General review of air-conditioning in green and smart buildings

Revisión general sobre sistemas de acondicionamiento de aire en edificios ecológicos e inteligentes

D. Bravo ^{1*}, A. Bennia ^{1*** **}, H. Naji ^{****}, H. Fellouah ^{*****}, A. Báez ^{*****}

* Universidad San Francisco de Quito – Quito, ECUADOR

** Mohamed El Bachir El Ibrahim University – El Anceur, ARGELIA

*** University Hassiba Benbouali of Chlef – Ouled Fares, ARGELIA

**** University of Artois, University of Lille – Béthune, FRANCE

***** University of Sherbrooke – Quebec, CANADA

***** Universidad Central del Ecuador – Quito, ECUADOR

Fecha de Recepción: 23/03/2020

Fecha de Aceptación: 29/06/2020

PAG 192-202

Abstract

The aim of this paper is to present a general bibliographic review about recent scientific papers focused on the design and operation of air conditioning systems in green and smart buildings. The suggested review is developed using tools offered by the Scopus academic research directory, with a defined search criteria. Furthermore, the VOSviewer science bibliometric analysis software has been used. This paper has several reviews of cooling and heating systems existing or under development available for residential buildings (green and smart buildings) and some initiatives and research projects from recent years. The present paper is an academic research guide for engineers, architects, and students interested in designing, constructing and efficiently managing the cooling processes of green and smart buildings. Economic powers characterized by large megacities of countries such as the United States of America, China, Italy, Malaysia, Germany and Australia; Nowadays, increasing energy efficiency and decreasing carbon footprint of current and future buildings, both green and smart is considered more important. The most frequent fields of research in scientific contributions related to the cooling of green buildings are: sustainable development, energy efficiency and the construction industry; while in smart buildings they are: energy efficiency, smart grids, energy management.

Keywords: Ecological buildings; intelligent building; cooling system; energy efficiency; bibliometric analysis; text mining

Resumen

El objetivo de este artículo es presentar una revisión bibliográfica general sobre artículos científicos recientes, centrados en el diseño y operación de sistemas de aire acondicionado en edificios ecológicos e inteligentes. La revisión sugerida se desarrolla utilizando las herramientas ofrecidas por el directorio de investigación académica Scopus, con un criterio de búsqueda definida. Además, se ha utilizado el software de análisis bibliométrico de ciencia VOSviewer. Este documento tiene varias revisiones de los sistemas de refrigeración y calefacción existentes o en desarrollo, disponibles para edificios residenciales (edificios verdes e inteligentes) y algunas iniciativas y proyectos de investigación de los últimos años. El presente documento es una guía de investigación académica para ingenieros, arquitectos y estudiantes interesados en diseñar, construir y administrar eficientemente los procesos de enfriamiento de edificios ecológicos e inteligentes. Poderes económicos caracterizados por grandes megaciudades de países como los Estados Unidos de América, China, Italia, Malasia, Alemania y Australia; Hoy en día, se considera más importante aumentar la eficiencia energética y disminuir la huella de carbono de los edificios actuales y futuros, tanto ecológicos como inteligentes. Los campos de investigación más frecuentes en contribuciones científicas relacionadas con la refrigeración de edificios ecológicos son: desarrollo sostenible, eficiencia energética y la industria de la construcción; mientras que en edificios inteligentes son: eficiencia energética, redes inteligentes y gestión energética.

Palabras clave: Edificios ecológicos; edificios inteligentes; sistemas de refrigeración; eficiencia energética; análisis bibliométrico; minería de datos

1. Introduction

Facing climate change and its consequences for the environment has been one of the greatest challenges of modern life. Actually, the intention of reducing the carbon footprint is associated with most current sustainable strategies (Elghamry and Hassan, 2020). The built environment is by far the dominant sector responsible for the carbon footprint of contemporary civilization (Hidalgo and Perez, 2017). The foregoing is fundamentally due to the fact that the built environment represents the intersection of three large-scale polluting processes: energy, transport and buildings (Hidalgo and Perez, 2017); (Hidalgo and Guerra, 2016). While commercial and residential buildings release around 40% of total electricity-related Greenhouse Gas (GHG) emissions in developed nations (Zhang et al., 2020); (Tian et al., 2019) additional emissions stem from the extensive use of raw materials, industrial processes to manufacture construction products, and the subsequent transportation of these products (Bixler et al., 2019).

