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Review Article

# Energy retrofit and climate adaptive design of dwellings in the hot arid climate: Trends and future challenges

Dunya Abdulazeez Gheni Aldhaher<sup>\*</sup> and Semra Arslan Selçuk

*Department of Architecture, Faculty of Architecture, Gazi University, TÜRKİYE*

**Abstract.** As long as buildings face various climate change impacts in recent decades, such as increased heat, particularly in the residential sector. Therefore, energy retrofit, and climate-adaptive designs may contribute significantly to climate change mitigation and adaptation strategies. At the same time, these strategies do not only improve the sustainability of dwellings/houses/residences but also contribute to broader goals of increasing energy efficiency, reducing environmental impact, offering economic benefits, and enhancing the community's resilience in the challenges they face impact from the effects of climate change. This study aims to examine and present the development of energy retrofitting, energy efficiency and climate-adaptive design for dwellings/ residential buildings in hot weather publications through bibliometric research. The research has been examined within the Web of Science™ Core Collection (W.O.S.) online database spanning from 2012 to November 2023 by using the "Title/Abstract/Keywords" category, and a comprehensive data visualisation has been conducted utilising the VOSviewer and CiteSpace programmes. The findings indicate the research trends in the literature and future challenges, and the results from these findings demonstrate the need for sustainable and energy-efficient buildings to preserve the environment and climate. These sustainable developments focus on improvements in energy retrofitting technologies, energy efficiency and saving targets, indoor thermal comfort, optimising passive design and minimising energy demand. This study will probably be a source to provide valuable insights for researchers, practitioners, experts, and policymakers to understand the implications of energy retrofitting and climate-adaptive design in hot arid climates. As well as it would offer theoretical and practical initiatives to be applied in this field.

**Keywords:** Energy Retrofit, Energy Efficiency, Climate Adaptive Design, Hot Arid Climate, Dwellings, Bibliometric Analysis



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## 1. Introduction

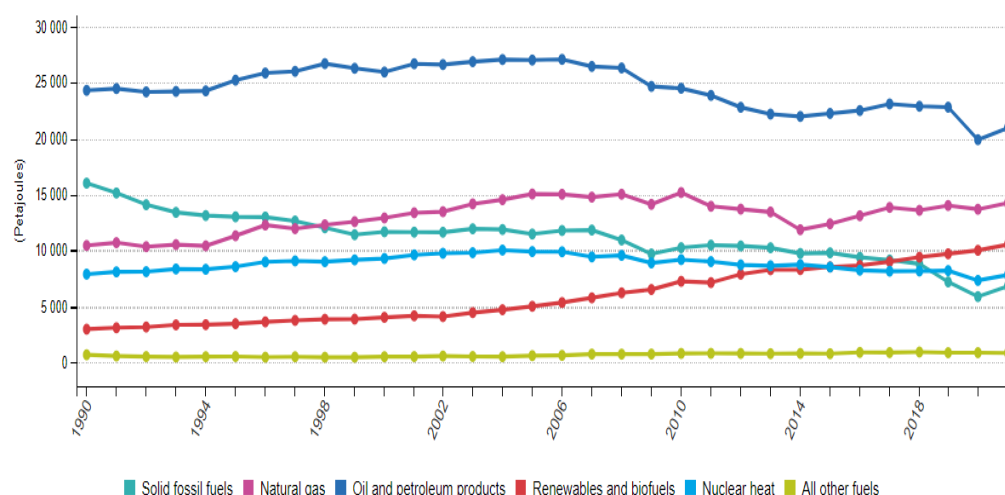
The importance of energy-efficient and sustainable buildings has grown significantly in the effort to preserve the environment. Due to the growing population and rapid urbanisation, there was a need to raise the energy demand in buildings over the previous decades (Zhao & Zhang, 2018; Aversa *et al.*, 2016). According to the International Energy Agency (IEA) (IEA, 2019), the building sector accounts for the largest share of global energy usage. Therefore, inefficient buildings play a significant role in global energy consumption and the emission of greenhouse gases, making it imperative to address this issue (Pham *et al.*, 2020). Moreover, building energy consumption is influenced by various factors, such as human behaviour, building envelope, and climate (Streimikiene *et al.*, 2024; Yoshino *et al.*, 2017; Hu *et al.*, 2017). As a result, the proportions consumed by buildings contribute significantly to environmental issues such as climate change, air pollution, thermal pollution, and other adverse impacts that seriously threaten human existence (Dandotiya *et al.*, 2020).

Approximately 40% and 61% of the total energy utilised in commercial and residential buildings worldwide is used for space heating and cooling, respectively (Ürge-Vorsatz *et al.*, 2015). This trend is expected to continue, with predictions

indicating that in 2050, space heating and cooling will require a significant amount of energy, up to 12% for commercial and 37% for residential buildings (IEA, 2018). Because of the changes in outdoor circumstances, climate change will significantly affect how much energy buildings consume for heating and cooling (Radhi, 2009). Temperature changes, humidity levels, winds, and solar radiation are all expected to change due to increased CO<sub>2</sub> emissions throughout time (Federal Advisory Committee, 2009). As well as the effects of climate change on the amount of energy used for heating and cooling will vary significantly depending on the building type and geographic area (Li *et al.*, 2024; Wilbanks, 2009; Sailor, 2001).

In addressing the issue of climate change, the residential building sector is experiencing a continuous increase in building-related energy consumption due to living space. For example, in Europe, residential buildings account for around 36% of CO<sub>2</sub> emissions and 40% of energy consumption (European Commission, 2023). Moreover, over 75% of residential buildings are considered energy-inefficient, and around 35% of the stock is over 50 years old (Economidou *et al.*, 2011). In Australia, residential buildings account for more than

<sup>\*</sup> Corresponding author  
Email: [dunyaalldhahir88@gmail.com](mailto:dunyaalldhahir88@gmail.com) (D. Aldhaher)



**Fig. 1** Gross available energy EU 1990-2021 (Eurostat, 2023)

10% of total carbon emissions and around 24% of total power demand. Poor energy performance in homes and apartments influences the energy system and the economy (Dcceew, 2023).

In 2021, the European Commission introduced a comprehensive set of proposals to align the European Union's (EU) energy, climate, transport, and tax policies so that net greenhouse gas emissions are reduced by at least 55% by 2030 compared to 1990. Moreover, the ultimate goal is for the EU to become the world's first climate-neutral continent by 2050. Thus, the most critical targets for the 2030 climate and energy framework include increasing the reduction of greenhouse gas emissions from 40% to at least 55%, raising the share of renewable energy from 32% to 43%, enhancing the target for energy efficiency in final energy consumption from 32% to 36%, and establishing a target of 39% for energy efficiency in primary energy consumption (European Commission, 2023; Geske, 2022). However, 70–80% of the residential buildings that need climate-neutral by 2050 have already been constructed and equipped with non-climate-neutral technology because of their extended lifespan. Therefore, most of the energy used in buildings worldwide comes from fossil fuels, such as coal, oil, and natural gas; improving building energy efficiency has emerged as a critical concern in reducing gas emissions and using fossil fuels, as shown in Figure 1. For example, an estimated 20 percent increase in the energy performance of buildings in the European Union (E.U.) might result in an annual savings of 60 billion euros (Li *et al.*, 2010). So, when it comes to changing the present energy system, the decarbonisation of power generation and the use of contemporary renewables must come first. A sustainable future may be significantly enhanced by, for example, introducing energy efficiency improvements and technologies at the district level to transition to sustainable energy practices (Olczak *et al.*, 2022; Pu *et al.*, 2021).

This study aims to examine and present the development of energy retrofitting, energy efficiency, and climate-adaptive design for dwellings/houses/residential buildings in hot weather publications. The examination has turned to questions that will be answered in the objectives (O1-O5) in this study, and they are:

O1: What are the emerging trends in the annual publications related to energy retrofitting, energy efficiency, and climate-adaptive design for dwellings/ residential buildings in hot weather?

O2: Which journals have published studies that contributed to energy retrofitting and energy efficiency from 2012 to 2023?

O3: Which countries were the studies conducted with the highest productivity?

O4: What are the new techniques, primary contributions, and future research needs for achieving energy efficient and climate adaptive design?

O5: What are the essential characteristics of the content of the most cited publications that need to be studied and analysed?

Thus, bibliometric research was done within the scope of this study, and some findings are mentioned. The progress started with the examined publications from the Web of Science to find bibliometric indicators for this study. These indicators included analysis of annual publications, research areas, geographical areas, authorship, institutions/organisation, citation by sources, co-occurrence of keywords, and content analysis of the chosen articles. Next, VOSviewer and CiteSpace are used to visualise data, as described in Section 3. At the same time, the bibliometric results are examined in Section 4. Therefore, energy retrofit and climate adaptive design of dwellings in hot, arid climates must be highlighted in recent research and studies due to their potential to address climate change impacts, improve energy efficiency, offer healthy and economic benefits, and enhance resilience.

## 2. Literature Review

Numerous research studies on retrofitting strategies to reduce the energy consumption of new and existing buildings have been conducted to date. Particularly in the last 20 years, there has been a significant shift and growth in the number of publications on energy efficiency and sustainable living in the residential sector. The term "retrofit" in architecture often refers to "renovation that stretches beyond the norm to address sustainability matters" (Bernardier *et al.*, 2010). According to Baeli (2013), "retrofit" and other related concepts, including "renovation" "repair," "refurbishment," and "restoration" are used to characterise the construction work done to increase the lifecycle of existing buildings in the context of housing. Therefore, enhancing energy efficiency and quality of life via retrofitting existing building stock is a primary goal towards attaining a more sustainable built environment and reducing energy use. According to Phan (2010), "retrofitting offers many opportunities for the substantial improvement of the energy

performance of residential buildings and the provision of sustainable alternatives to conventional heating and cooling.” However, selecting the buildings that should be retrofitted is crucial in the decision-making process. So, it is essential to either construct a new building or retrofit an existing one. (Dolšak, Hrovatin & Zorić, 2020) and (Appleby, 2013) discussed the factors to consider when making this choice, including the location, size of the land, structural issues, whether the building types are residential or not, financial constraints, and ownership status of the buildings (private or public).

