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Applications of Renewable Energy Sources in Cooling and Heating of Buildings

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ABSTRACT

The present investigation focuses on renewable energy applications to the cooling and heating of buildings. This aim is achieved by analyzing the statistical reports issued by the International Renewable Energy Agency (IRENA) and the performance of this thematic area in the international scientific community. To study this last aspect, the Web of Science database is used. The results of the work are directed to: the bibliometric analysis of the scientific contributions related to the applications of renewable sources of energy to the cooling and heating of buildings; the energetic drive of cooling and heating systems with renewable sources; energy supply options; energy efficiency; the benefits of using renewable sources in cooling and heating processes; and thermal storage as a cornerstone for the energy transition, in indoor thermal conditioning.

Keywords: Thermal comfort, clean energy sources, energy efficiency, energy supply, quality of life, energy storage

1. Introduction

Energy is fundamental in many aspects of contemporary society. Population growth on a global scale and the increase in quality-of-life standards have modified the quantities and forms of energy consumption. Technological progress and the desire to constantly improve living conditions has caused a constantly increasing energy demand (Bravo Hidalgo, González Alonso, & Martínez Pérez, 2017; Ugursal, 2014). Reconciling economic growth with the reasonable use of conventional resources and the protection of the natural environment is one of the most pervasive global challenges. Environmental protection is of particular importance, since, as indicated by scientific contributions (Bravo, Bennia, Naji, Fellouah, & Báez, 2020), approximately 73.5% of the world's electricity at the end of 2017 was generated from non-renewable sources. According to available estimates, global carbon dioxide emissions will continue to increase, reaching 36 billion tons in 2020 and double that by 2050 (Nejat, Jomehzadeh, Taheri, Gohari, & Majid, 2015).

In the last decade, the European Union (EU), in response to rising energy prices and increasing dependence on energy suppliers, adopted a variety of strategies to improve the energy security of its member states, the protection of the environment and the global competitiveness of the (EU) industry (Halkos & Skouloudis, 2018). This goal can be achieved by developing and supporting energy-efficient and environmentally friendly solutions, especially in-built spaces (Bravo Hidalgo, 2015a; Hidalgo & Guerra, 2016; Tesfa, Mishra, Zhang, Gu, & Ball, 2013). Making the use of renewable and non-renewable energy sources efficient, as well as curbing climate change, are the greatest challenges facing most nations. In the European Union, almost 40% of final energy demand is led by internal consumption of public and corporate premises (Zinzi, Agnoli, Ulpiani, & Mattoni, 2021).

In buildings, two thirds of this energy is used for thermal conditioning of interior spaces. Publicly occupied buildings represent up to 12% of the buildable surface area of the European Union. Therefore, it is essential to focus on energy management problems in this sector. Technically, in this context, "energy efficiency" means using fewer energy inputs while maintaining levels of thermal comfort and air quality inside buildings. This term is often used interchangeably with “energy savings,” which is a broader concept that also includes reducing consumption through changing the choices of building users (Bravo, González, & González, 2018). . Unfortunately, a great potential for energy savings remains untapped (Bravo Hidalgo, 2015b). There are several techniques to reduce energy consumption by half in a non-industrial building sector, but the acceptance of efficient strategies is too low (Bravo-Hidalgo, 2018).

It is necessary to overcome the barriers in the energy efficiency of buildings. Taking into account the above challenges, the European Union has set a goal of saving 20% of its primary energy consumption by 2020, a key step to achieve long-term energy and climate goals (Commission, 2011). As a result, in recent years in Spain awareness has increased on issues related to energy saving, such as the control of greenhouse gas emissions into the atmosphere and environmental degradation.

In this context, the use of renewable energy sources for cooling and space heating purposes becomes a viable and timely alternative. In this sense, many nations have formulated national heating and cooling policies with renewable energy sources; as shown in figure 1. It can be seen that there is a lot of work to be done in this thematic area in both third and first world nations.

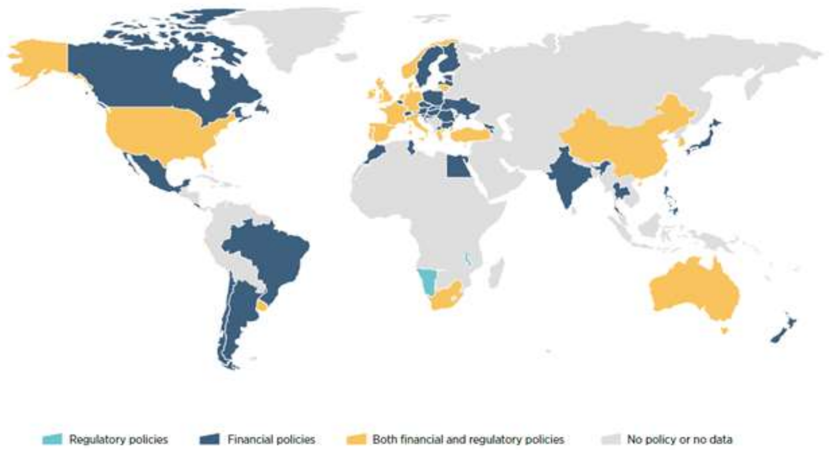

Fig 1. National heating and cooling policies with renewable energy sources, by country, 2019. Source: International Renewable Energy Agency.

Currently, heating demand in buildings and industry exceeds cooling demand. However, the latter is gradually recovering, especially due to the increasing demand for air conditioning and/or refrigeration of food and medical supplies. For example, according to the (EU), by 2030 the energy used to cool buildings across Europe is likely to increase by 72%, while the energy used to heat buildings will decrease by 30% (Henley, 2015). Globally, heating energy demand is expected to increase until 2030 and then stabilize. It is estimated that by the year 2060 approximately the amount of energy used worldwide for cooling purposes will exceed that used for heating and domestic hot water in buildings (Isaac & Van Vuuren, 2009).