¹ Corresponding author:

Universidad San Francisco de Quito – Quito, ECUADOR

E-mail: dbrayanbh@gmail.com

abderazak.bennia@USherbrooke.ca

The number of buildings has grown dramatically in recent decades, thus increasing the demand for air conditioning; this reality makes engineers and architects focus on the energy and operational optimization of the designs and installations of the thermal machines in charge of maintaining thermal comfort conditions within buildings (Png et al., 2019). The energy consumption of air conditioning systems in buildings represents 40 to 60% of the total energy consumption of non-industrial type buildings in tropical countries (Venkateswara and Datta, 2020); (Liu et al., 2020). In this scenario, green and smart buildings are shown as viable alternatives to optimize energy in the air conditioning process of interior spaces (Pezzutto et al., 2017).

A green building is a sustainable construction that uses natural materials, eliminates toxic substances in the manufacture of construction materials, minimizes the negative impacts of the human habitat on the environment and reduces energy consumption (Sua et al., 2020). A green building adapts to its natural environment and to the inhabitants. Green buildings are environmentally friendly and respect the following practical process: design, construction, maintenance, rehabilitation, demolition and recycling (Tan et al., 2020). On the other hand, a green building is a combination of techniques and materials that, together, contribute to improve the environmental performance of the built space.

Several criteria must be taken into account in the design and construction of a green building. Indeed, engineers and architects have to consider the project globally, emphasizing installations with natural light and good thermal insulation of the building, the using of materials with a low energy footprint in their treatment and transport. Furthermore, using Renewable energy and selecting equipment such as lighting and air conditioning systems with high efficiency (Li et al., 2020); (Chen and Luo, 2019); (Zhang et al., 2019).

On the other hand, an intelligent building is known to be one that has incorporated equipment with high energy efficiency and an interactive energy drive with the environment and the users or inhabitants of the building (Van Cutsem et al., 2020); (Ahmad, et al., 2020). The term especially applies to: office buildings, corporate buildings, hotels and the like. A built environment is considered to be a smart building if it incorporates information systems throughout its structure, offering an advanced technique of control and telecommunications services (Chen et al., 2020); (Vázquez-Canteli et al., 2019). With automated control, monitoring, management and maintenance of the different subsystems or services of the building, optimally and integrated, locally and remotely. Designing the entire system with enough flexibility so that the implementation of future technologies is simple and economically profitable (Safari et al., 2019); (Ostadijafari et al., 2019). Under this new concept, the comprehensive automation of buildings with high technology is defined. The centralization of the building data makes it possible to monitor and control the operating states of high energy consumption systems such as thermal machines on loaded computers, to determine the conditions of thermal comfort and quality of indoor air. The intelligent building integrates automated homes within a network structure (Michalec et al., 2019); (Jimenez-Castillo et al., 2019).

The aim of this scientific contribution is to give a general bibliographic review of scientific papers focused on the design and operation of air conditioning systems in green and smart buildings. The result section of this manuscript contains the following sub-sections: Bibliometrics analysis of air-conditioning in green and smart buildings. Current global scenario of energy management in the air conditioning and heating of buildings. Air conditioning in green and smart buildings, current and latest trends in research.

2. Materials and methods

This scientific contribution based on a critical bibliographic review of scientific publications focused on the design and operation of air conditioning systems in green and smart buildings. To develop the proposed idea, search and analysis tools for scientific documentation offered by the Scopus directory have been used. The selected database comprises top scientific journals that have large readability visibility and socialize research results, scientific advances and technological parts addressed in this paper (Falagas et al., 2008). Similarly, the tool analysis and bibliometric mapping of scientific activity VOSviewer is used. This software is used to perform text mining on the selected scientific contributions. This process allows to create maps based on network data; as well as visualize and explore evolutionary maps of scientific activity in this investigation area (Van Eck and Waltman, 2010).

The data has been extracted from the Scopus academic directory was exported as (.csv) files, to be processed in the mentioned bibliometric analysis tool. The exploration analyzes works from 2000 to November 6, 2018.

The information search methods and criteria in Scopus were developed in four different stages, which are described below:

- a) Within the timeline (2000 to November 6, 2018) and under the search criteria "Green building" only in the title of article-type scientific contributions, 2,665 documents and 198,186 registered patents were detected.

- b) Previously declared timeline and under the search criteria "Smart building" only in the title of article-type scientific contributions, 1,738 documents and 174,689 registered patents were obtained.
- c) The defined period of time and under the search criteria "Green building" in the title, the keywords and the abstract, in scientific contributions such as article, review and conference paper, 2 779 documents were achieved.
- d) In said period of time and under the search criteria "Smart building" in the title, the keywords and the abstract, in scientific contributions such as article, review and conference paper, 2,288 documents were detected.

(Figure 1) and (Figure 2) were prepared with the information from stages a) and b). And with the information from stages c) and d), the data that was processed in the VOSviewer software was detected, allowing the creation of terms in (Figure 3) and (Figure 4); from the text mining carried out on the title, abstract and key words of the detected contributions.