Numerous thorough studies have been carried out to determine the condition of building retrofitting on a global scale, outlining the many market-promoted initiatives and the solutions that are currently accessible. For example, (Dolšak, 2023) analysed the determinants of Energy-efficient retrofits (E.E.R.s) in residential buildings in his study. These determinants can be broadly categorised into five groups: information and policy measures, economic factors, households’ socioeconomic characteristics, technical and building characteristics, and behavioural factors. Furthermore, the study recommended that future energy policies employ various strategies to support E.E.R.s, fully addressing the many parts of household members’ decision-making processes and the identified categories of determinants.

(Ma *et al.*, 2015) conducted a systematic approach to correctly choose and identify the best retrofit alternatives for existing buildings to promote energy conservation and sustainability. The researchers presented the generic building retrofit optimisation problem, identifying, executing, and using the most cost-effective retrofit technologies to deliver better energy performance while maintaining appropriate service levels and acceptable interior thermal comfort and the proper selection of cost-effective retrofit measures. In addition, important building retrofit tasks are covered, including energy auditing, building performance assessments, economic analyses, risk assessments, measurement, and energy savings verification.

Regarding sustainable retrofitting strategies and energy efficiency optimisation for residential buildings, the study of (Li *et al.*, 2019) proposes establishing a system of planning strategies suitable for complex existing residential situations, emphasising hierarchical and partial reforms. The focus is on addressing weaknesses in the thermal performance of various components of existing residential buildings. The study argues for advancing the quantitative assessment of the renovation performance of existing residential buildings during the planning phase and integrating optimisation technology methods to improve energy efficiency in building renovations. Using existing residential buildings in Northeast China built between 1980 and 2000 as a case study, the optimisation methods for green design strategies for residential buildings will be investigated, with green retrofit as both a source of design strategies and a target for energy efficiency optimization.

Another study aimed to determine climate-responsive design techniques and human thermal comfort in dry-hot and dry-cold climates. This might motivate residents to use passive measures to enhance the interior thermal environment (Yang *et al.*, 2020). Concerning adapting social housing to climate change, Makantasi and Mavrogianni (2015) evaluated the effects of several building fabric retrofit techniques on interior thermal comfort in a case study of social housing buildings in central London, considering both present and projected weather patterns. In addition, they used a comprehensive assessment methodology when assessing retrofit options, considering the yearly savings, capital investment, embodied and operational CO<sub>2</sub> emissions, and related energy usage.

In addition to the studies above, there are many reviews discussed the energy efficiency and retrofit and climate adaptive design of dwellings/residential sector, such as retrofit/renovation in a temperate climate (Hamid *et al.*, 2018; Alfariš *et al.*, 2016), energy performance optimisation and challenges in the retrofitting process (Costa-Carrapiço *et al.*, 2020; Hashempour *et al.*, 2019; Tian *et al.*, 2018; Memon, 2014), managing energy efficiency and renewable energy in the residential sector (Sotnyk *et al.*, 2023), diffusion of energy efficiency technologies (Camarasa *et al.*, 2019); retrofit measures for the hot summer/ cold winter regions (Liu *et al.*, 2023; Felius *et al.*, 2020); indoor environmental quality and thermal comfort (Ozarisoy, 2022; Ortiz *et al.*, 2020).

### 3. Method

As this research aims to contribute to the understanding of the energy retrofit of dwellings in hot, arid climates to reduce overheating in the summer season, therefore the deductive study has been chosen as it represents the most appropriate approach to offer high-quality, transparent, and replicable reviews (Dybå *et al.*, 2008). This approach usually starts with research questions, thus leading to data collection and analysis (Davidavičienė, 2018). So, a bibliometric analysis was conducted to reduce bias in selecting and mapping the article titles. As described by (Ale Ebrahim, 2019 Zhang *et al.*, 2018 Daim *et al.*, 2006), bibliometric analysis is a potent quantitative tool for investigating knowledge networks derived from published literature, extensively applied to examine and assess the structure and research trends in a specific scientific field or discipline. Many developed tools have made it easier and more effective to produce bibliometric studies (Ellegaard *et al.*, 2015). These tools encompass databases like Scopus, Web of Science (WoS), and Google Scholar (Adhikari *et al.*, 2024; Martín *et al.*, 2018). A comprehensive search strategy was employed for scholarly literature published in English, utilising the Web of Science™ Core Collection (WoS) online database using the "Title/Abstract/Keywords" category. The search, limited to research articles, proceeding papers, and review articles spanning from 2012 to November 2023, focused on the topics of "energy retrofit\*," "energy efficiency\*," "hot arid climate\*," "carbon reduction\*," "dwelling\*," "residential building\*" and "climate adaptive design\*" date of retrieval: 15th November 2023. A total of 227,175 entries were initially retrieved, with more than 200,000 being excluded based on WoS categories, such as green sustainable science, construction building technology, architecture, urban studies, engineering civil, and regional urban planning. At the same time, the research areas were limited to construction building technology, urban studies, architecture, and materials science. Moreover, for further analysis, the information retrieved from the previous step was summarised into tables, diagrams, graphs, and photos using software packages such as VOSviewer, CiteSpace, and Microsoft Excel.

The study was conducted in four stages; data collection and identification were the first step, where all the energy retrofit in residential buildings-related words were screened in WoS and filtered in the second step. Subsequently, a bibliometric analysis was done to complete the research. Then, the fourth stage assessed the countries’ characteristics, dominant issues, academic trends, challenges, research collaboration, and significant contributions. Figure 2 shows the methodology framework of this study.

This study aims to examine global scientific publications on the energy retrofit of dwellings in hot summer regions, indexed in the Web of Science (WoS). The goal is to identify critical research areas in energy retrofit and climate adaptive design

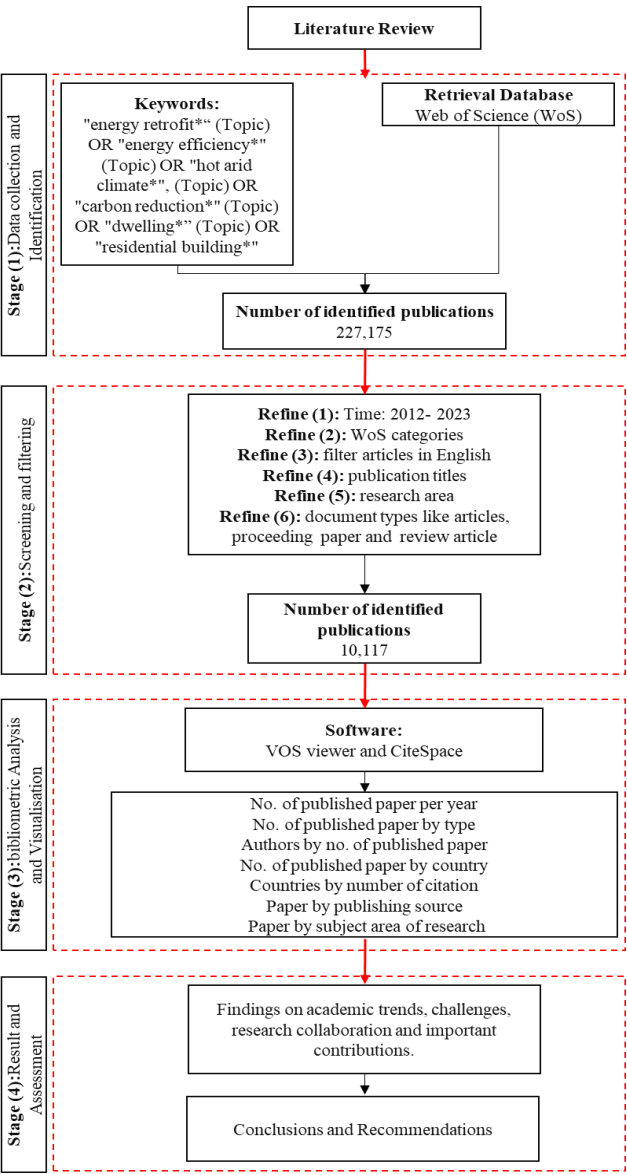


Fig. 2 Stages of bibliometric analysis of the study. Note: WoS core collection was last updated in November 2023

and to highlight international collaborations among researchers and institutions. The Web of Science (WoS) selection is based on its status as one of the most extensive and reputable citation indexes globally.

4. Findings

This section provides the bibliometric analysis outcomes, including the general analysis, network analysis, and keywords analysis. The general analysis illustrates the progress and distribution of publications on energy retrofit and efficiency. It encompasses an exploration of annual indicators, publication types, and the source journals of these publications. At the same time, the analysis of collaboration networks employed VOSviewer to visually present the quantity of co-authored publications and the collaborative relationships among various countries/states/ regions, institutions/organisations/authors. Keywords work as a brief means for authors to articulate the conceptual framework of their work (Henry *et al.*, 2021). Consequently, using tools like CiteSpace and cluster analysis, these visualisations make it easier to understand complex

Table 1

| The annual number of publications from 2012 to November 2023 |              |             |
|--------------------------------------------------------------|--------------|-------------|
| Publication Years                                            | Record Count | % of 10,140 |
| 2023                                                         | 1065         | 10.503      |
| 2022                                                         | 1129         | 11.134      |
| 2021                                                         | 1187         | 11.706      |
| 2020                                                         | 1131         | 11.154      |
| 2019                                                         | 1000         | 9.862       |
| 2018                                                         | 807          | 7.959       |
| 2017                                                         | 971          | 9.576       |
| 2016                                                         | 746          | 7.357       |
| 2015                                                         | 714          | 7.041       |
| 2014                                                         | 497          | 4.901       |
| 2013                                                         | 528          | 5.207       |
| 2012                                                         | 365          | 3.600       |

relationships among papers, authors, and research topics, and identify emerging trends to evaluate the influence and significance of research contributions. Of the total 10,140 publications searched in the database, 8,445 were articles, followed by proceeding papers (1,236), reviews (481), and 86 early access.