A recent report from the International Renewable Energy Agency (IRENA) evaluated the management and processes of District Heating and Cooling. This is defined as the centralized heating or cooling of water, which is then distributed to multiple buildings through a network of pipes. Urban Heating and Cooling systems are powered mainly by fossil fuels such as coal and natural gas. This energy practice meets most of the demand for thermal conditioning of buildings today.

This research focuses on analyzing the evolution of the applications of renewable energy sources in the cooling and heating of buildings. This objective is achieved by analyzing the statistical reports issued by the International Renewable Energy Agency (IRENA) and the performance of this thematic area in the international scientific community. To study this last aspect, the Web of Science database is used.

The result areas of this research are composed of: (i) Bibliometric analysis and evolution of scientific contributions related to applications of renewable energy sources in the cooling and heating of buildings. (ii) Energy operation of cooling and heating systems of buildings with renewable sources. (iii) Energy supply options for cooling and heating systems, through renewable energy sources (iv) Energy efficiency as a facilitator of sustainable and economical cooling and heating solutions. (v) Benefits of using renewable sources in the cooling and heating processes of buildings. (vi) Thermal storage as a cornerstone for the energy transition, in indoor thermal conditioning.

2. Materials and methods

To develop this work, information from the database of the International Renewable Energy Agency (IRENA), its statistical analysis, its academic bulletins and its scientific reports was used. The information from the IRENA database, considered, was for the period 2010 to 2021 and only the "Heating & Cooling" section of this database. In addition, the characteristics and research trends of scientific production in applications of renewable energy sources in the cooling and heating of built environments are analyzed in the "Web of Science" database. The research is limited to the last ten years, the search criteria used, by topic, in the Web of Science database was: "Applications of renewable energy sources in the cooling and heating of buildings". Under these conditions, 13,642 scientific article type documents were detected. The bibliometric information of the detected research was processed in the VOSviewer Software as files (.RIS).

VOSviewer is a software tool for creating maps based on network data and for viewing and exploring these maps. The functionality of VOSviewer can be summarized as follows:

- Creation of maps based on network data. You can create a map based on a network that is already available, but it is also possible to build a network first. VOSviewer can be used to build networks of scientific publications, scientific journals, researchers, research organizations, countries, keywords or terms. Elements of these networks can be connected through co-authorship, co-occurrence, citation, bibliographic coupling, or co-citation links. To build the network, bibliographic database archives, in other words, Web of Science, Scopus, Dimensions and PubMed archives; and reference manager files, meaning RIS, EndNote and RefWorks files, can be provided as input to VOSviewer. Alternatively, VOSviewer can download data through an Application Programming Interfaces (API), such as Microsoft Academic API, Crossref API, Europe PMC API and many others).

- Viewing and exploring maps. This powerful tool provides three views of a map: the network view, the overlay view, and the density view. Zoom and pan functionality allows you to explore a map in fine detail, which is essential when working with large maps containing thousands of features.

Although VOSviewer is primarily designed to analyze bibliometric networks, in fact, it can be used to create, visualize and explore maps based on any type of network data. This program has been developed in the Java programming language. Because Java is platform independent, this program runs on most existing hardware and operating system platforms.

3. Results and discussion

3.1 Bibliometric analysis of scientific contributions related to applications of renewable energy sources in the cooling and heating of buildings.

Increasing the quality of life, and extending its limits, is an objective that unifies almost all fields of scientific endeavor. Thermal comfort is an aspect that affects the quality of life and people's health and is a process that demands enormous amounts of energy. Consequently, the international scientific community; increases, every year, the research and published results in this field. As shown in figure 1 between the years 2010 and March 2020, there is a growing trend in the number of publications. Extending the use of renewable energy sources, energy efficiency and the integration of energy storage systems, are the lines main research projects, to achieve sustainable and financially attractive cooling and heating processes. The powers of the world economic axis such as the United States of America, China, India and Germany are nations that invest a large amount of scientific and financial resources in the development of research to promote the use of renewable energy sources in the cooling and heating of buildings.

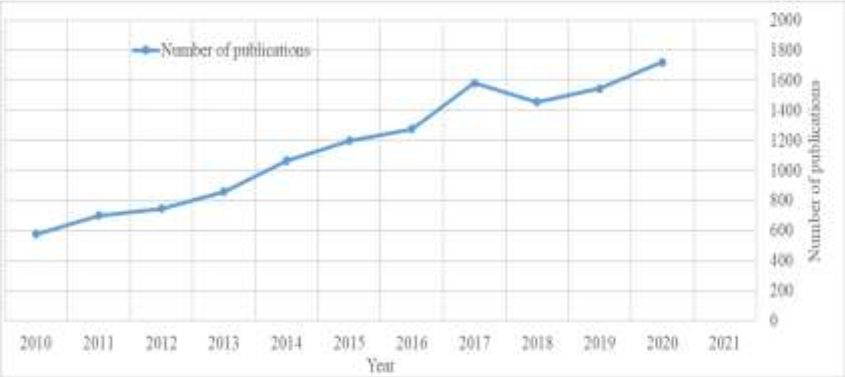

Fig 2. Number of scientific contributions per year, detected within the Web of Science academic research directory, with the search criteria and delimitations defined in the methods section. Source: Bibliometric data analyzed in Microsoft Excel Software.

The bibliometric information of the 13,642 documents such as scientific articles held in the Web of Science, under the search criterion “Applications of renewable energy sources in the cooling and heating of buildings”, between the years 2010 to 2021; was processed as a file (.RIS) in the VOSviewer software. This process provided the term density graph by keywords shown in Figure 3. This graph is made up of the indexing keywords and a mesh of at least 5 co-occurrences. This strategy made it possible to visualize what the thematic nuclei of research are regarding the use of renewable energy sources in the cooling and heating of buildings.

