EU issued in 2020 a heating and cooling strategy for the building sector and the industry to hit the decarbonization of the economy goals. It promoted the energy System Integration by linking various energy carriers —electricity, heat, cold, gas, solid and liquid fuels, involving existing and emerging technologies (European Commission 2020). Indeed, according to the Renewable Heating and Cooling Platform last strategic report (Renewable heating & cooling European Technology Platform 2021), there is a clear tendency towards sector coupling, cross-cutting technologies, and hybrid systems; increasing the efficiency and optimizing the systems. Note that the trend towards a major inclusion of other renewable technologies, particularly hydrogen-based renewable energy systems, but also waste heat recovery, district heating (DH) and cooling (DC), and thermal energy storage.

Among the different solutions, the most common hybrid application in buildings is the combination of a fossil fuel burner (driven by gas or oil) and solar thermal collectors. Nowadays, electricity-driven heat pumps combined with PV, solar thermal or thermally-driven heat pumps with solar thermal are common examples (Landolina 2012). In the industrial sector, hybrid systems used to supply the thermal energy required vary attending to the different processes as the proposed systems are then more diverse. For example, metal or chemical industry needs temperatures up to 400 ºC. Many strategic reports (Renewable heating & cooling European Technology Platform 2021)(Landolina 2012)(2050 vision for 100%

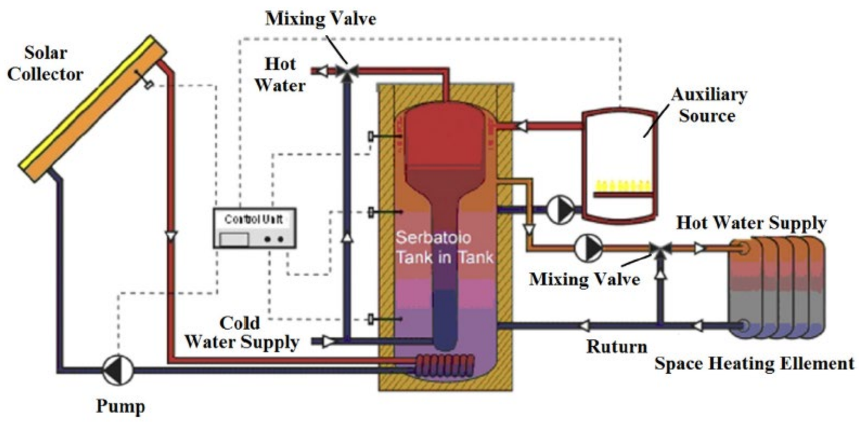
renewable heating and cooling in Europe 2019) emphasize the promising solution that represents the hybrid systems to achieve the efficiency of the resources aiming to reduce the use of primary energy, along with cross-cutting technologies and storage. This paper reviews the hybrid technologies recently developed and proposed in the specific literature and focuses on the evolution of technologies applied both for thermal and power purposes separately or together during the last years.

2. Hybrid Renewable energy systems

Hybrid Renewable Energy Systems (HRES) are used to describe any energy system with more than one type of generator. They usually consist on a generator powered by fossil fuel, such as diesel, and a renewable energy source such as Photovoltaic (PV), wind or Wind/PV (Deshmukh and Deshmukh 2008). It can be found hybrid systems able not only to produce electricity, but also space Heating and Cooling (H&C). The latter systems are called trigeneration or Combined Cooling, Heat, and Power (CCHP) (Nosrat, Swan, and Pearce 2013). Hybrid systems are used in small-scale applications (such as single-family Heating and Cooling systems for houses), as well as in large-scale applications suitable for District Heating and Cooling or industrial processes.

Initially, the use of RE hybrid technologies focused on the power generation in remote areas (Nayar, Lawrance, and Phillips 1989). In fact, nowadays they are still quite popular as stand-alone power systems for providing electricity in remote areas. However, hybrid systems to give H&C are also quite popular since climatic comfort of the housing sector became relevant. When H&C is required, the applications and combinations of RE hybrid systems depend on the temperature required. For small-scale applications, such as those required for the building sector, the medium temperature of space heating and domestic hot water is usually bellow 80 ºC, even lower for under-floor heating solutions. In this case, typical applications used are based on low-temperature solar energy systems, which are convenient due to their economic conditions (Guo et al. 2017). Due the intermittence of the solar resource, this application is typically connected to biomass boilers, where the heat from the combustion process is used to offset the peak demand in heating mode, see Figure 1). Due to its steadiness, geothermal has been widely used with Ground Source Heat Pump (GSHP) for space heating and hot water (and space cooling in a lesser extent). GSHP technology combined with solar resource reaches to lower operational costs and higher COP (Shah, Krarti, and Huang 2022).