4.1 Scientific Mapping

4.1.1 Annual publications trends in energy retrofit and climate adaptive design of dwellings in the hot arid climate.

In the past ten years of development, there have been significant progressions in technologies promoting energy efficiency and innovative breakthroughs. These advancements have successfully tackled the increasing concerns regarding energy consumption, environmental impacts, and sustainable practices (IEA, 2023). Table (1) illustrates the annual number of energy retrofit and climate adaptive designs of dwellings in the hot, arid climate publications from 2012 to November 2023. In the dataset of 10,140 records, the most recent year, 2021, has the highest record count at 11.7%, with 1,187 records. Because the year 2023 did not end when this research was conducted, the number of research studies is expected to increase beyond this rate by the end of the year. The trend shows a gradual decrease in record counts as we move backward. In 2022, there were 1,129 records, constituting 11.1%. 2020 and 2019 follow closely with 11.1% (1,131 records) and 9.9% (1,000 records) respectively. The most remarkable jump can be seen in 2015 and 2019 when the number of papers increased by an average of 2%. The oldest year in the dataset, 2012, has the lowest record count at 3.6% (365 records).

4.1.2 Research areas of the publications

Based on the Web of Science analysis, the dataset provides a comprehensive overview of research areas within 10,140 records. Construction Building Technology is the predominant research focus, representing 90.4% of the total records with 9,167 entries. Engineering follows closely, constituting 70.71% of the records, totalling 7,170. Energy Fuels also commands substantial attention, accounting for 41.96% of the records with 4,255 entries. Science, Technology, Other Topics, Urban Studies, and Architecture contribute to the diversity of research interests, comprising 9.87% (1,001 records), 5.97% (605 records), and 5% (507 records), respectively. Environmental Sciences Ecology and Materials Science demonstrate noteworthy representation with percentages of 4.22% (428 records) and 3.73% (378 records), respectively. Public Administration, with 276 entries, and Public Environmental Occupational Health, with 240 entries, constitute 2.72% and 2.37% of the records, respectively. This dataset clarifies the



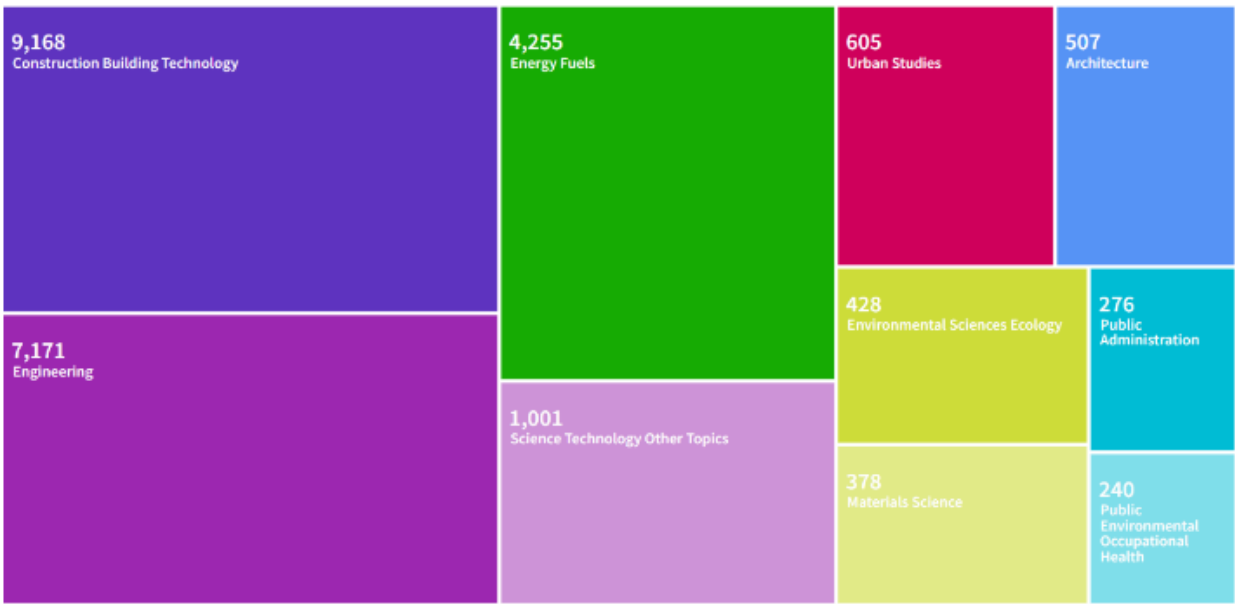


Fig. 3 The most 10 research areas of the publications

diverse landscape of research areas, emphasizing construction technology of buildings, engineering, and energy-related topics to provide valuable insights for researchers and stakeholders in these fields (Figure 3).

4.1.3 Journal publications contribution and most relevant sources

In academic publications, examining data presents a valuable insight into the landscape of research focus and impact. Journal contributions aim to provide detailed insights into which journals have focused the most on energy retrofitting and efficiency. The analysis reveals, as illustrated in Figure 4, that "Energy and Buildings" stands out with a noteworthy record count of 3188, underscoring its considerable influence in the exploration of energy efficiency within the built environment. Following closely are "Building and Environment" with 1205 records and "Journal of Building Engineering" with 813 records, emphasising their significance in the academic discourse. Noteworthy that contributions are also evident in journals such as "Buildings" (765 records), "Sustainable Cities and Society" (639 records), and "Energy Procedia" (306 records), each contributing uniquely to the broader understanding of sustainable practices in construction and urban development. Additionally, publications like "Building Simulation" (227

records) and "Building Research and Information" (204 records) play integral roles in advancing knowledge in the field. The data reflects a diversified landscape of scholarly contributions, mirroring the multifaceted nature of research within the domain of building sciences. This comprehensive analysis is a valuable resource for researchers and practitioners seeking deep searching in the academic literature.

Moreover, citation analysis of journals is used to evaluate journal quality and assess research impact. The majority of these top ten journals appear to be among the most prominent and impactful publications in energy retrofit and climate adaptive design of dwellings in hot, arid climates. As shown in Table 2, many factors affect the academic impact of journals, such as the H-index (which measures the productivity and the impact of a researcher's publications) of H indicates that the researcher has published H papers, each of which has cited at least H times. Another factor is IF, which measures the journal's influence on the academic community—the Times cited the most cited paper in the Journal of Energy and Building, with the second highest impact factor, reaching 769, followed by Sustainable Cities and Society Journal, which has the highest impact factor among the ten journals and 357 times cited for its most cited paper.

4.1.4 Global trend of publications and the most productive countries/regions

Examining the data on the distribution of publications across the various countries and regions reveals distinct patterns in research output. The study focuses on the ten most productive countries. Topping the list is the People's Republic of China, with a remarkable record number of publications in 2,020, underlining the country's outstanding contribution to academic literature. The United States follows closely behind with 1,237 publications, demonstrating a strong research presence. England and Italy contribute with 936 and 810 records respectively, emphasising their remarkable role in the global academic landscape. Other notable contributions come from Spain (594 records), Australia (544 records), and Canada (437 records). South Korea, with 345 records, and Germany, with 327 records, show their influence in the academic world. Portugal rounds off the tenth with 296 records, contributing to the diverse picture of global research endeavours. This analysis

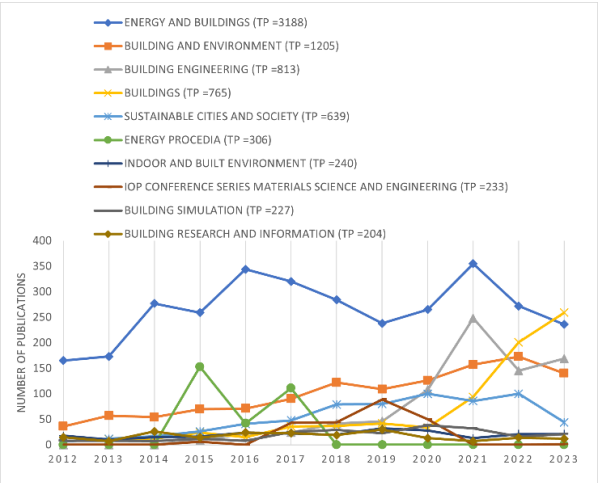
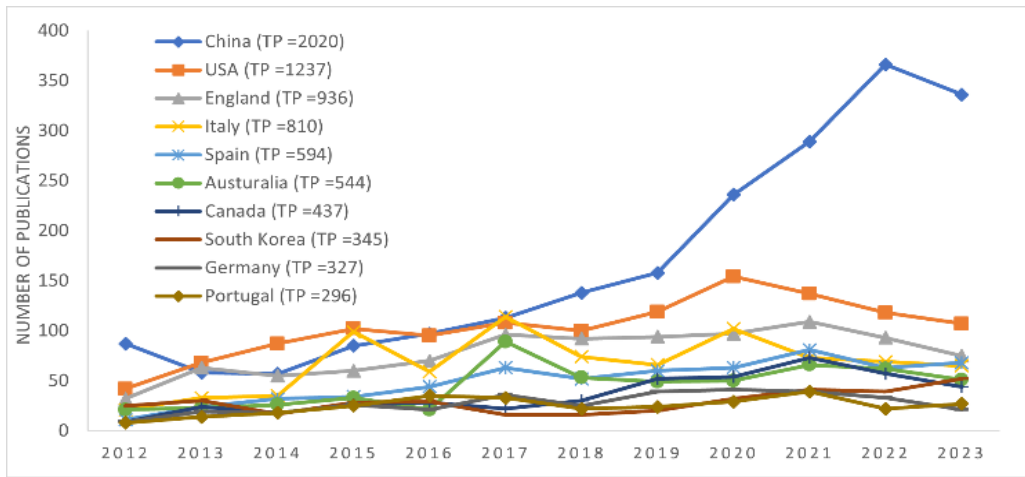