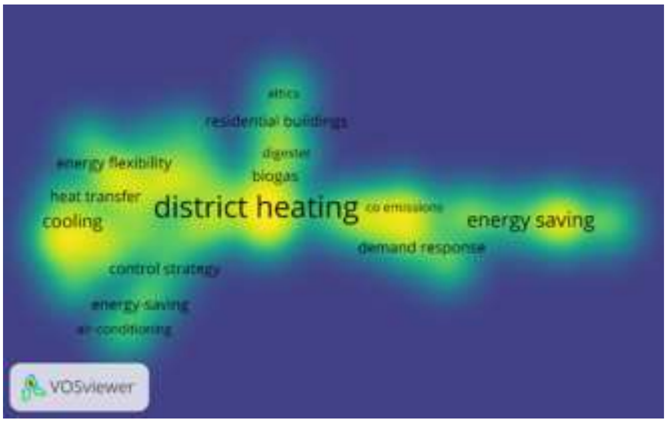

Fig 3. Mapa de densidad de términos por palabras claves de indexación, de las investigaciones detectadas dentro de directorio académico investigativo Web of Science, con el criterio y delimitaciones de búsqueda definidas en la sección de materiales y métodos. Fuente: Datos bibliométricos analizados en el Software VOSviewer.

The same bibliometric information contained in the file (.RIS) was processed in the VOSviewer software, but on this occasion to generate the network map of authors with greater scientific productivity; under the criteria already established. Figure 4 shows the co-authorship network of the publications detected within the Web of Science academic research directory. The network of author relationships has a circular shape because the majority of the contributions analyzed correspond to a short period of time (2010-2021) and is limited only to an academic directory. The authors identified in Figure 4 belong to universities and research centers in the United States of America, China, India and Germany. It was observed that scientific leaders in this line of research establish close links of scientific collaboration.

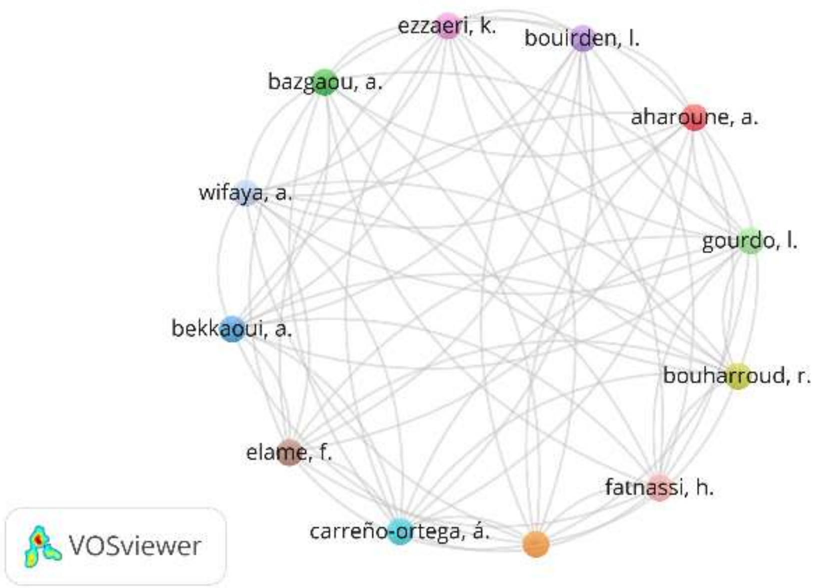

Fig 4. Co-authorship network of publications detected within the Web of Science academic research directory, with the search criteria and delimitations defined in the materials and methods section. Source: Bibliometric data analyzed in VOSviewer Software.

3.2 Energy operation of cooling and heating systems in buildings with renewable sources.

The energy used in thermal services represents around 50% of total final energy consumption. Of this quota, around half is consumed in industrial processes, while the other half is used in residential and commercial buildings, in thermal services such as domestic hot water and thermal conditioning of spaces. The small difference between these two large portions is the thermal energy used in agriculture, not only to heat greenhouses, but also for drying, soil heating and aquaculture (Yu et al., 2021).

The demand for cooling and heating varies by region due mainly to climatic factors, but also to levels of economic development. The majority of final demand in most Organization for Economic Co-operation and Development (OECD) countries comes from residential space, while in developing and emerging economies most cooling and heating is used in industrial processes. Asian powers account for a quarter of global demand for cooling and heating. About 60% of this cooling and heating demand is used in the chemical, food safety, pharmaceutical and electronic industries (Santamarta et al., 2021; Sayed Hassan Abdallah, 2021).

In the buildings sector, cooling and heating dominates energy use at more than three-quarters of total demand. Population growth worldwide, as well as sustained increases in the quality of life, have generated an inevitable and understandable increase in energy demand for cooling and heating. This fact has led the scientific community to focus its attention on renewable energy alternatives to meet this demand (Noorollahi, Golshanfard, Ansaripour, Khaledi, & Shadi, 2021).

Demand for cooling and heating is increasing sharply each year, having tripled globally since 1990. It is increasing most rapidly in developing and emerging economies, especially in Southeast Asia, driven by expanding wealth and population, changing lifestyles and extreme weather patterns, such as high temperatures caused by climate change (Noorollahi et al., 2021). Space cooling and heating represented 8.5% of total final electricity demand in 2019. The growing demand for cooling and heating in buildings has generated a notable increase in the consumption of electrical energy. And the most practical way to meet this growing demand for electrical energy is through renewable energy sources (Lu, Yu, Zou, & Yang, 2021). Figure 5 shows the participation of renewable energy sources in the total final energy consumption for heating and cooling in 2019.