On the other hand, the scientific articles most frequently cited within the Scopus academic directory, detected between all stages of searches a to d; are presented in (Table 1).

3. Results

3.1 Bibliometrics analysis of air-conditioning in green and smart buildings.

The international scientific community before 2000 had very few scientific contributions related to air-conditioning in green and smart buildings, but as of this year, the number of scientific contributions begins to increase gradually, with 2010 being the year from which shows an accelerated increase in research related to this field. This is largely because after the real estate crisis in 2008, engineers and architects focused on optimizing the design, construction and operation of built environments as much as possible. (Figure 1) shows the evolution of scientific research activities in this subject area between 2000 and 2018. In addition, it shows the evolution of registered patents related to this practice, which show a significant increase. It should be understood that the patent is one of the expressions of applicability of the scientific results.

Figure 1. Scientific evolution and development of patents related to the topic of air-conditioning in green and smart buildings.

By the end of the year 2016, cooling and heating accounted for 51% of final energy use, transportation 32%, and final demand for electricity. Excluding heating, cooling, or transportation purposes is around 17%, as shown in (Figure 5). Modern renewable heat provided about 10% of cooling and heating demand and did not grow significantly. While demand of renewable electricity increased by 25% between 2013 and 2017, modern demand of renewable heat increased by around 5% during this period (nearly the same rate as a global demand of energy). In transport sector, the consumption of biofuels, mainly ethanol and biodiesel increased by around 18% between 2013 and 2017, although from a small base (Raturi, 2016).

Figure 5. Distribution of Consumed Renewable energy, by sector in 2016.

Global thermal energy demand, including end uses for heating and cooling, represents approximately half of final energy consumption. The demand for heat constitutes the vast majority, although the demand for energy for cooling is growing rapidly. Energy consumption for heating and cooling continues to be highly dependent on fossil fuels and contributes almost 40% of global energy-related to CO₂ emissions.

Renewable energy supplies around a quarter of global heating and cooling demand. However, only around 40% of this is attributed to the modern renewable energy, while the rest is supplied by traditional biomass. Modern sources of renewable energy include direct renewable energy, such as modern bioenergy, geothermal heat, and solar heat, as well as renewable electricity which is used for heating and cooling, for example, through heat pumps with a source of air. In contrast, the traditional use of biomass, predominantly in open fires or highly inefficient interior stoves, generates major health problems and is often related to unsustainable levels of firewood collection (Raturi, 2016).

3.3 Air conditioning in green and smart buildings, current and latest trends in research.

The scientific works that are analyzed below are the most representative contributions within the international scientific community on this subject. Because, these investigations are the most read and cited according to the Scopus directory. So, these works have marked investigative trends based on the scientific realities of each investigation.

In the scientific research developed by (Jim, 2014), field experiment on the roofs of two residential buildings in subtropical Hong Kong was designed to measure air-conditioning electricity consumption in relation to three factors:

- building thermal insulation (BTI): omitted at Block 1 and installed at Block 2;
- green-roof type: each block had two extensive green-roof plots and a bare control namely complex herbaceous peanut vegetation and simple sedum; and
- three summer weather scenarios are considered: sunny, cloudy, and rainy.

Electricity consumption for air conditioner was monitored by precision loggers of energy for six vacant apartments under experimental plots. The unshielded Control forces high cooling load at Block 1, but BTI at Block 2 cuts heat ingress and this in all weather conditions. Sedum reduces energy consumption of and to a lesser degree it controls both blocks (with Block 2 better than Block 1). Sunny weather produces the best effect, followed by cloudy and rainy weather. Sedum-type roof with BTI enhances benefit of thermal. The simple green-type roof can not substitute BTI function because without BTI, Sedum-type roof consumes more energy. In three weather

scenarios, Peanut uses less electricity at Block 1 than Block 2, which indicates the operation of the building's heat sink joint effect (BHE) in block 2 and the green-type roof heat sink effect (GHE). The GHE generated by the thicker substrate with higher ability to retain moisture. Creation of BHE has been realized by material addition of BTI, with a low thermal resistance due to high temperature and moisture penetration. Their joint effect has increased thermal mass capacity. Steeply thermal gradient has formed to induce breaching to thermal-insulation for push heat into indoor. In Block 1, Peanut-type roof can partly compensate for BTI omission. However, in Block 2, Peanut coupled with BTI can synergistically increase cooling-load. The findings can inform design of green-type roof and associated BTI in regions with hot summer and policies.

The contribution given in (Yang and Hwang, 2007) express that because of the superior performance of the multi-unit variable frequency-driven (VFD) direct expansion (DX) air-conditioning system, installing this type of system in dwelling houses, schools and rental commercial buildings is becoming more popular in Taiwan. Even if the characteristics of the multi-unit VFD DX system and the features are different from the system of central, it is still evaluated by the traditional method used to assess the efficiency of all air conditioning systems, which are mainly designed for centralized systems. The problems that occur when applying the current evaluation method to a VFD DX multi-unit system are explained in this article.