Fig. 4 Journal publication contributions during 2012-2023

**Table 2**  
The ten most influential journals with highly cited publications (R.C.: Record count)

| Journal names                                           | R.C.  | IF 2022 | Total times cited | H-ind ex | The most cited papers                | Times Cited |
|---------------------------------------------------------|-------|---------|-------------------|----------|--------------------------------------|-------------|
| Energy and Buildings                                    | 3,188 | 6.7     | 101,970           | 11       | (Oldewurtel <i>et al.</i> , 2012)    | 769         |
| Building and Environment                                | 1,205 | 7.4     | 35,220            | 87       | (Wang <i>et al.</i> , 2018)          | 314         |
| Building Engineering                                    | 813   | 6.4     | 11,100            | 42       | (Belussi <i>et al.</i> , 2019)       | 217         |
| Buildings                                               | 765   | 3.8     | 4,955             | 30       | (Bland <i>et al.</i> , 2017)         | 102         |
| Sustainable Cities and Society                          | 639   | 11.7    | 15,454            | 56       | (Bourdeau <i>et al.</i> , 2019)      | 357         |
| Energy Procedia                                         | 306   | NA      | 2,891             | 21       | (Sakin <i>et al.</i> , 2017)         | 128         |
| Indoor and Built Environment                            | 240   | 3.6     | 2,659             | 25       | (Shrubsole <i>et al.</i> , 2014)     | 79          |
| IOP Conference Series Materials Science and Engineering | 233   | NA      | 299               | 8        | Karandashova <i>et al.</i> , 2017)   | 13          |
| Building Simulation                                     | 227   | 5.5     | 3,827             | 31       | (Ahmad <i>et al.</i> , 2016)         | 145         |
| Building Research and Information                       | 204   | 3.9     | 4,526             | 37       | (Sunikka-Blank <i>et al.</i> , 2012) | 346         |



**Fig. 5** The annual number of publications for 10 productive countries during 2012-2023

provides valuable insights into the geographical distribution of scientific contributions. It illustrates countries' and regions' diverse and widespread engagement in generating academic knowledge, as shown in Figure 5.

4.1.5 Most Relevant authors and affiliations

The presented data in Table 3 outlines the affiliations and corresponding research contributions in energy retrofit and climate adaptive design of dwellings in the hot, arid climate. Tsinghua University in China emerges as the leading institution with a substantial contribution of 245 publications, highlighting its prominent role in advancing research in this domain. The United States Department of Energy (DOE) closely follows with 234 publications, underlining the significant research output from this governmental organisation. The University of London and Lawrence Berkeley National Laboratory in the U.S.A. also exhibit noteworthy contributions with 163 and 160 publications, respectively. Reflecting the global nature of research, diverse countries are represented among the top contributors, including the U.K., Norway, Italy, Switzerland, Spain, Denmark, and the Netherlands. This international collaboration is particularly evident with institutions like University College London, Polytechnic University of Milan, Swiss Federal Institutes of Technology Domain, University of Sevilla, Technical University of Denmark, and Delft University of Technology making substantial contributions.

Table 3 indicates the most productive 20 authors according to their publications' number and country during the searched years. Li BZ. (China) is the first author to have 51 publications. After Li, the authors came as follows for those who published 40-50 documents: Kim J. (South Korea) 46, Pisello AL. (Italy) 45, Hong TZ (USA) 44, Zhang Y (Australia) 42, Yan D (China) 41 and Krati M. (USA) 40 documents. While from 30-39 publications are published by Wang Y. (China) with 39; Lin BR. (China), Santamouris M. (Australia), and Wang Z. (China) with 36; Kim S. (South Korea) 35; Liu H. (China) and Zhang H. (China) with 34; Kim JT. (South Korea) and Zhang X. (China) with 33; Liu JJ. (China), Yang L. (China), and Zhang L. (China) with 31 and Almeida M (Portugal), respectively.

4.2 Collaborative Network Analysis

VOSviewer software was used in network analysis to build and visualise bibliometric networks, allowing users to create maps of scientific literature based on co-citation, co-occurrence, bibliographic coupling, or co-authorship data.

4.2.1 Co-countries/ regions and institutions network analysis

In this analysis, collaborations and relationships between different countries/regions based on scientific publications have been visualised. The default setting of the software was used (a threshold of the minimum number of documents in a

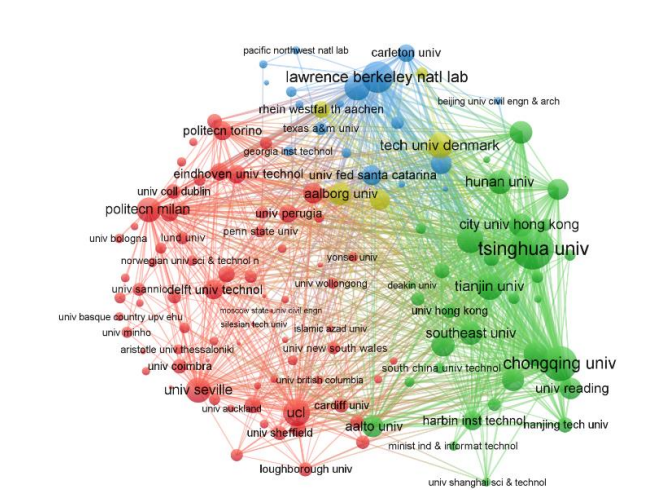
**Table 3**  
The most relevant and contributed authors and affiliations with their countries in the field. (R.C.: Record count)

| R  | Affiliations                                    | R.C. | Countries   | Authors       | R.C. | Countries   |
|----|-------------------------------------------------|------|-------------|---------------|------|-------------|
| 1  | Tsinghua University                             | 245  | China       | Li BZ         | 51   | China       |
| 2  | United States Department of Energy DOE          | 234  | USA         | Kim J         | 46   | South Korea |
| 3  | University Of London                            | 163  | UK          | Pisello AL    | 45   | Italy       |
| 4  | Lawrence Berkeley National Laboratory           | 160  | USA         | Hong TZ       | 44   | USA         |
| 5  | University College London                       | 157  | UK          | Zhang Y       | 42   | Australia   |
| 6  | Chongqing University                            | 145  | China       | Yan D         | 41   | China       |
| 7  | Norwegian University of Science Technology NTNU | 137  | Norway      | Krarti M      | 40   | USA         |
| 8  | Tianjin University                              | 133  | China       | Wang Y        | 39   | China       |
| 9  | Hong Kong Polytechnic University                | 128  | China       | Lin BR        | 36   | China       |
| 10 | Tongji University                               | 126  | China       | Santamouris M | 36   | Australia   |
| 11 | Polytechnic University of Milan                 | 123  | Italy       | Wang Z        | 36   | China       |
| 12 | Swiss Federal Institutes of Technology Domain   | 122  | Switzerland | Kim S         | 35   | South Korea |
| 13 | Xi An University of Architecture Technology     | 117  | China       | Liu H         | 34   | China       |
| 14 | University of Sevilla                           | 112  | Spain       | Zhang H       | 34   | China       |
| 15 | Technical University of Denmark                 | 109  | Denmark     | Kim JT        | 33   | South Korea |
| 16 | Aalborg University                              | 102  | Denmark     | Zhang X       | 33   | China       |
| 17 | University of California System                 | 102  | USA         | Liu JJ        | 31   | China       |
| 18 | Egyptian Knowledge Bank EKB                     | 99   | Egypt       | Yang L        | 31   | China       |
| 19 | Polytechnic University of Turin                 | 98   | Italy       | Zhang L       | 31   | China       |
| 20 | Delft University of Technology                  | 96   | Netherlands | Almeida M     | 30   | Portugal    |

country is five while the minimum number of citations in a country is 1). Those used thresholds provide a powerful indication of a country's commitment to collaborate with other countries. Seventy-eight countries have met the thresholds out of 124, and those 78 countries were grouped into 5 clusters with (2988) links and (3607946) total link strength. It is essential to mention that the links and the total link strength identify more vital collaboration between countries and measure the complex network of connections characterising international relationships.

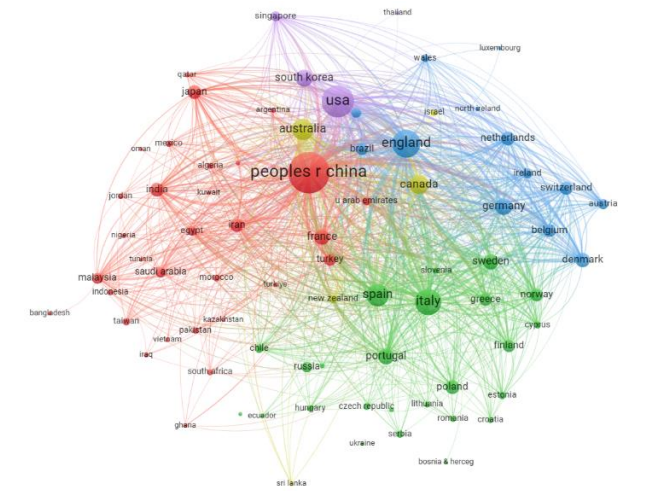
Figure 6 shows the top three countries with the highest total link strength (no less than 100,000) in each coloured cluster. China (925,056), France (160,136), and India (138,099) are recognized as the countries with the most collaborations in the red colour cluster. Italy, Spain, and Portugal (463075, 339587, and 173701 respectively) got second place in green. The third cluster is blue and contains countries like England (584305), Germany (168732), and the Netherlands (143567). The fourth colour is yellow, containing countries such as Australia (339702) and Canada (235322). While the fifth is purple and consists of countries such as the U.S.A (618973) and South Korea (138025).