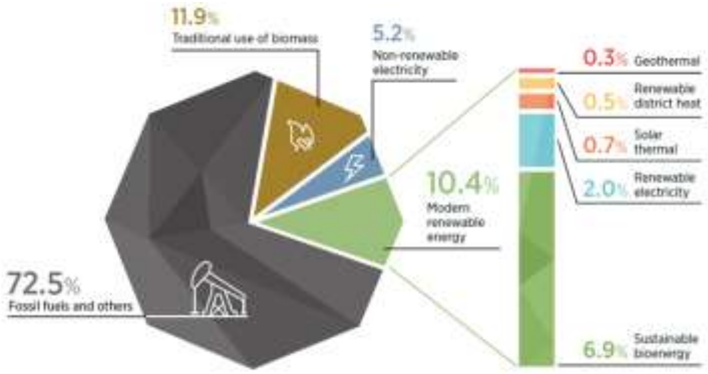

Fig 5. Distribution of the use of renewable energy sources in total final energy consumption for heating and cooling purposes, 2019. Source: International Renewable Energy Agency.

3.3 Energy supply options for cooling and heating systems, through renewable energy sources.

Heating and cooling energy uses encompass a wide range of end-use applications and technologies, all relevant to basic human needs, economic development and comfort. Traditionally, energy for these purposes has been supplied by fossil fuels. In buildings, heating and cooling activities include cooking, water heating, room heating and cooling, and refrigeration. The agri-food chain also comprises a wide range of heating and cooling activities, including greenhouse heating, soil heating, crop drying, and refrigeration (Hashemizadeh, Ju, Bamakan, & Le, 2021).

In industry, energy needs for industrial processes vary from temperatures below 0 0C, for example in the food industry, where refrigeration allows the storage and transport of products, to high temperature applications, for example, 800- 1400 0C in the cement, iron and steel industries. As such, heating and cooling uses include activities with very different needs in terms of temperatures. Fossil fuels, thanks to their high heating values and energy density, have provided all heating services and, combined with electric chillers and refrigerators, can cover the entire spectrum of heating and cooling services (Q. Chen, Li, & Feng, 2021; Y. Chen, Hua, Wang, & Lund, 2021a).

Renewable energy sources such as geothermal, solar energy and bioenergy are good alternatives to electricity and fossil fuels for low temperature heating services. Solar thermal technology includes a variety of collector types, from unglazed collectors to concentrating collectors. Temperature ranges between 20 and 200 0C. Geothermal fluids can provide heat above 300 0C. Biomass, biogas and biomethane can provide heat at 600 0C. The working temperature that a specific renewable energy practice can provide depends on multiple factors. For example, the amount of heat a flat plate solar system can supply will depend on how much sunlight it receives and at what angle. The amount of heat from bioenergy depends on the treatment and nature of the biomass, that is, presence of humidity, density; as well as the technologies used (Østergaard, Tunzi, & Svendsen, 2021; Pablo-Romero Gil-Delgado, Sánchez Braza, & Galyan, 2021).

Bioenergy can provide high temperature heat. However, costs, sustainability issues, and availability are barriers to large-scale employment. Renewable fuel absorption cycles can provide cooling services, but the technology required remains more expensive than electric alternatives. To cover both high temperature services and cooling demand, renewable electricity and green hydrogen can help close the gap, allowing renewable energy sources to provide the full range of services for heating and cooling needs (Razmjoo et al., 2020).

The exact working temperature requirements for heating or cooling a particular building, or for a given industrial process, depend on factors such as system type, size, location, and efficiency. Energy efficiency, in particular, plays an important role in accelerating the deployment of renewable energy technologies for heating and cooling; since it can reduce the necessary working temperatures. This makes the use of cost-effective technologies that provide low working temperatures more feasible (Larwa, Cesari, & Bottarelli, 2021). Figure 6 shows the working temperatures for several thermo-energy technologies that use renewable sources, which are used to power the cooling and heating systems of built spaces.

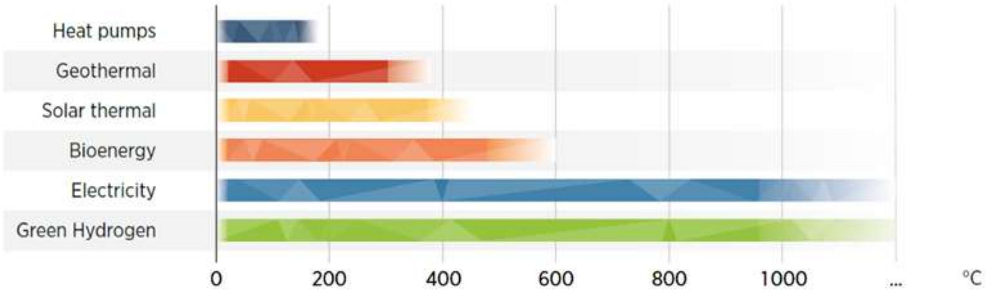

Figure 6. Working temperatures for various thermo-energy technologies that use renewable sources. Source: International Renewable Energy Agency.

3.4 Energy efficiency as a facilitator of sustainable and economical cooling and heating solutions.

Efficient energy management is an indisputable aspect in the energy transition process currently being experienced (Santamarta et al., 2021). It is a cost-effective, out-of-the-box solution ready to scale. By combining renewable energy practices with energy efficiency, decarbonization goals can be much easier to achieve. Accompanying the electrification of end uses with increases in electricity generation through renewable energy sources and the direct uses of thermal energy from renewable sources would generate around 75% of the reductions in CO2 emissions related to the energy demanded in the year 2050 (Borrelli et al., 2021; Xue et al., 2021). This would be a great step in the direction of putting the world on track to meet the goals of the Paris Agreement on Climate Change. When energy efficiency is added, the participation exceeds 90% (Trepci, Maghelal, & Azar, 2021; Yang et al., 2021).