The authors' contribution given in (Chen et al., 2016) explains that as a key part of smart building ventilation systems, air conditioners highly impact the overall energy consumption of smart buildings also the experience of their occupants. Therefore, how to design and evaluate feasible planning strategies for air conditioning systems becomes a major challenge in the design of smart buildings. Especially if it comes to many uncertainties factors caused by the physical environment are concerned, the strategy evaluation complexity increases drastically. Although existing approaches allow the evaluation of smart buildings from the perspectives of energy consumption and performance, few of them consider the evaluation of the scheduling strategies themselves. On the basis of priced timed automata, this paper proposes an effective framework that enables accurate evaluating and modeling scheduling strategies for smart building air conditioning systems with an uncertain environment. This framework uses the statistical model checker UPPAAL-SMC as the engine to quantitatively analyze user-specified performance queries in the form of properties. The framework can automatically report the results of a quantitative analysis of energy consumption and user satisfaction in an uncertain environment; this is according to the underlying random simulations monitored by UPPAAL-SMC. Experimental results proved that the proposed approach can effectively help smart building designers to make their decisions in the selection and optimization of scheduling strategies.

The authors' scientific work developed in (Wang and Tang, 2017) argue that responding to the energy demand (DR) of buildings is considered one of the most promising solutions to the problems of energy imbalance and reliability in smart grids, while controlling responding to demand for air conditioning systems is the most effective means. A rapid demand response control strategy, direct control of the load by shutting down part of the operational coolers, has received much attention in recent DR research and applications.

However, this method would lead to an uneven rise in indoor air temperature between individual air-conditioned spaces due to failure of adequate distribution of the cooling supply limited by the commonly used demand-based feedback control strategy today. Therefore, a new supply-based feedback control strategy is proposed to effectively solve the problems caused by rapid response to demand and the power limitation control strategy. The proposed strategy uses global and local cooling distributors based on the adaptive service function to air flow set points for each zone and line space, and reset the chilled water. Simplified online and offline identification methods, respectively for the two parameters, ensure the robustness and convenience for the adaptive utility function in applications. Case studies are performed in a simulated air conditioning system to validate and test the proposed strategy of control. The results show that the proposed control strategy is not only able maintaining uniform increases in indoor air temperature, but also preventing operational problems during DR events. Also, the fairly high indoor relative humidity obviously decreases. The power rebound phenomenon is also alleviated and the original comfort control of the spaces can be resumed very quickly.

(Table 1) shows a group of scientific articles of great interest for the development of future research, in the opinion of the authors of this contribution. These articles were selected for having the following characteristics:

- a) Seminal papers, have started the theories or methods that have the greatest influence on the topic under investigation (Alonso et al., 2017).
- b) Some articles the research directions proposed for the topic in question (Alonso et al., 2017).

Table 1. Most scientific contributions cited in Scopus about air conditioning of green and smart buildings.