About collaboration among institutions, Figure 7 presents the co-institution network. The threshold used for the minimum



**Fig. 7** Co-institutions network analysis

number of documents in a country is 25, and the minimum number of citations in a country is 10. As a result, 128 out of 4,893 institutions have met the threshold. The created clusters are connected by links, showing a cooperative network. Then, four clusters have been created (according to coupling analysis and total strength of the co-institutions links) starting with the red colour, which contains UCL/UK (56326), University of Seville/Spain (50014), and Politecn Milan/Italy (48454). The second cluster is green, and the highest three institutions are Tsinghua University/China, Chongqing University/ China, and Tianjin University/China (113072, 84196, and 56609, respectively). Moreover, the blue color represents the third cluster with the highest three cooperative institutions, such as Lawrence Berkeley National Laboratory/U.S.A. (70700), Concordia University/Canada (52558), and the National University of Singapore N.U.S./Singapore (48431). The last cluster is yellow and contains the Technical University of Denmark, Aalborg University (both in Denmark), and the Norwegian University of Science and Technology (52924, 41541, 35616). From the basic principle of bibliographic coupling analysis, China and Tsinghua University have led the research frontiers in this field.



**Fig. 6** Co-countries/regions network analysis



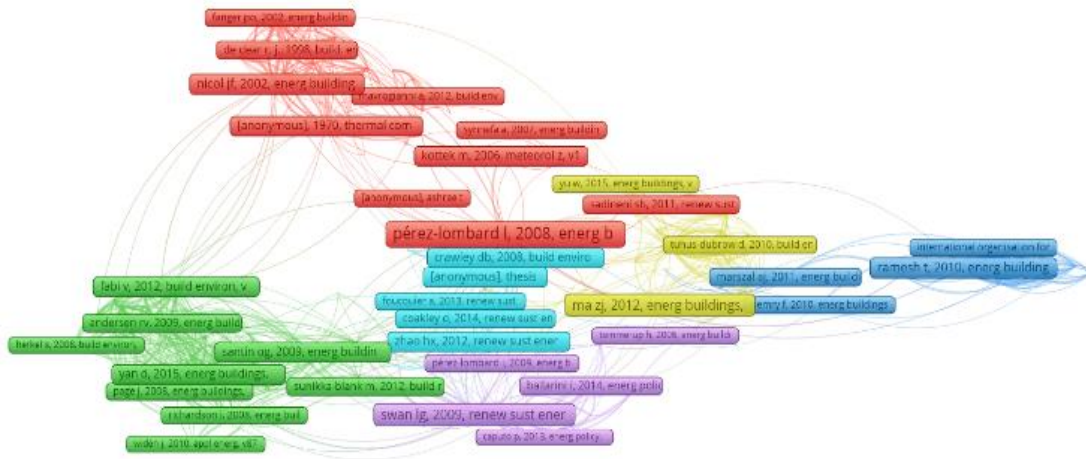


Fig. 8 Co-reference network analysis

**Table 4**  
The top 6 literature of each cluster are related to the topic.

| Colours   | Clusters | Cited papers                      | Sources                                  | Links | No. of Citations |
|-----------|----------|-----------------------------------|------------------------------------------|-------|------------------|
| Red       | (1)      | (Crawley D. <i>et al.</i> , 2001) | Energy Buildings                         | 150   | 198              |
| Green     | (2)      | (De Wilde P, 2014)                | Automation in Construction               | 138   | 128              |
| Blue      | (3)      | (Ramesh T. <i>et al.</i> , 2010)  | Energy Buildings                         | 110   | 164              |
| Yellow    | (4)      | (Ma Z. <i>et al.</i> , 2012)      | Energy Buildings                         | 130   | 210              |
| Purple    | (5)      | (Swan L. <i>et al.</i> , 2009)    | Renewable and Sustainable Energy Reviews | 138   | 220              |
| Turquoise | (6)      | (Crawley D. <i>et al.</i> , 2008) | Building and Environment                 | 141   | 162              |

4.2.2 Co-reference network analysis

The scholarly interests are often unveiled through citations (Horkoff *et al.*, 2015). The co-reference network is depicted through an analysis of co-citations among cited references in the field of energy retrofit and climate adaptive design of dwellings in the hot, arid climate. The minimum number of citations of a cited reference has been set at 50. Moreover, as a result, 174 out of 269,455 cited references exceed the threshold. For each of these 174 cited references, the total strength of co-citation links with other cited references can be calculated. At the same time, the total link strength of nodes reflects the weight of citations for a specific reference. A total of 6 clusters have been identified, the total link strength is 28611, and the co-reference networks analysis is presented in Figure 8.

The top 6 classic literature of each cluster and related to the topic have been listed in Table 4. Moreover, it can be noticed that these six articles were published after 2000 and in the top journals. Thus, indications reveal that the literature on energy retrofit of dwellings in hot, arid climates frequently witnesses noteworthy and innovative discoveries within specific time intervals.

4.2.3 Co-authorship visualisation analysis

VOSviewer enables the authors and their collaboration networks to be identified. Figure 9 analyses a co-authorship visualisation developed for authors between 2012 and 2023. There are 159 authors and 18 co-authorship clusters with different circle colours and sizes. Li B. is the principal author; his publications are concentrated between 2012 and 2023. In addition, Li, Hong T., and Lin B. are among the most collaborated authors between 2014 and 2023. Those three authors appeared as 1st, 4th, and 9th in the analysed scientific papers. It is worth highlighting the contribution of research in

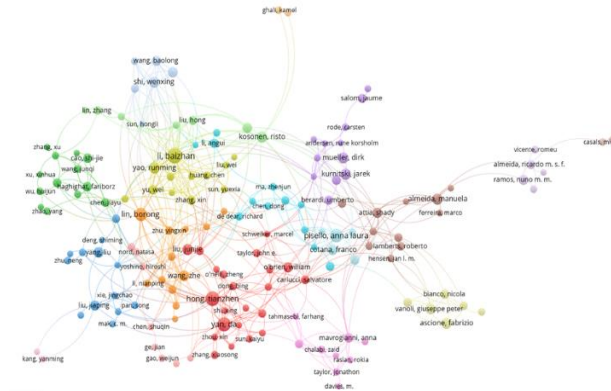


Fig. 9 Co-authorship network and author collaborations (minimum number of documents of an author is 10 publications and minimum 5 citations)

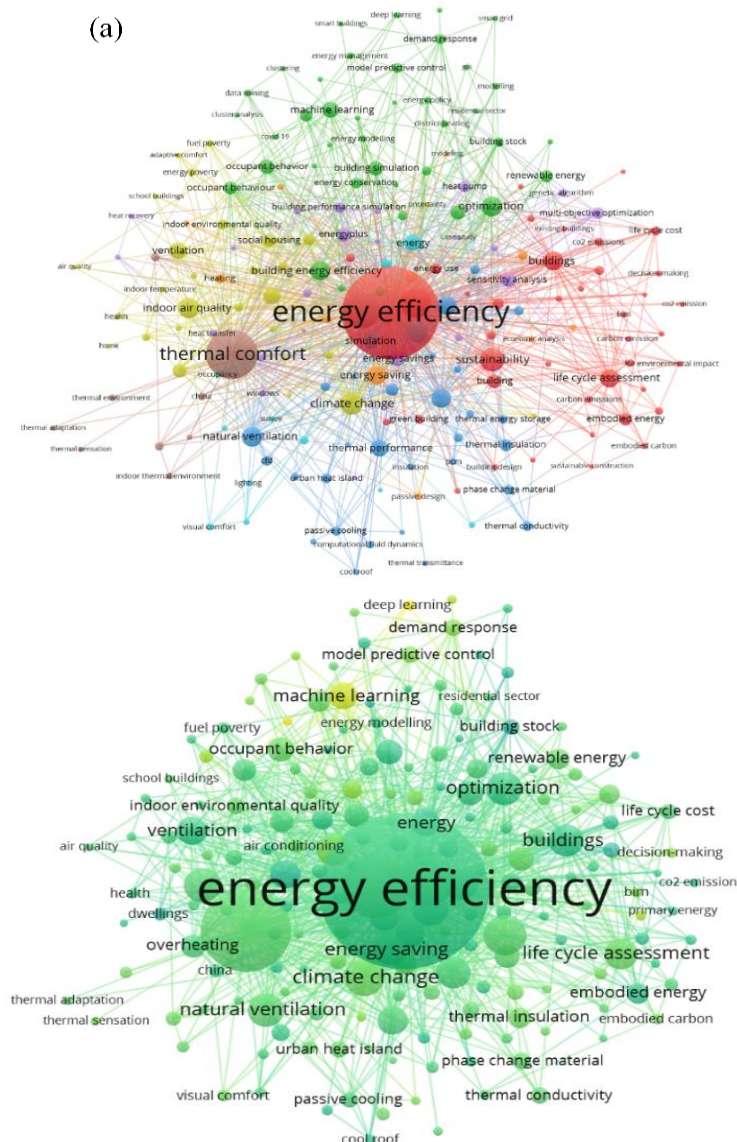
different clusters, showing the existence of collaborative networks between authors. For instance, it is observed that Li made contributions in 7 different groups, 26 links, 50 documents, and generated a connection node. As well as Hong T. is connected to 6 groups through 44 documents and 24 links with different authors. At the same time, Lin B. contributed to 9 groups, 21 links through 35 documents.