Figure 1: Hybrid solar-biomass systems for space heating (Guo et al. 2017).



In addition, space cooling can also be obtained by integrating a cycle of absorption refrigeration. A common example can be seen in Figure 2. It consists of three main components: a solar water heater, a biomass gasifier-boiler, and an absorption chiller. This cycle usually works with a binary solution based on lithium bromide-water combination; the former works as an absorber and the latter as a refrigerant (Prasartkaew and Kumar 2013). This system was proposed in 1990 for the first time by (A. K. Singhal, S. K. Philip, S. R. Patel 1990).

Regarding CCHP, a typical configuration combines biomass with concentrated solar power (CSP) with heliostats, parabolic trough collector (PTC), or Photovoltaic (PV); see Figure 2. The sequential connection of solar PTC conducts highly efficient use of the biomass stock and decrease its consumption. However, optimizing the operational timing between both technologies is still challenging. Hybrid solar-geothermal combination systems have been also developed and proposed in the specific literature. This combined approach compensates the possible temporary lack of solar resource and the geothermal resource regional distribution. In addition, wind-solar systems are also developed to produce both off-grid or grid-connected solutions. Storage options are specially indicated for wind-solar systems, with fuel cells, batteries, or hydrogen generator as the most convenient options. Hybrid energy systems often give better performance in terms of economic and environmental aspects than wind, solar, geothermal or trigeneration stand-alone systems by themselves (Memon, Upadhyay, and Patel 2021).

Figure 2: A hybrid solar-biomass power system. Fuente:*(Sahoo et al. 2016)*

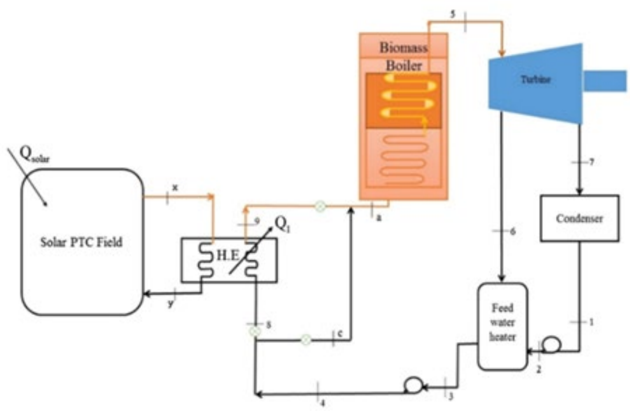


Table 1 summarizes the contributions analyzed, covering from 2016 to the beginning of 2022.

Table 1. Contributions analyzed (2016-2022).

Year	Reference
2016	Oliveira, Soheyli S. et al., Nakomčić-Smaragdakis et al.
2017	Liu et al.,Ercan et al., Maleki et al., Agabalaie Fakhim et al.
2018	Li et al., Buonomano A et al., Shahinur I. et al, Hassanzadeh Fard H. et al.
2019	Wang et al., Lui et al., Hossein Jahangir M. et al, Pater S., Zhou Y. et al, Ren F. et al., Mazzeo D., Assaf J. et al.
2020	Wu H. et al, Amrouche O. et al., Hoseinzadeh S. et al., Luo J. et al., Liu Z. et al., János Mayer M. et al., Reza Akhtari M et al., Elkadeem M.R. et al., Wang J. et al., Esfandi S. et al., Abdelsalam M.Y. et al.
2021	Das B.K. et al., Wang J. et al., Sanaye S. et al., Lee C.-G. et al., Elkadeem M.R. et al., Caro R. et al., Haj Assad M. et al., Al-Ghussain L. et al., Salameh T.,et al., Loy-Benitez J. et al., Allouhi A. et al.
2022	Guo J. et al., Hassan R. et al., Xu J. et al., Chen Q. et al., Hoseinzadeh S. et al., Chen H.et al., Mohammadzadeh Bina S. et al, Ghorab, M. et al.

3. Results and Discussion

Contributions focused on hybrid renewable heating/cooling systems have increased considerably from 2016 to 2022 (Q1). Indeed, the rate of increase is 1100%, assuming constant in 2022 (8 contributions) the number of references per quarter during this year, see Figure 3. Note that the research works constitute the experimental basis for the implementation of real projects. In 2020, a sale decreasing around 50% of coal, oil and natural gas boilers was reported (International Energy Agency. [IEA], 2021); subsequently, a participation of new clean technologies was increasing globally. A comparison among countries shows that China largely contributed by most jobs related to hybrid systems for heating/cooling: 27% of the jobs analyzed make up a case study in China. This fact is crucial for this country, aiming to reduce its high-level emissions through integrating these clean technologies (International Renewable Energy Agency [IRENA], 2022). Iran, Australia, and Spain-Italy continue in the ranking with 19%, 8% and 6% respectively, see Figure 3.