	Title	Abstract
1	Comparative study of air conditioning systems with vapor compression chillers using the concept of green buildings.	Pereira et al presents a comparative study of two cooling systems that use vapor compression chillers to air conditioning environments. It is suggested to compare different processes in combined action and isolated processes. These processes are evaluated in the green buildings concepts. The model equations were solved by the Engineering Equation Solver program (EES). The main HVAC functioning parameters of the chilled water system is evaluated by the model, when functioning under three configurations. The results show that the system with screw coolers in the 0-300 RT range has a COP equal to that of the system with differentiated compression, and in a COP hat is on mean 9% higher in the 400-800 range RTs (Pereira et al., 2015).
2	Design and performance of a solar-powered air-conditioning system in a green building.	Designed and installed for the green building of Shanghai Research Institute of Building Sciences, the solar absorption air-conditioning systems. This system contains two adsorption chillers with 8.5 kW nominal refrigeration capacity and 150 m ² solar collectors. The operating mode of the solar air conditioning system has been improved by maintaining a phase difference of 540 seconds between the adsorption chillers. Subsequently, the system realized stable operation by refrigeration output and the balance of heat consumption. The solar powered air-conditioning system continuously operated 8 hours/day, from June to August 2005. During the 8 hours of operation, the maximum refrigeration output exceeded 20 kW and the average refrigeration output was 15.3 kW. Solar fraction in summer for this system was 71.7%, corresponded 15 kW of the design cooling load. Compared to the ambient temperature, it was concluded that the performance of the solar powered air conditioning system clearly influenced by the intensity of solar radiation (Zahi, 2008).
3	Flexible operation of active distribution network using integrated smart buildings with heating, ventilation and air-conditioning systems.	Jiang suggested for integrated smart buildings with the active distribution network an optimal scheduling method and a combined modeling; this proposed is to use the flexibility of smart buildings. Based on the characteristics of heat storage in building, Jiang developed a prediction model of energy consumption of buildings taking into account the different heating areas with different orientations using the model of Resistor-Capacitor thermal network. He also developed different optimal methods of control for the building's heating, ventilation and air conditioning system. The management of energy consumption in the ventilation, heating and air-conditioning system is attained by adjusting the ambient temperature of within the appropriate temperature comfort range. The optimal planning results of the aggregation for the smart buildings in different control method in the winter heating are equally analyzed. So, the impact of the optimal planning of the aggregation for the smart buildings on the security and economic operation is further evaluated. Through numerical studies, the proposed optimal planning method can contribute to reducing the operating costs of smart buildings and also take full advantage of the potentials of demand response of smart buildings. Finally, the optimization of active distribution networks with the factor of load of the buildings aggregation can increase the minimum voltage size of the active distribution networks and also reduce loss of power using the smart buildings flexibility (Jiang, 2018).
4	A direct load control strategy of centralized air-conditioning systems for building fast demand response to urgent requests of smart grids.	To solve the HVAC problems, Tang presented a new approach based on three schemes. To a received DR request, the threshold of power limiting and the cooling demand of building in response predicts by a scheme of power demand optimization. The operating chillers number/pumps to be to conserve determines by a scheme of system sequence control resetting. An online scheme of control and regulation ensures the system power follows the profile of expected by regulating the total flow of chilled water delivered into the building and thus the load of chiller. The distributors of cooling also uses for distribute chilled water to individual areas for different sacrifices/sensitivities to increases of temperature. Studies are carried out on a system of simulated dynamic building air conditioning. The strategy proposed by (Tang, 2018) could achieve the expected reduction of power (about 23%) as well as maintain the acceptable area temperature despite uncertainties about the process of prediction.
5	Efficient heating and cooling systems for low-energy houses	Buildings represent for large amount of water and energy consumption, use of land, and pollution of atmospheric. Statistics of 2006 show that the United States for example, they used 40% of the total consumption of national energy (56% by dwellings residential), presented 12.2% of the total water quantity, and produced 38% of the total emissions of carbon dioxide. To achieve the objectives of energy saving and climate protection in the residential and commercial / institutional sectors, it is necessary to reduce the energy consumption of buildings. (Minea, 2012), reviewed a number of cooling and heating systems-existing or under development-available for buildings and Briefly identified some research initiatives and projects, as well as some recent technical achievements in developed countries in general and in Canada in particular.
6	Smart ventilation energy and indoor air quality performance in residential buildings: A review	For better indoor air quality and to solve energy problems, ventilation must become smarter. The use of ventilation controls is one of the key concepts of smart ventilation it provides either quality of indoor air (IAQ) or an energy advantage (or both) and less when it provides a disadvantage. As a result of incorporating some smart ventilation strategies into standards and codes in many countries, demand-controlled ventilation (DCV) systems are easy and widely available in the market. Over 20 systems of DCV approved and available in many countries such as: France, Belgium and the Netherlands. (Guyot et al., 2018) published a review of the literature on smart ventilation used in residential building, based on indoor air quality and energy performance. A meta-analysis performed by (Guyot et al., 2018) includes 38 studies of smart ventilation systems with control based on several criteria including humidity, carbon dioxide, co-carbon dioxide, total volatile organic compounds (TVOC) and temperature of outdoor. This meta-analysis implied that energy of ventilation savings of 60% can be achieved without compromising the IAQ, and sometimes improving it. However, some results include less than favorable, with 26% of excessive energy consumption in some cases (Guyot et al., 2018).

4. Discussion

Review papers are a tool that allows to the scientific community at all levels to observe the past, present and future of research and practices in a given subject area. As long as this review is carried out in an objective, deep and critical way (Bravo and León, 2018).

This review-type scientific contribution shows a less common part of scientific research in this area of knowledge. Most of the research in the technologies and practices of the conception, development and operation of green and smart buildings focus on the case of green buildings, on the ecological management of construction resources, use of solar availability and maximum synchrony of the building with the environment. While smart buildings focus more on optimizing energy resources through automation and control. These clear differences between green and smart buildings define them. But there are several points of coincidence, and one of them is the great energetic responsibility that thermal machines present that provides and maintain the conditions of air quality and thermal comfort inside buildings. This last bridge is where the strength and originality of the research presented lies.