4.3 Collaborative Network Analysis

4.3.1 Author Keywords Co-Occurrence and Frequency Analysis

Keyword co-occurrence analysis in VOSviewer is used to explore and visualise the relationships between keywords provided by authors in academic publications between 2012





**Table 5**  
The top 25 keywords with the most robust citation bursts from 2012 to 2023

| keywords             | Year | Strength     | Begin | End  | 2012-2013 |
|----------------------|------|--------------|-------|------|-----------|
| Energy Efficiency    | 2012 | <b>63.23</b> | 2012  | 2015 |           |
| Machine Learning     | 2019 | <b>19.13</b> | 2021  | 2023 |           |
| Building Stock       | 2012 | <b>19.03</b> | 2012  | 2016 |           |
| Social Housing       | 2015 | <b>14.59</b> | 2015  | 2019 |           |
| Building Simulation  | 2012 | <b>14.54</b> | 2015  | 2017 |           |
| Energy Use           | 2012 | <b>13.72</b> | 2012  | 2014 |           |
| UK                   | 2014 | <b>12.41</b> | 2016  | 2019 |           |
| Energy Simulation    | 2014 | <b>12.2</b>  | 2014  | 2017 |           |
| Occupancy            | 2019 | <b>11.95</b> | 2019  | 2020 |           |
| Building Performance | 2012 | <b>11.87</b> | 2017  | 2019 |           |
| Gap                  | 2016 | <b>11.54</b> | 2018  | 2019 |           |
| Neural Network       | 2021 | <b>11.05</b> | 2021  | 2023 |           |
| Energy retrofit      | 2015 | <b>10.82</b> | 2015  | 2017 |           |
| HM                   | 2016 | <b>10.71</b> | 2016  | 2019 |           |
| Performance Gap      | 2017 | <b>10.7</b>  | 2017  | 2018 |           |
| Classification       | 2021 | <b>10.62</b> | 2021  | 2023 |           |
| Energy Savings       | 2013 | <b>10.35</b> | 2013  | 2015 |           |
| Thermal Mass         | 2012 | <b>9.75</b>  | 2012  | 2014 |           |
| Coatings             | 2014 | <b>9.6</b>   | 2014  | 2016 |           |
| Energy Saving        | 2012 | <b>9.48</b>  | 2012  | 2015 |           |
| Life Cycle Energy    | 2017 | <b>9.17</b>  | 2017  | 2018 |           |
| Heat Island          | 2015 | <b>9.16</b>  | 2015  | 2016 |           |
| Demand Side Manage.  | 2019 | <b>8.96</b>  | 2019  | 2020 |           |
| Deep Learning        | 2021 | <b>8.62</b>  | 2021  | 2023 |           |
| Energy               | 2012 | <b>8.59</b>  | 2012  | 2014 |           |

cluster in purple (Figure 10a, middle central, cluster 5, 22 items) included keywords related to “integrated energy-efficiency strategies,” such as energy savings, building energy modelling, daylighting, multi-objective optimization, etc. Another cluster in Turquoise (Figure 10a, cluster 6, 13 items) comprised keywords like building materials, lighting, occupancy, residential, visual comfort, etc., which are more concerned with “Environment Analysis.” The last two clusters, orange (cluster 7, 11 items) and brown (cluster 8, 10 items) in the middle-left part of Figure 10a, gathered keywords like economic energy, energy renovation, energy saving, energy simulation, heating, cooling, passive design, etc., which are mainly concerning “energy management.” The eighth cluster contains keywords like adaptive thermal comfort, thermal adaption, thermal comfort, thermal sensation, etc., and is related to “adaptive thermal comfort.”

In Figure 10b, overlay visualisation has been used to visually represent how nodes are spread across a network, offering insights into scopes of low and high activity (VOSviewer, 2023). and the colours represent the time-varying keyword occurrences from 2012 (in dark purple) to 2022 (in yellow). Almost in each energy efficiency and retrofit research sub-field, a set of frequent or interesting words has been found. Some of them are related to the energy sector, such as energy consumption, energy use, energy conservation, energy demand, energy storage, energy simulation, energy performance, energy modelling, energy savings, energy renovation, etc. Other keywords include sustainable building, building envelope, building performance, indoor environment, and more.

4.3.2 The frequencies of keyword appearances over time (Burst detection)

The burst detection in CiteSpace is utilised to analyse research trends and frontier changes. Therefore, citation bursts for the keywords indicate a sudden surge in citations for some of these keywords within a time frame, signifying the emergence of a new concept during a pivotal year (Kenekayoro, 2020). Table (5) shows the 25 keywords with the most robust citation bursts in energy retrofit, energy efficiency, and climate-adaptive

design between 2012-2023. The strength of each burst is quantified, and blue and red segments represent the timeline. The blue lines represent the time interval of one year, while the red lines represent the time of keyword bursts.

The keyword “energy efficiency” was one of the earliest outbreaks in 2012, with the highest burst strength value of 63.23, lasting four years. It appeared in the same year with “building simulation,” “energy use,” “building performance,” ‘thermal mass,” and “energy saving.” Then, “machine learning” had suddenly been on fire for the last three years with neural network and deep learning.

4.4 Renewable Energy Technologies for Energy Production

There are numerous technologies to produce renewable energy, such as, solar energy which is commonly used in the residential sector as source of electricity via rooftop solar panels. Therefore, they can reduce electricity cost and carbon footprint by generating clean energy. Another technology is wind turbines which can be installed on properties with sufficient wind resources to generate electricity for home use. While Biomass energy system can provide an eco-friendly and fossil fuels alternative source for heating and electricity generation as it uses organic materials like wood and agricultural waste.

One more technology for efficient heating and cooling with reducing energy consumption is Geothermal energy. Geothermal heat pumps can be installed in dwellings to utilise the stable temperatures below the earth's surface for efficient heating and cooling. This technology significantly reduces energy consumption and provides consistent indoor climate control year-round (Adhikari et al, 2024; Sotnyk et al, 2023; IRENA, 2020)

4.5 Content Analysis of the Selected Articles

Content analysis is an essential part of bibliometric analysis that helps examine the published literature's qualitative aspects and provides a more comprehensive understanding of the energy retrofit and climate adaptive design of dwellings in the hot, arid climate. Therefore, the 33 most cited and related publications between 2012 and 2023 are listed and analysed in this section. The ten most cited publications are reviews published in energy and buildings journals and between 2013-2018, as shown in Table 6. These publications are critically analysed to give general information and descriptions of the topics.

The ten documents are categorised to make the process more effective and ensure the content analysis is evaluated accurately and meaningfully. The development related to the field according to the purpose/status of the problem, the used methods, the findings/outcomes, and conclusions are the evaluation criteria for the content of the studies based on the citation number ranking of the publications as seen in table (7).

The following summarised four topics are primarily covered in the most highly cited works about building science and sustainable design, energy flows and efficiency in buildings, and what these topics can achieve, as shown in Figure (11)

4.5.1 Energy efficiency

Addressing the complex challenges of energy shortages, carbon emissions, and environmental threats requires a comprehensive approach to the energy efficiency of buildings. The impact of global climate change on the energy consumption of buildings, mainly for space heating and cooling, emphasises the urgency of advances in building envelopes and ventilation systems (Cao *et al.*, 2016). Proposed passive cooling systems are

**Table 6**  
The top ten cited publications during 2012-2023.

| Authors                      | Publication Year | Article Title                                                                                                                       | Source Title             | Document Type | Times Cited |
|------------------------------|------------------|-------------------------------------------------------------------------------------------------------------------------------------|--------------------------|---------------|-------------|
| (Cao, <i>et al</i> )         | 2016             | Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade | Energy and Buildings     | Article       | 735         |
| (Yan, <i>et al</i> )         | 2015             | Occupant behavior modeling for building performance simulation: Current state and future challenges                                 | Energy and Buildings     | Article       | 614         |
| (Rupp, <i>et al</i> )        | 2015             | A review of human thermal comfort in the built environment                                                                          | Energy and Buildings     | Review        | 528         |
| (Wang, <i>et al</i> )        | 2018             | Individual difference in thermal comfort: A literature review                                                                       | Building and Environment | Review        | 338         |
| (Hong, <i>et al</i> )        | 2017             | Ten questions concerning occupant behaviour in buildings: The big picture                                                           | Building and Environment | Article       | 335         |
| (Rhee, <i>et al</i> )        | 2015             | A 50-year review of basic and applied research in radiant heating and cooling systems for the built environment                     | Building and Environment | Review        | 308         |
| (Santamouris, <i>et al</i> ) | 2013             | Passive cooling dissipation techniques for buildings and other structures: The state of the art                                     | Energy and Buildings     | Review        | 295         |
| (Vilches, <i>et al</i> )     | 2017             | Life cycle assessment (LCA) of building refurbishment: A literature review                                                          | Energy and Buildings     | Review        | 260         |
| (Yoshino, <i>et al</i> )     | 2017             | IEA EBC annex 53: Total energy use in buildings Analysis and evaluation methods                                                     | Energy and Buildings     | Article       | 254         |
| (Chastas, <i>et al</i> )     | 2016             | Embodied energy in residential buildings-towards the nearly zero energy building: A. literature review                              | Building and Environment | Review        | 240         |

characterised by high efficiency and exceptional environmental quality and offer promising solutions for the future (Santamouris *et al.*, 2013). Bertoldi (2022) discussed the requirement for policies that emphasise the conservation and sufficiency of energy alongside conventional energy efficiency policies. However, the researchers Wang and Chen (2014) mentioned that the projections suggest that by the 2080s, rising temperatures in certain cities could compromise the effectiveness of natural ventilation. Future scenarios highlight the importance of energy-efficient buildings and emphasise the selection of low embodied energy building materials and optimisation approaches for heating/cooling systems. Life Cycle Assessment (L.C.A.) is a powerful tool for eco-design and contributes to impact reduction (Asdrubali *et al.*, 2013). On the road to Zero Energy Buildings (Z.E.B.), (Belussi *et al.*, 2019) indicated a complex web of factors to manage, influenced by the intricate relationship between buildings, environment, and climate. Achieving ZEB goals requires overcoming various challenges, such as differences in legislation, economic feasibility, and climate impact. Over the last 50 years, European policies have been taken to improve energy security, equity, and environmental sustainability to promote competitiveness, as described by (Economidou *et al.*, 2020). A focus on applying nearly Zero Energy Buildings (nZEB) in Southern Europe highlights the technical and societal challenges, accompanied by recommendations on how to turn the identified gaps into opportunities for climate-adaptive high-performance buildings. Furthermore, He (2019) analysed the relationship between the impact of the Urban Heat Island (UHI) and the performance of Green Buildings (GB), and this analysis emphasizes the urgency of incorporating UHI mitigation techniques into existing G.B. systems. On the other hand, according to the environmental impact of the building industry, Norouzi *et al.* (2021) emphasised Circular Economy (C.E.) to enhance sustainability, energy efficiency, life cycle assessment, renewable energy, and recycling. The building sector fits the circular economy concept, emphasising resource reduction, reuse, and recycling. It has been demonstrated that retrofitting existing residential buildings is economical and ecologically beneficial and is in line with the circular economy's principles. The collective efforts

outlined in these diverse perspectives underscore the need for a holistic and collaborative approach to ensure the future development of climate-adaptive/resilient and energy-efficient buildings.