Advances in energy efficiency are particularly critical in the buildings sector. In these, total energy use has continued to increase as population growth, floor space and cultural changes in comfort standards have more than offset reductions in demand achieved through energy efficiency (D'Amico, Pomponi, & Hart, 2021; Lu et al., 2021). Energy savings generated by high-efficiency cooling, for example, could generate cost savings of USD 1.2 trillion through 2050 by avoiding spending on generating capacity (Li, Zhang, Yu, Wu, & Li, 2021; Żabnieńska-Góra, Khordehgah, & Jouhara, 2021).

Greater energy efficiency in buildings can be achieved through more efficient appliances, better insulation and smarter energy management, while in industry, more efficient industrial processes are key (Bravo Hidalgo et al., 2017; Ugursal, 2014).

In China, equipment efficiency could reduce the energy needed to meet cooling needs by approximately 205 Tera-watt hours (TWh) in 2030, while improving building envelopes could save another 100 TWh, avoiding around of a third of the projected energy demand (Saikia, Vallès, Fabregat, Saez, & Boer, 2020). In built environments, energy efficiency interventions also improve the quality of life of inhabitants. Finally, increased energy efficiency in energy-scarce and off-grid areas reduces residents' energy expenditures and the need for energy subsidies (Abusoglu, Tozlu, & Anvari-Moghaddam, 2021).

However, the rate of improvement in energy intensity (energy consumption per unit of gross domestic product) slowed in 2018. The 2019 improvement was just 1.2%, down from the 1.8% annual average recorded over the previous decade. To achieve the goals of limiting global warming to less than 2 0C and closer to 1.5 0C during this century, the rate of improvement in energy intensity must increase to 3.2% per year. In this context, the need for more effective measures and policies to achieve energy intensity improvements, so important in the thermal conditioning of buildings sector, is evident (Guelpa & Verda, 2021).

3.5 Benefits of energy supply with renewable sources in the cooling and heating processes of buildings.

The use of renewable energy sources in the operation of cooling and heating systems in non-industrial buildings presents a considerable number of advantages of great interest in the energy, financial and ecological fabric (Pablo-Romero Gil-Delgado et al., 2021). These are:

- Strengthening energy security.
- Achieve universal access to energy.
- Reduce air pollution and the incidence of respiratory diseases.
- Reduce energy poverty.
- Stimulate job creation and local economic development.
- Reduce greenhouse gas emissions.

Renewable energy sources can improve countries' energy security and energy independence by diversifying the fuel mix and infrastructure in use and reducing dependence on imports (Huan & Hong, 2021). Fossil fuels are vulnerable to potential global supply chain disruptions, while renewable energy sources may have simpler regional supply chains or, depending on the technology, no fuel supply chain at all. To cite an example, the case of solar thermal energy (Anastasovski, 2021).

Countries with declining fossil fuel resources can preemptively replace existing infrastructure with renewable energy sources, to reduce domestic demand and mitigate increases in future imports. The Netherlands, which became a net importer of natural gas for the first time in 2019 after a sharp drop in production in 2013, made plans to increase the share of employment of renewable energy sources used in heating and cooling. Analogous alternatives have been undertaken by nations of the global economic axis such as China and the United States of America (Patala, Juntunen, Lundan, & Ritvala, 2021).

Renewable energy sources facilitate access to energy for various forms of heating and cooling. Cooling and/or heating with adsorption or absorption machinery, powered by solar thermal energy, is combined with mechanical compression systems of refrigerant vapor combined with energy from photovoltaic panels. These techniques, in turn, are integrated with thermal energy and electrical energy accumulation systems, increasing the efficiency and availability of thermal comfort within buildings. These processes facilitate users' access to the most regular, efficient, cheap, and environmentally friendly energy services (Tian, Huang, Lu, Zhou, & Duan, 2021).

The contribution of heating and cooling to air pollution is mainly associated with the burning of fossil fuels and biomass, the latter to a much lesser extent, for heating and cooking. In 2018, around 91% of urban dwellers around the world were regularly exposed to air pollution. Although part of this pollution is particle emissions from the transportation sector. A considerable contribution is the use of fossil fuels for heating and cooling (Liu, Tang, Zhou, & Yang, 2021). The combustion of coal can emit numerous toxic gases, including sulfur dioxide, nitrogen oxides and airborne particles, and coal still accounts for a substantial part of heat production for district heating in China, Poland, Russia, Kazakhstan and other countries. Eastern European and Eurasian states where it is cheap and easily available.

Air pollution has important negative consequences for public health. It can cause respiratory infections, lung diseases, and higher mortality rates in general. The World Health Organization estimates that each year, some 3.8 million deaths are attributable to indoor air pollution, primarily from indoor biomass burning, primarily affecting women and children; Another 4.2 million deaths are due to ambient air pollution through exposure to fine particles. Household air pollution from traditional stoves is linked to 4 million premature deaths annually in developing and emerging economies, also disproportionately affecting women and children (Aghaziarati & Aghdam, 2021; Borrelli et al.., 2021).

Energy poverty covers a wide spectrum of negative effects on well-being, attributable to insufficient access to modern energy technologies. A household struggling with energy poverty cannot guarantee a level and quality of domestic energy services sufficient to satisfy its basic needs in a socioeconomic context. In the context of heating and cooling, an example of energy poverty would be a household that cannot adequately finance heating and/or cooling services. Situations of energy poverty are usually accompanied by the use of fossil fuels or the traditional use of biomass (Y. Chen, Hua, Wang, & Lund, 2021b).

Adopting energy practices through renewable sources offers socio-economic benefits, such as more local jobs and improvements in well-being. The sector accounted for 11.5 million jobs worldwide in 2019, and could reach 42 million by 2050, with more than 823 thousand people employed in solar heating and cooling in 2019 and 764 thousand in solid biomass (Pablo-Romero Gil-Delgado et al., 2021).