The operation of air conditioning systems represents the majority of the operating expenses of non-industrial type building, office buildings, residential buildings; green or smart buildings. The bibliometric analysis shows a great interest on the part of the scientific community for reducing energy consumption, at the same time that renewable energy sources are used; because these two processes participate together to optimize operating costs, energy costs and ecological footprint. To realize these points the optimization study of energy consumption in thermal machines that provide thermal comfort conditions inside buildings must be proposed.

Energy optimization process of chiller or air conditioning machines is studied from different analysis perspectives:

- a) Using strategies for passive or active accumulation of thermal energy in the building (Chen et al., 2014).
- b) Through drive strategies based on the management of the building's occupants and their habits; using for this the science of data (Shaikh et al., 2014).
- c) From strategies of combining different capacities of thermal machines to better adjust to the characteristics of the thermal load of the building (Bravo et al., 2018).
- d) Combining passive air conditioning and ventilation systems such as green roofs and natural convection thermal processes, with the operation of chiller machines (Bravo-Hidalgo, 2018).
- e) Through computer systems with the ability to influence the operation of the chiller according to a predictive analysis of the meteorological variables and the building's occupancy levels (Chou and Bui, 2014).
- f) By combining non-renewable energy powered chillers, renewable chillers and different levels and methods of thermal energy storage (Balta et al., 2010).
- g) Integrating the concept of Power System Flexibility in the management of the building's cooling process (Vuarroz et al., 2019).

The present paper is considered as an academic research guide for engineers, architects, and students interested in designing, constructing and efficiently managing the cooling processes of smart and green buildings.

4.1 Study limitations :

- a) Research is limited to scientific contributions in the Scopus directory.
- b) Only English language publications are considered.
- c) Only article, review and conference paper documents are considered.
- d) The study is limited to the information generated from the year 2000.
- e) The text mining analysis was performed on title, keywords and abstract of the articles detected by each search criteria.

5. Conclusions

The objective of this scientific contribution is to give (or show) a general bibliographic review of recent scientific publications, focused on the design and operation of air conditioning systems in green and smart buildings. The main points considered in this study are given as follow:

- a) Research in this domain has been increased considerably over the past decade.*
- b) Economic powers characterized by large megacities such as the United States of America, China, Italy, Malaysia, Germany and Australia; Research in this subject area is considered a viable way to increase energy efficiency and decrease the carbon footprint of current and future buildings, both green and smart.*
- c) The most frequent fields of research in scientific contributions related to the cooling of green buildings are: sustainable development, energy efficiency and the construction industry.*
- d) The most common fields of research in scientific contributions related to the cooling of smart buildings are: energy efficiency, smart grids, energy management.*
- e) Optimizing energy consumption of air-conditioning systems is currently being studied from different analysis perspectives: accumulation of thermal energy, management of building occupancy, predictive analysis of thermal load, combination of renewable and non-renewable sources.*