The main objective of this paper focuses on renewable hybrid systems with the aim of replacing heating systems powered by fossil resources. Only 12% of the reviewed contributions focus on this specific objective, and 4% on hybrid systems for heating and cooling solutions. However, 68% (34 works) of the proposed methodologies are not only intended for Heating/Cooling, but also for electricity generation purposes, either to replace boilers with heat pumps or for electricity self-consumption, which are strongly in line with the first pillar of decarbonization: electrification (Capros et al., 2018). In addition, 12% of the methodologies generate hydrogen, currently relevant for small-scale supply (Abdin et al., 2020); and 4% include a process for obtaining fresh water, aligned with an objective of sustainable development: Clean Water and Sanitation (Goal 6. Clean Water and Sanitation) see Figure 4 (left).

Regarding storage technologies, 70% of the analyzed methodologies include some storage system, see Figure 4 (top-right). An Energy Storage System (ESS) can be charged and discharged flexibly to accumulate surplus energy and, subsequently, supply this energy when appropriate. ESS is a key driver for renewable hybrid systems by removing intermittent power barriers (Miao et. al., 2021). In fact, to favorably evaluate renewable hybrid systems, they must integrate optimization procedures, either to achieve efficient designs, to make cost/benefit decisions, or to achieve viable economic operation scenarios. To solve these multidimensional problems, 78% of such methodologies provide optimization techniques (see Figure 4 (bottom-right)), either by defining an objective function by using programming algorithms or multi-criteria evaluation methods (MCDM) for decision making processes. On the other hand, isolated/autonomous hybrid systems need to be optimized to avoid supply disconnection (Shahzad et al., 2021).

Figure 3: Annual evolution and by country of articles of renewable hybrid systems for heating and cooling (2016-2022 (First quarter)). Own elaboration.

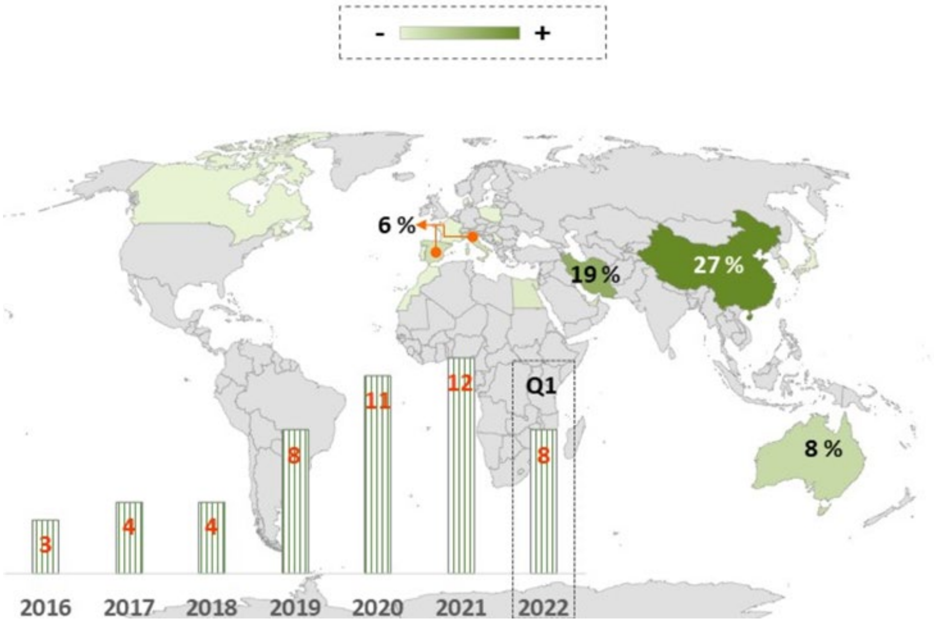
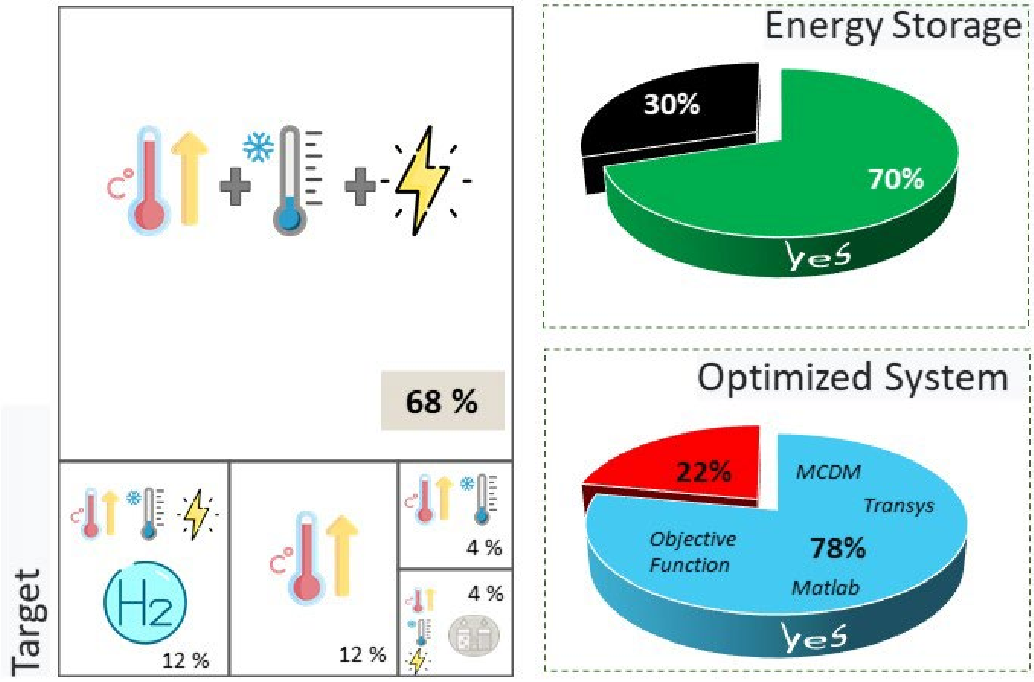