Heating and cooling accounted for approximately 40% of energy-related CO2 emissions worldwide in 2018 (Patala et al., 2021). A proportion that has remained almost unchanged over the last decade, due to the continued dominance of fossil fuels (Saikia et al., 2020).

Along with improvements in energy efficiency and energy sufficiency behaviors, the shift to modern renewable energy sources is key to mitigating climate change and limiting the rise in global temperatures, as stipulated in the Paris Agreement on Climate Change of 2015 and the Sustainable Development Goals.

3.6 Thermal storage as a cornerstone for the energy transition, in interior thermal conditioning.

Thermal storage is the process of storing thermal energy so that it can be used after the source stops generating. Since cooling and heating demand for a given end use tends to vary throughout the day, from day to day, or from season to season, storage is necessary to balance demand and supply over time. , especially when the supply is variable. Renewable sources such as solar and wind are worthy examples of variable supply. In solar thermal applications, thermal storage is an essential component. In general, it is not a complex technology, with water being the most common storage medium. Other solutions include sand, molten salts, rocks and ice (Alzaid et al., 2021; Endo et al., 2021).

Thermal energy storage systems can be centralized or decentralized. Centralized applications can be used in district heating and cooling systems, along with a variable power source. Underground seasonal hot water storage systems are already applied for small, solar-powered district heating and cooling systems, such as the one in Munich, Germany; where a 6000 m3 thermal storage facility allows solar energy to meet approximately half of the heat demand of 320 apartments. Decentralized systems are applied in buildings to capture solar energy for water and space heating, but could become more common as more heat pumps are installed. Ice-based thermal energy storage for refrigeration is also promising. Underground ice storage has been applied throughout history, with ice stored in centrally located ice reservoirs allowing for radial distribution (Dahash, Ochs, Tosatto, & Streicher, 2020).

When combined with electric heating and cooling applications, thermal storage can increase system flexibility by allowing electricity consumption when variable resources are available (and energy prices are lower). Thermal energy storage has a particularly important role to play in cities where population density is high enough to allow the use of district heating and cooling systems. Thermal energy storage technologies that allow power generation to be decoupled from consumption can adapt to a variety of time scales, from hourly to seasonal, balance supply with demand, reduce constraints and avoid the need for costly reinforcement of the electrical network (Guerrero Delgado, Sánchez Ramos, Álvarez Domínguez, Tenorio Ríos, & Cabeza, 2020).

IRENA's “Innovation Outlook, Thermal Energy Storage” analyzes thermal energy storage technologies and user cases for heating and cooling systems, and projects development and innovation needs in the coming decades (Hoekstra et al., 2020).

3.7 Limitations of the research:

- This scientific contribution only considers the information and statistics issued by the International Renewable Energy Agency (IRENA), between the years 2010 to 2021.
- Only scientific article type contributions and content in the Web of Science academic scientific directory are considered.
- 71.70% of the documentation cited in this scientific contribution was published as of 2020.
- Only information published in English was considered.

4. Conclusions

Thermal comfort is an aspect that affects the quality of life and health of people. The climatic conditioning of interior spaces is a process that demands enormous amounts of energy. Consequently, the international scientific community; increases, every year, the research and published results in this field. Most of the research on the applications of renewable energy sources to the operation of cooling and heating systems in buildings is focused on Urban Heating and Cooling, the energy efficiency of the systems, energy flexibility, demand management and integration of energy accumulation alternatives. The leading nations in this research are the United States of America, China, India and Germany.

The energy used in thermal services represents around 50% of total final energy consumption. The demand for cooling and heating varies by region due mainly to climatic factors, but also to levels of economic development. The majority of final demand in most Organization for Economic Co-operation and Development (OECD) countries comes from residential space, while in developing and emerging economies most cooling and heating is used in industrial processes. Only 10.4% of energy demand for cooling and heating is supplied by renewable sources.

Renewable energy sources such as geothermal, solar energy and bioenergy are good alternatives to electricity and fossil fuels for low temperature heating services. Solar thermal technology includes a variety of collector types, from unglazed collectors to concentrating collectors, with temperature ranges between 20 and 200 0C. Geothermal fluids can provide heat above 300 0C. Biomass, biogas and biomethane can provide heat at 600 0C. The working temperature that a specific renewable energy practice can provide depends on multiple factors. For example, the amount of heat a flat plate solar system can supply will depend on how much sunlight it receives and at what angle.

Efficient energy management is an indisputable aspect in the energy transition process that is currently being experienced. However, the rate of improvement in energy intensity, energy consumption per unit of gross domestic product, slowed in 2018. The improvement in 2019 was only 1.2%, less than the 1.8% annual average recorded. during the previous decade. To achieve the goals of limiting global warming to less than 2 0C during this century, the rate of improvement in energy intensity must increase to 3.2% per year in this sector.

The main benefits of supplying energy with renewable sources to the cooling and heating processes of buildings are strengthening energy security, achieving universal access to energy, reducing air pollution and the incidence of respiratory diseases, reducing energy poverty, stimulate job creation and local economic development, and reduce greenhouse gas emissions.

Thermal energy storage technologies that allow energy generation to be decoupled from consumption can be adapted to a variety of time scales, from hourly to seasonal. This energy practice makes it possible to balance supply with demand, reduce restrictions and avoid the need for costly reinforcement of the electrical grid. IRENA's "Innovation Outlook, Thermal Energy Storage" analyzes thermal energy storage technologies and user cases for heating and cooling systems. In addition, it projects the needs for development and innovation in the coming decades.