6. References

- Ahmad, T.; Zhang, H.; Yan, B. (2020). "A review on renewable energy and electricity requirement forecasting models for smart grid and buildings," (in English), Sustainable Cities and Society, Review vol. 55, Art. no. 102052.
- Alonso, J. A. G. ; Perez, Y. M.; Hidalgo, D. B. (2017). "Empleo de indicadores bibliométricos para la realización de un estado del arte. Un enfoque práctico," Revista Publicando, vol. 3, no. 9, pp. 81-97.
- Balta, M.T.; Dincer, I.; Hepbasli, A. (2010). "Performance and sustainability assessment of energy options for building HVAC applications," (in English), Energy and Buildings, Article vol. 42, no. 8, pp. 1320-1328.
- Bixler, T.S.; Houle, J.; Ballester, T.; Mo, W. (2019). "A dynamic life cycle assessment of green infrastructures," (in English), Science of the Total Environment, Article vol. 692, pp. 1146-1154.
- Bravo, D.; González, F.; González, J. (2018). "Solar cooling in buildings. A state of the art," Revista Ingeniería de Construcción, vol. 33, no. 2, pp. 115-126, 2018.
- Bravo-Hidalgo, D. (2018). "Night air conditioning of buildings by external air ventilation," Revista Facultad de Ingeniería, vol. 27, pp. 35-47.
- Bravo Hidalgo, D.; León González, J. L. (2018). "Divulgación de la investigación científica en el Siglo XXI," Revista Universidad y Sociedad, vol. 10, no. 3, pp. 88-97.
- Chen, M.S.; Gu, F.; Xu, S.Y.; Chen, X.H. (2016). "Formal evaluation of scheduling strategies for smart building air-conditioning systems under uncertain environment," (in Chinese), Ruan Jian Xue Bao/Journal of Software, Article vol. 27, no. 3, pp. 655-669.
- Chen, Y.; Athienitis, A.K.; Galal, K.E. (2014). "A charging control strategy for active building-integrated thermal energy storage systems using frequency domain modeling," (in English), Energy and Buildings, Article vol. 84, pp. 651-661.
- Chen, Y.; Luo, L. (2019). "Analysis of environmental benefits of green buildings from the perspective of carbon emissions," in 2019 International Academic Exchange Conference on Science and Technology Innovation, IAECST 2019, vol. 145: EDP Sciences.
- Chen, Y.; Tong, Z.; Zheng, Y.; Samuelson, H.; Norford, L. (2020). "Transfer learning with deep neural networks for model predictive control of HVAC and natural ventilation in smart buildings," (in English), Journal of Cleaner Production, Article vol. 254, Art. no. 119866.
- Chou, J. S.; and Bui, D.K. (2014). "Modeling heating and cooling loads by artificial intelligence for energy-efficient building design," (in English), Energy and Buildings, Article vol. 82, pp. 437-446.
- Elghamry, R.; Hassan, H. (2020). "Impact of window parameters on the building envelope on the thermal comfort, energy consumption and cost and environment," (in English), International Journal of Ventilation, Article vol. 19, no. 4, pp. 233-259.
- Falagas, M.E.; Pitsoini, E.I.; Malietzis, G.A.; Pappas, G. (2008). "Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and weaknesses," (in English), FASEB Journal, Article vol. 22, no. 2, pp. 338-342.
- Guyot, G.; Sherman, M.H.; Walker, I.S. (2018). "Smart ventilation energy and indoor air quality performance in residential buildings: A review," (in English), Energy and Buildings, Review vol. 165, pp. 416-430, 2018.
- Hidalgo, D.B.; Guerra, Y. P. (2016). "Eficiencia energética en la climatización de edificaciones," Revista Publicando, vol. 3, no. 8, pp. 218-238.
- Hidalgo, D.B.; Pérez, Y.M. (2017). "Eficiencia energética, competitividad empresarial y economía verde," Revista Publicando, vol. 3, no. 9, pp. 447-466.
- Jiang, T.; Li, Z.; Jin, X.; Chen, H.; Li, X.; Mu, Y. (2018). "Flexible operation of active distribution network using integrated smart buildings with heating, ventilation and air-conditioning systems," (in English), Applied Energy, Article vol. 226, pp. 181-196.
- Jim, C.Y. (2014). "Air-conditioning energy consumption due to green roofs with different building thermal insulation," (in English), Applied Energy, Article vol. 128, pp. 49-59.
- Jimenez-Castillo, G.; Tina, G.M. ; Munoz-Rodriguez, F.J.; Rus-Casas, C. (2019). "Smart meters for the evaluation of self-consumption in zero energy buildings," in 10th International Renewable Energy Congress, IREC 2019: Institute of Electrical and Electronics Engineers Inc.
- Li, Q.; Long, R.; Chen, H.; Chen, F.; Wang, J. (2020). "Visualized analysis of global green buildings: Development, barriers and future directions," (in English), Journal of Cleaner Production, Article vol. 245, Art. no. 118775.
- Liu, Y.; Liu, T.; Ji, B.; Wang, B. (2020). "An economic evaluation of refrigeration and air-conditioning system retrofit in large-scale public buildings: A case study of Beijing Capital International Airport Terminals," (in English), Journal of Cleaner Production, Article vol. 245, Art. no. 118934.
- Michalec, A.O.; Hayes, E.; Longhurst, J. (2019). "Building smart cities, the just way. A critical review of "smart" and "just" initiatives in Bristol, UK," (in English), Sustainable Cities and Society, Article vol. 47, Art. no. 101510.