4.5.2 Thermal comfort

Occupant behaviour emerges as a critical factor in building performance, introducing uncertainties that have significant implications for energy efficiency and occupant comfort (Hong *et al.*, 2017; Yan *et al.*, 2015). Despite the acknowledged impact of occupant behaviour, Hong *et al.* (2017) mentioned that it is often oversimplified in building life cycle assessments, resulting in performance gaps between simulated models and actual energy consumption. The influence of personal and environmental variables on thermal comfort, encompassing factors like age, weight, gender, controls, layout, air movement, and humidity, underscores the intricate nature of occupant behaviour, as stated by Rupp *et al.* (2015).

To address individual differences in thermal comfort, Wang *et al.* (2018) focused in their research on the proposed paradigm shift from centralised to personalised air conditioning systems, involving the collection of individual physiological and psychological responses. Machine learning algorithms are then employed to predict individual comfort, leading to the development of Personalised Comfort Systems. Moreover, Rhee and Kim (2015) reviewed the constant development and enhancement of Radiant Heating and Cooling (R.H.C.) systems that aim to boost energy efficiency and thermal comfort. Zhang *et al.* (2018) confirmed how understanding specific occupant behaviours affecting indoor thermal comforts, such as window opening, lighting control, and space heating/cooling behaviours, is essential for a comprehensive perspective on building energy consumption. On the other hand, Li *et al.* (2021) stated that an interdisciplinary approach is crucial, leading to the formulation of a new comprehensive framework named "environment-people-building" that delves into the mechanisms between internal factors under dual perspectives. Additionally, (Arumugam *et al.*, 2022) discussed that incorporating Phase

**Table 7**

The content analysis of the top ten cited publications (Cao *et al*, 2016; Yan *et al*, 2015; Rupp *et al*, 2015; Wang *et al*, 2018; Hong *et al*, 2016; Rhee *et al*, 2015; Santamouris *et al*, 2013; Vilches, *et al*, 2017; Yoshino, *et al*, 2017; Chastas, *et al*, 2016) respectively

| Article Title                                                                                                                       | Purpose/Status of problem                                                                                                                           | Methods                                                                                                         | Findings/Outcomes                                                                                                                                                                                                            | Conclusions                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade | -A brief overview of:<br>-Building energy-consumption situations,<br>-Relevant energy-saving approaches<br>-The influence of global climate change. | -Literature review<br>technologies for ZEB<br>-Similarities and differences between the U.S., China, and the EU | -Effect of climate change on building envelope and ventilation (especially space heating and cooling)                                                                                                                        | -Dominance of space heating and water heating in total building energy use in the studied regions<br>-Fossil fuels constitute the most significant portion of global building energy use.<br>-To enhance Z.E.B. performance, cost-optimal integration, control, and scheduling strategies are essential for hybrid energy systems.<br>-34% decrease in global residential heating demand and a 72% increase in cooling demand in the next century. |
| Occupant Behavior Modeling for Building Performance Simulation: Current State and Future Challenges                                 | -Discuss current research, challenges, and future directions in modelling occupant behaviour for building simulation tools.                         | -Literature review<br>-Observational studies<br>-Surveys and interviews<br>-Laboratory studies.                 | -Propose new research areas to advance occupant behaviour modelling and simulation.                                                                                                                                          | -Emphasise the importance of increased rigor in experimental methodologies.<br>-Promote thorough detailed, honest, and candid reporting of methods and outcomes.<br>-Highlight the significance of creating effective methods to implement occupant behaviour models.                                                                                                                                                                              |
| A review of human thermal comfort in the built environment                                                                          | -Review the literature on human thermal comfort in the built environment.                                                                           | -Literature review<br>-Experiments<br>-Field studies                                                            | -The factors that influence the sensation of thermal comfort<br>-The use of personalised conditioning systems                                                                                                                | -Studies on thermal comfort in connection to multidisciplinary research are lacking.<br>-Enhanced comprehension of thermal comfort to address the needs of energy-efficient buildings and climate change.                                                                                                                                                                                                                                          |
| Individual difference in thermal comfort: A literature review                                                                       | -Examine the magnitude and significance of individual differences in the preferred/neutral/comfort temperature                                      | -Literature review<br>-Climate chamber experiment<br>-Field study                                               | -Categories of individual difference are 1. significant difference, 2. insignificant difference, 3. weak difference, and significance not reported                                                                           | -Causal factors for individual differences<br>- A paradigm shift from centralised to personalised air conditioning; the three steps for this shift are:<br>1. Collecting individual physiological and psychological response<br>2.Predict individual comfort with machine learning algorithms<br>3.Accommodating individual differences with Personalised Comfort Systems.                                                                         |
| Ten questions concerning occupant behaviour in buildings: The big picture                                                           | -Highlighting some of the most critical issues regarding concepts, applications, and methodologies in occupant behaviour research.                  | -Literature review<br>-Questions                                                                                | -Information on occupant behaviour for current academics, designers, and policymakers and in the future<br>-Encourage innovative research and applications to boost energy efficiency and reduce building energy consumption | -The interaction of occupants with the indoor environment in the search for a personal comfortable condition<br>-Research on occupant behaviour should be integrated during the design, operation, and retrofitting phases to achieve the goal of low-energy or zero-net-energy buildings.<br>-Occupant behaviour affects a building's energy efficiency                                                                                           |
| A 50-year review of basic and applied research in radiant heating and cooling systems for the built environment.                    | -Find out the research trend, discover the main issues of the R.H.C. system                                                                         | -Literature review                                                                                              | -The RHC system has undergone continuous development, modification, and refinement to improve thermal comfort and energy efficiency.                                                                                         | -The R.H.C. system has been proven to be an effective way to increase thermal comfort and energy efficiency.<br>-Future studies are required to overcome the limitations of the R.H.C. system for extending its application to various building types and climates and exploring further potentials for energy saving and a healthy environment.                                                                                                   |



**Table 8 (Cont'd)**

The content analysis of the top ten cited publications (Cao *et al*, 2016; Yan *et al*, 2015; Rupp *et al*, 2015; Wang *et al*, 2018; Hong *et al*, 2016; Rhee *et al*, 2015; Santamouris *et al*, 2013; Vilches, et al, 2017; Yoshino, *et al*, 2017; Chastas, *et al*, 2016) respectively

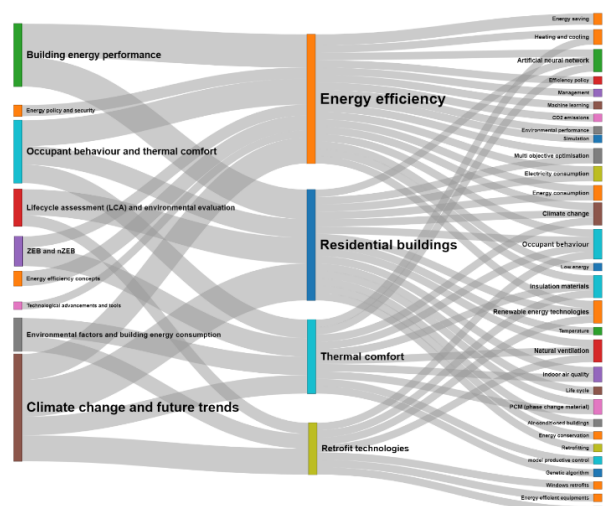
| Article Title                                                                                         | Purpose/Status of problem                                                                                                                                                                                                                                                                                                                                                                           | Methods                                                                                                                                                          | Findings/Outcomes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Conclusions                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Passive cooling dissipation techniques for buildings and other structures: The state-of-the-art       | -Review the recent technologies for passive cooling dissipation techniques in the built environment and their contribution to improving indoor environmental quality and reducing cooling needs.                                                                                                                                                                                                    | -Literature review<br>-Example of applications                                                                                                                   | -The role of passive cooling in the urban environment<br>-Earth cooling techniques and applications<br>-Ventilative cooling techniques and applications<br>-The role of evaporative cooling as a heat dissipation technique for buildings<br>-The strengths and limitations of the use of passive cooling as a heat dissipation technique                                                                                                                                                                                            | -The proposed passive cooling systems demonstrate high efficiency and excellent environmental quality.<br>-Further research to optimise the existing systems and develop new ones.                                                                                                                                                                                                                                    |
| Life cycle assessment (LCA) of building refurbishment: A literature review                            | -The current contributions of the lifecycle assessment (LCA) methodology's application to the environmental assessment of building renovation and refurbishment                                                                                                                                                                                                                                     | -Literature review                                                                                                                                               | -The manufacturing and use phases are the most frequently studied life cycle stages.<br>-The most considered impact categories are global warming potential and embodied energy.                                                                                                                                                                                                                                                                                                                                                     | -Most LCAs focus on energy refurbishment and compare the environmental impacts before and after refurbishment. However, few L.C.A.s study the environmental impact of building system reparations, such as structure or finishing.<br>-It discusses the main barriers found for dissemination, such as end-of-life stage definition, and so on                                                                        |
| IEA EBC annex 53: Total energy use in buildings Analysis and evaluation methods                       | -The primary barrier is a lack of knowledge about the factors influencing energy usage in buildings, particularly the role of human behaviour, with further research in this area.                                                                                                                                                                                                                  | -Case studies<br>-state-of-the-art<br>-Online data collection systems and technologies (from Finland, China, Japan, Germany, and Spain)<br>-Statistical analysis | -The outcomes from Annex 53 improved understanding and enhanced knowledge of the robust prediction of building energy usage, allowing for the accurate assessment of energy-saving strategies, policies, and techniques.                                                                                                                                                                                                                                                                                                             | -The interdisciplinary approach employed in Annex 53 has improved understanding and knowledge regarding predicting total energy use in buildings.                                                                                                                                                                                                                                                                     |
| Embodied energy in residential buildings-towards the nearly zero energy building: A literature review | -Review of the Life Cycle Energy Analysis (LCEA) of residential buildings, addressing challenges in comparability and the need for further standardisation.<br>-Identification of an underestimation of embodied energy in case studies using process analysis compared to hybrid analysis<br>-Highlighting the increasing share of embodied energy in low energy and nearly zero energy buildings. | -Literature review<br>-Case studies                                                                                                                              | -Transitioning from conventional to passive, low energy, and nearly zero energy buildings results in an increased share of embodied energy, despite an overall reduction in total life cycle energy (up to 50%).<br>-Dominance of embodied energy is observed in low energy and nearly zero energy buildings<br>-In passive buildings, the share of embodied energy varies between 11% and 33%<br>-The use of renewable energy sources in passive houses aligns them with the embodied energy range of nearly zero energy buildings. | -Providing a revised definition of nearly zero energy buildings (nZEB) based on current trends and energy efficiency regulations.<br>-Analysing and discussing issues of comparability, uncertainty, and the importance of reuse, recovery, and recycling potential in LCEA results<br>-Highlighting a significant gap in the share of embodied energy between the nearly zero and the most energy-efficient building |