References

Abusoglu, A., Tozlu, A., & Anvari-Moghaddam, A. (2021). District heating and electricity production based on biogas produced from municipal WWTPs in Turkey: A comprehensive case study. Energy, 223, 119904. doi:https://doi.org/10.1016/j.energy.2021.119904

Aghaziarati, Z., & Aghdam, A. H. (2021). Thermoeconomic analysis of a novel combined cooling, heating and power system based on solar organic Rankine cycle and cascade refrigeration cycle. Renewable Energy, 164, 1267-1283. doi:https://doi.org/10.1016/j.renene.2020.10.106

Alzaid, M., Alsalh, F., Malik, R. A., Maqbool, A., Almoisheer, N., Hadia, N. M. A., & Mohamed, W. S. (2021). LiTaO3 assisted giant strain and thermally stable energy storage response for renewable energy storage applications. Ceramics International. doi:https://doi.org/10.1016/j.ceramint.2021.02.142

Anastasovski, A. (2021). Improvement of energy efficiency in ethanol production supported with solar thermal energy–A case study. Journal of Cleaner Production, 278, 123476.

Borrelli, M., Merema, B., Ascione, F., Francesca De Masi, R., Peter Vanoli, G., & Breesch, H. (2021). Evaluation and optimization of the performance of the heating system in a nZEB educational building by monitoring and simulation. Energy and Buildings, 231, 110616. doi:https://doi.org/10.1016/j.enbuild.2020.110616

Bravo-Hidalgo, D. (2018). Night air conditioning of buildings by external air ventilation. Revista Facultad de Ingeniería, 27, 35-47.

Bravo, D., Bennia, A., Naji, H., Fellouah, H., & Báez, A. (2020). General review of air-conditioning in green and smart buildings. Revista Ingeniería de Construcción, 35(2), 192-202.

Bravo, D., González, F., & González, J. (2018). Solar cooling in buildings. A state of the art. Revista Ingeniería de Construcción, 33(2), 115-126.

Bravo Hidalgo, D. (2015a). Climatización solar de edificaciones. Centro Azúcar, 42(2), 72-82.

Bravo Hidalgo, D. (2015b). Energía y desarrollo sostenible en Cuba. Centro Azúcar, 42(4), 14-25.

Bravo Hidalgo, D., González Alonso, J., & Martínez Pérez, Y. (2017). Costos de las tecnologías de almacenamiento de energía térmica. Centro Azúcar, 44(4), 67-76.

Chen, Q., Li, N., & Feng, W. (2021). Model predictive control optimization for rapid response and energy efficiency based on the state-space model of a radiant floor heating system. Energy and Buildings, 238, 110832. doi:https://doi.org/10.1016/j.enbuild.2021.110832

Chen, Y., Hua, H., Wang, J., & Lund, P. D. (2021a). Integrated performance analysis of a space heating system assisted by photovoltaic/thermal collectors and ground source heat pump for hotel and office building types. Renewable Energy, 169, 925-934. doi:https://doi.org/10.1016/j.renene.2020.12.117

Chen, Y., Hua, H., Wang, J., & Lund, P. D. (2021b). Thermodynamic performance analysis and modified thermo-ecological cost optimization of a hybrid district heating system considering energy levels. Energy, 224, 120067. doi:https://doi.org/10.1016/j.energy.2021.120067

Commission, E. (2011). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on External Dimension of the Common Fisheries Policy: Publications Office of the European Union.

D'Amico, B., Pomponi, F., & Hart, J. (2021). Global potential for material substitution in building construction: The case of cross laminated timber. Journal of Cleaner Production, 279, 123487.

Dahash, A., Ochs, F., Tosatto, A., & Streicher, W. (2020). Toward efficient numerical modeling and analysis of large-scale thermal energy storage for renewable district heating. Applied Energy, 279, 115840. doi:https://doi.org/10.1016/j.apenergy.2020.115840

Endo, N., Goshome, K., Tetsuhiko, M., Segawa, Y., Shimoda, E., & Nozu, T. (2021). Thermal management and power saving operations for improved energy efficiency within a renewable hydrogen energy system utilizing metal hydride hydrogen storage. International Journal of Hydrogen Energy, 46(1), 262-271. doi:https://doi.org/10.1016/j.ijhydene.2020.10.002

Guelpa, E., & Verda, V. (2021). Demand response and other demand side management techniques for district heating: A review. Energy, 219, 119440. doi:https://doi.org/10.1016/j.energy.2020.119440

Guerrero Delgado, M., Sánchez Ramos, J., Álvarez Domínguez, S., Tenorio Ríos, J. A., & Cabeza, L. F. (2020). Building thermal storage technology: Compensating renewable energy fluctuations. Journal of Energy Storage, 27, 101147. doi:https://doi.org/10.1016/j.est.2019.101147

Halkos, G., & Skouloudis, A. (2018). Corporate social responsibility and innovative capacity: Intersection in a macro-level perspective. Journal of Cleaner Production, 182, 291-300.

Hashemizadeh, A., Ju, Y., Bamakan, S. M. H., & Le, H. P. (2021). Renewable energy investment risk assessment in belt and road initiative countries under uncertainty conditions. Energy, 214, 118923. doi:https://doi.org/10.1016/j.energy.2020.118923

Henley, J. (2015). World set to use more energy for cooling than heating. The Guardian, 26.

Hidalgo, D. B., & Guerra, Y. P. (2016). Eficiencia energética en la climatización de edificaciones. Revista Publicando, 3(8), 218-238.

Hoekstra, N., Pellegrini, M., Bloemendal, M., Spaak, G., Andreu Gallego, A., Rodriguez Comins, J., . . . Saccani, C. (2020). Increasing market opportunities for renewable energy technologies with innovations in aquifer thermal energy storage. Science of the Total Environment, 709, 136142. doi:https://doi.org/10.1016/j.scitotenv.2019.136142

Huan, N. Q., & Hong, T. T. T. (2021). Energy Efficiency: Determinants and Roles on Sustainable Development in Emerging Country. International Journal of Energy Economics and Policy, 11(2), 7.

Isaac, M., & Van Vuuren, D. P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. Energy Policy, 37(2), 507-521.