Figure 4: Participation according to objectives (left area). Works that include energy storage (upper right area) and optimized methodologies (lower right area). Own elaboration.



Photovoltaic solar panels stand out in the individual participation of the different renewable energies, 78% of the articles include this solar technology in the hybrid system. Wind energy (small-scale-mini-wind) is included in 27 contributions: solar thermal panels, geothermal energy and biomass, see Figure 5 (left). It is noteworthy that geothermal energy, being highly effective for heating/cooling systems (Ramos-Escudero et al., 2021). This low current integration could be increased by improving economic viability and technology maturity.

The combination of photovoltaic solar panels and mini-wind systems is the most used hybrid solutions in the analyzed methodologies: 52% of the contributions propose these combined resources. The solar irradiance during the day and strong winds at night help to overcome the intermittency drawback of such renewable hybrid systems (Gil García, I.C, 2022), therefore, this merger is logical. Therefore, mutual complementarity of such renewable resources has been reported by different studies. 28% of proposed solutions use solar and thermal modules, and 12% geothermal with photovoltaic solar panels, see Figure 5 (right). Finally, systems with more than two renewable technologies, trihybrid systems, mostly combine mini wind with photovoltaic and thermal solar panels: 16% of the analyzed contributions propose to merge and combine these technologies, see Figure 5 (right).

4. Conclusions

To replace efficiently energy fossil fuel applications and decrease emissions, renewable energy hybrid systems emerge as an effective solution. In fact, the number of renewable hybrid system studies published over the last years has increased considerably. In addition, they provide a technological trial of the future developments contributing to the energy transition worldwide. In Europe, these systems are in line with the policies promoted by the European Commission, and the most relevant energy-related platforms, to reduce energy demand and emissions. Moreover, these renewable systems improve dramatically the efficiency of the local resources as well as bring us the opportunity to become more independent energetically. From the different contributions analysed, at small-scale applications, they are eminently designed to provide heating, cooling, and domestic hot water (DHW). However, the majority introduce the production of electricity (78%). Among them, combinations with solar energy keep on leading the renewable heating and cooling applications, followed by wind, biomass, and geothermal. To range their energy efficiency, they are increasingly being coupled with energy storage systems (70%), such as fuel cells, batteries, or hydrogen. In addition, 78% of the works include renewable hybrid system optimization technology. Further investigations should be carried out in this field to optimize current renewable energy system combinations and foster those site-specific renewables and local resources. In summary, to contribute significantly for the economy decarbonization process and achieve the sustainable development goals ensuring access to reliable, affordable, modern, and sustainable energy framework.

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