- Minea, V. (2012).** "Efficient heating and cooling systems for low-energy houses," (in English), *Journal of Green Building, Review* vol. 7, no. 4, pp. 16-35.
- Ostadijafari, M.; Dubey, A.; Liu, Y., Shi, J.; Yu, N. (2019).** "Smart Building Energy Management using Nonlinear Economic Model Predictive Control," in 2019 IEEE Power and Energy Society General Meeting, PESGM 2019, vol. 2019-August: IEEE Computer Society.
- Pereira, G. S.; Primo, A.R.; Villa, A.A.O. (2015).** "Comparative study of air conditioning systems with vapor compression chillers using the concept of green buildings," (in English), *Acta Scientiarum - Technology, Article* vol. 37, no. 4, pp. 339-346.
- Pezzutto, S.; De Felice, M.; Fazeli, R.; Kranzl, L.; Zambotti, S. (2017).** "Status quo of the air-conditioning market in europe: Assessment of the building stock," (in English), *Energies, Article* vol. 10, no. 9, Art. no. 1253.
- Png, E.; Srinivasan, S.; Bekiroglu, K.; Chaoyang, J; Su, R.; Poolla, K. (2019).** "An internet of things upgrade for smart and scalable heating, ventilation and air-conditioning control in commercial buildings," (in English), *Applied Energy, Article* vol. 239, pp. 408-424.
- Raturi, A.K. (2016).** "Renewables 2016 Global status report".
- Safari, A.; Tahmasebi, M.; Pasupuleti, J. (2019).** "Smart Buildings Aggregator Bidding Strategy as a Negawatt Demand Response Resources in the Spinning Reserve Electricity Market," in 2019 IEEE PES Innovative Smart Grid Technologies Europe, ISGT-Europe 2019, 2019: Institute of Electrical and Electronics Engineers Inc.
- Shaikh, P.H.; Nor, N.B.M.; Nallagownden, P.; Elamvazuthi, I.; Ibrahim, T. (2014).** "A review on optimized control systems for building energy and comfort management of smart sustainable buildings," (in English), *Renewable and Sustainable Energy Reviews, Review* vol. 34, pp. 409-429.
- Sua, L.S.; Balo, F.; Ucar, U. (2020).** "Tomorrow's Green Buildings: Optimum Natural Insulation Material Modeling," in *Green Energy and Technology*, ed: Springer Verlag. pp. 109-124.
- Tan, H.; Hao, X.; Long, P.; Xing, Q.; Lin, Y.; Hu, J. (2020).** "Building envelope integrated green plants for energy saving," (in English), *Energy Exploration and Exploitation, Article* vol. 38, no. 1, pp. 222-234.
- Tang, R.; Wang, S.; Yan, C. (2018).** "A direct load control strategy of centralized air-conditioning systems for building fast demand response to urgent requests of smart grids," (in English), *Automation in Construction, Article* vol. 87, pp. 74-83.
- Tian, W.; Wu, X.; Zhao, X.; R. Ma, R.; Zhang, B. (2019).** "Quantifying global CH4 and N2O footprints," (in English), *Journal of Environmental Management, Article* vol. 251, Art. no. 109566.
- Van Cutsem, O.; Ho Dac, D.; Boudou, P.; M. Kayal, M. (2020).** "Cooperative energy management of a community of smart-buildings: A Blockchain approach," (in English), *International Journal of Electrical Power and Energy Systems, Article* vol. 117, Art. no. 105643.
- Van Eck, N.J.; Waltman, L. (2010).** "Software survey: VOSviewer, a computer program for bibliometric mapping," (in English), *Scientometrics, Article* vol. 84, no. 2, pp. 523-538.
- Vázquez-Canteli, J.R.; Ulyanin, S.; Kämpf, J. Nagy, Z. (2019).** "Fusing TensorFlow with building energy simulation for intelligent energy management in smart cities," (in English), *Sustainable Cities and Society, Article* vol. 45, pp. 243-257.
- Venkateswara Rao, V.; Datta, S.P. (2020).** "A feasibility assessment of single to multi/hybrid evaporative coolers for building air-conditioning across diverse climates in India," (in English), *Applied Thermal Engineering, Article* vol. 168, Art. no. 114813.
- Vuarnoz, D.; Niederhäuser, E.L.; Torregrossa, D.; Gabioud, D. (2019).** "On the Necessity to Integrate Power Flexibility in Cooling Systems," in Joint 2019 International Conference on Ubiquitous Power Internet of Things, UPIOT 2019 and 2019 3rd International Symposium on Green Energy and Smart Grid, SGESG 2019, vol. 1346: Institute of Physics Publishing.
- Wang, S.; Tang, R. (2017).** "Supply-based feedback control strategy of air-conditioning systems for direct load control of buildings responding to urgent requests of smart grids," (in English), *Applied Energy, Article* vol. 201, pp. 419-432, 2017.
- Yang, K. H.; Hwang, R.L. (2007).** "An improved assessment model of variable frequency-driven direct expansion air-conditioning system in commercial buildings for Taiwan green building rating system," (in English), *Building and Environment, Article* vol. 42, no. 10, pp. 3582-3588.
- Zhai, X.Q.; Wang, R.Z.; Wu, J.Y.; Dai, Y.J.; Ma, Q. (2008).** "Design and performance of a solar-powered air-conditioning system in a green building," (in English), *Applied Energy, Article* vol. 85, no. 5, pp. 297-311.
- Zhang, Q. et al. (2020).** "Global timber harvest footprints of nations and virtual timber trade flows," (in English), *Journal of Cleaner Production, Article* vol. 250, Art. no. 119503.
- Zhang, Y. et al., (2019).** "A survey of the status and challenges of green building development in various countries," (in English), *Sustainability (Switzerland), Review* vol. 11, no. 19, 2019, Art. no. 5385.