Larwa, B., Cesari, S., & Bottarelli, M. (2021). Alternative Energy Sources, Materials & Technologies (AESMT'20), Volume XX, (pp. XX - XX) 2020 Study on thermal performance of a PCM enhanced hydronic radiant floor heating system. Energy, 120245. doi:https://doi.org/10.1016/j.energy.2021.120245

Li, H., Zhang, S., Yu, Z., Wu, J., & Li, B. (2021). Cooling operation analysis of multienergy systems in a nearly zero energy building. Energy and Buildings, 234, 110683. doi:https://doi.org/10.1016/j.enbuild.2020.110683

Liu, Z., Tang, Y., Zhou, H., & Yang, S. (2021). Life cycle performance of a distributed energy system in comparison with a conventional energy system for district heating and cooling in China. Journal of Cleaner Production, 288, 125663.

Lu, F., Yu, Z., Zou, Y., & Yang, X. (2021). Cooling system energy flexibility of a nearly zero-energy office building using building thermal mass: Potential evaluation and parametric analysis. Energy and Buildings, 236, 110763. doi:https://doi.org/10.1016/j.enbuild.2021.110763

Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., & Majid, M. Z. A. (2015). A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renewable and Sustainable Energy Reviews, 43, 843-862.

Noorollahi, Y., Golshanfard, A., Ansaripour, S., Khaledi, A., & Shadi, M. (2021). Solar energy for sustainable heating and cooling energy system planning in arid climates. Energy, 218, 119421. doi:https://doi.org/10.1016/j.energy.2020.119421

Østergaard, D. S., Tunzi, M., & Svendsen, S. (2021). What does a well-functioning heating system look like? Investigation of ten Danish buildings that utilize district heating efficiently. Energy, 120250. doi:https://doi.org/10.1016/j.energy.2021.120250

Pablo-Romero Gil-Delgado, M. d. P., Sánchez Braza, A., & Galyan, A. (2021). Renewable energy use for electricity generation in transition economies. Renewable and Sustainable Energy Reviews, 138.

Patala, S., Juntunen, J. K., Lundan, S., & Ritvala, T. (2021). Multinational energy utilities in the energy transition: A configurational study of the drivers of FDI in renewables. Journal of International Business Studies, 1-21.

Razmjoo, A., Kaigutha, L. G., Rad, M. V., Marzband, M., Davarpanah, A., & Denai, M. (2020). A Technical analysis investigating energy sustainability utilizing reliable renewable energy sources to reduce CO2 emissions in a high potential area. Renewable Energy.

Saikia, K., Vallès, M., Fabregat, A., Saez, R., & Boer, D. (2020). A bibliometric analysis of trends in solar cooling technology. Solar Energy, 199, 100-114.

Santamarta, J. C., García-Gil, A., Expósito, M. d. C., Casañas, E., Cruz-Pérez, N., Rodríguez-Martín, J., . . . Gemeni, V. (2021). The clean energy transition of heating and cooling in touristic infrastructures using shallow geothermal energy in the Canary Islands. Renewable Energy, 171, 505-515. doi:https://doi.org/10.1016/j.renene.2021.02.105

Sayed Hassan Abdallah, A. (2021). Passive Air Cooling System and Solar Water Heater with Phase Change Material for Low Energy Buildings in Hot Arid Climate. Energy and Buildings, 110854. doi:https://doi.org/10.1016/j.enbuild.2021.110854

Tesfa, B., Mishra, R., Zhang, C., Gu, F., & Ball, A. (2013). Combustion and performance characteristics of CI (compression ignition) engine running with biodiesel. Energy, 51, 101-115.

Tian, C., Huang, G., Lu, C., Zhou, X., & Duan, R. (2021). Development of enthalpy-based climate indicators for characterizing building cooling and heating energy demand under climate change. Renewable and Sustainable Energy Reviews, 143, 110799. doi:https://doi.org/10.1016/j.rser.2021.110799

Trepci, E., Maghelal, P., & Azar, E. (2021). Urban built context as a passive cooling strategy for buildings in hot climate. Energy and Buildings, 231, 110606. doi:https://doi.org/10.1016/j.enbuild.2020.110606

Ugursal, V. I. (2014). Energy consumption, associated questions and some answers. Applied Energy, 130, 783-792.

Xue, X.-D., Zhang, T., Zhang, X.-L., Ma, L.-R., He, Y.-L., Li, M.-J., & Mei, S.-W. (2021). Performance evaluation and exergy analysis of a novel combined cooling, heating and power (CCHP) system based on liquid air energy storage. Energy, 222, 119975. doi:https://doi.org/10.1016/j.energy.2021.119975

Yang, F., Wang, G., Hu, D., Liu, Y., Zhou, H., & Tan, X. (2021). Calibrations of thermo-hydro-mechanical coupling parameters for heating and water-cooling treated granite. Renewable Energy, 168, 544-558. doi:https://doi.org/10.1016/j.renene.2020.12.042

Yu, Y., You, S., Zhang, H., Ye, T., Wang, Y., & Wei, S. (2021). A review on available energy saving strategies for heating, ventilation and air conditioning in underground metro stations. Renewable and Sustainable Energy Reviews, 141, 110788. doi:https://doi.org/10.1016/j.rser.2021.110788

Żabnieńska-Góra, A., Khordehgah, N., & Jouhara, H. (2021). Annual performance analysis of the PV/T system for the heat demand of a low-energy single-family building. Renewable Energy, 163, 1923-1931. doi:https://doi.org/10.1016/j.renene.2020.10.123

Zinzi, M., Agnoli, S., Ulpiani, G., & Mattoni, B. (2021). On the potential of switching cool roofs to optimize the thermal response of residential buildings in the Mediterranean region. Energy and Buildings, 233, 110698. doi:https://doi.org/10.1016/j.enbuild.2020.110698