ventilation in buildings significantly reduces energy demands. The selection of an appropriate technique is contingent upon factors like building type, location, weather patterns, and ventilation potential, with a recommendation to analyse feasibility for thermal performance and cost benefits throughout the year. Lastly, Yao *et al*. (2022) reviewed various approaches, including the heat balance approach, adaptive regression-based model, and adaptive heat balance approach, recognised as mainstays in predicting thermal comfort. Therefore, these perspectives and strategies contribute to a more cohesive

understanding of the interplay between occupant behaviour, building design, and energy efficiency.

4.5.3 Residential buildings

In the context of residential buildings, dwellings, and urban households, space heating and cooling emerge as significant energy consumers in China (as an example), where urban residential buildings exhibit lower energy consumption than developed countries. This disparity can be attributed to factors



**Fig. 11** Sankey diagram illustrates most topics are primarily covered in highly cited works.

such as smaller family sizes, traditional lifestyles, and distinct energy usage behaviours, as stated by (Hu *et al.*, 2017). To address this, there is a call to optimise the passive design of newly built residential buildings in China's hot summer and cold winter regions. This optimisation aims to enhance indoor thermal comfort while simultaneously reducing building energy demand, providing a clear framework for achieving both objectives (Goe *et al.*, 2018). The need for changes in energy end-users' behaviour and lifestyle are emphasised as a complement to energy efficiency technologies in achieving additional energy savings. Arumugam *et al.* (2022) further delve into the broader concept of energy savings compared to energy efficiency, introducing the notion of energy sufficiency, and exploring various policy instruments such as personal carbon allowances, energy/carbon taxation, and progressive building codes that can contribute to energy conservation and sufficiency.

Additionally, Deng *et al.* (2023) provided an analysis of occupancy patterns in residential buildings, revealing temporal changes, with shifts in duration and location of occupancy influenced by factors like age, education level, and employment status. These findings provide valuable insights into the evolving dynamics of occupancy patterns and their potential impacts on energy consumption in residential buildings. So, these approaches can diminish carbon and greenhouse gas emissions, offering new possibilities for energy-saving strategies and optimizing energy efficiency in the residential sector.

4.5.4 Retrofit technologies:

Various studies have explored energy retrofit measures in the context of multi-family residential and non-residential buildings, aiming to reduce energy consumption during the operational phase. While single-family studies predominantly concentrated on national or Passive House standards, as mentioned by (Vilches *et al.*, 2017). Thus, future climate uncertainty is an essential factor affecting the ideal values of building energy retrofit measures. Substantive polyurethane foam insulation and the passive home infiltration requirement are advised for long-term future climate circumstances.

Future climatic uncertainties do not affect the ideal values of glazing materials, horizontal shading projection factors, or window-to-wall ratio, as stated by (Liu *et al.*, 2023). In pursuing energy efficiency improvement at the city scale, a tool named AutoBPS (Automated Building Performance Simulation) has been introduced by (Deng *et al.*, 2023) for urban building energy modelling. This tool calculates energy demands and assesses

the potential of energy retrofit and rooftop photovoltaic measures. Results indicate that window upgrades prove most effective for residential buildings, while lighting upgrades stand out for commercial buildings. In addition, they mentioned that the combined implementation of various measures could lead to an 18.5% reduction in total energy demand, and introducing photovoltaic installations further enhances savings, reaching 38.6%. Lozoya-Peral *et al.* (2023) studied energy retrofit strategies for a traditional house in a dry climate: increasing thermal insulation, improving solar control glazing, raising window size, and boosting natural ventilation with ceiling fans.

Reducing carbon emissions and global warming requires enhancing the energy efficiency of existing residential buildings. As previously mentioned, numerous international studies have demonstrated that retrofitting efficiently reduces building energy usage.

5. Conclusions and Recommendations

5.1 Conclusions

In this research, the bibliometric analysis is performed as an effective tool to fulfil the most intended objectives, such as filling the gap in this kind of review in the existing literature and presenting a systematic overview of the main actions and methods implemented energy retrofitting and climate adaptive design of dwellings.

An overview of previous studies on energy retrofitting, efficiency, and climate adaptive design of residential buildings/ dwellings/ houses in hot, arid climates is provided. The research results are evaluated based on 10,140 publications extracted from the WoS database to perform the bibliometric analysis using VOSviewer and CiteSpace software packages. Thus, the paper provides a broad and comprehensive insight into the development of global studies in residential energy retrofit and efficiency issues, emphasises the importance of authors, countries, and institutions' contributions and current trends in the field of architecture, engineering construction building technology, energy fuel, and urban studies.

The significance of energy retrofit and efficiency of buildings (especially in the residential sector) and climate adaptive design in arid or temperate regions since 2012 is visualised and examined through a more in-depth analysis of the publications using, for example, keywords analysis and collaboration network analysis. Number of publications per year, document types, research areas, journal contributions, productive countries/regions, and authors/affiliations analysis are explained. Moreover, the 32 most cited publications from 2012 to November 2023 were discussed and summarised with more evaluation and analysis of the contents of the most cited ten according to the purpose/status of the problem, the methods used, the findings/outcomes, and conclusions. The results would contribute to advancing the field by building upon previous studies and providing new insights. They help to build upon previous research and provide new insights, which can be necessary for the progress of the discipline.

The conclusions of the paper are outlined as follows:  
O1: The first objective of the research has been achieved; during the period from 2012 to November of 2023, there was a noticeable increase during this period in the number of publications related to the topic, except for the years 2014 and 2018, which witnessed a slight decrease and increased again in the followed years. However, most of the 10,140 publications were made in the year 2021. In addition, this increased number of publications indicates the importance of the topic in the fields in which it works, as well as identifying the current trends, which is basically the aim of this research. While related to research

areas of publications, construction building technology, engineering, and energy fuel had the most research area records. So, the interconnection of these fields might be critical for addressing contemporary challenges related to sustainability, energy efficiency, and environmental impact. Other research areas of publication have been found during this study, including science technology, urban studies, environmental sciences ecology, materials science, public administration, and public environmental occupational health.

O2: More than 3000 analysed publications were published in the Energy and Building journal (the most in 2016 and 2021) because this journal's scope aligns with research interests and topics. It has been noticed that the following four journals are related to buildings and cities with good records of publications (no less than 500 publications), Impact factor, times cited, total times cited, and H-index.

O3: Regarding the most productive countries/ regions in publication, China and the USA are the top countries in the list of publications on the researched subject. At the same time, the leading contributed affiliations in the field of energy retrofit and climate adaptive design of dwellings in the hot, arid climate are Tsinghua University in China and the United States Department of Energy (D.O.E.) in USA. Between the years searched, the five most productive authors are, Li BZ. (China), Kim J. (South Korea), Pisello AL. (Italy), Hong TZ (USA) and Zhang Y (Australia). Again, Li B. is the principal co-author in the list of co-authorship analyses with 26 links and 50 documents and collaborated with 6 clusters.

According to the collaborative network analysis, co-countries/ regions and institutions analysis show that China, the USA, and England are the top three countries to collaborate, according to total link strength, documents, and citations. The institution's network analysis presents Tsinghua University (China), Chongqing University (China), and Lawrence Berkley National Lab. (U.S.A.) as the highest three in the cooperative network. In the co-referencing, the top literature of each cluster was published after 2000 and in the best journals; thus, the topic can be interesting for further examination and research.

O4: Regarding the part of keyword analysis, keywords such as energy efficiency, thermal comfort, residential buildings, energy consumption, and sustainability have the most occurrences, respectively. In addition, each cluster assigned to label based on the keywords; for example, the red cluster is named "energy efficient and sustainable buildings," the green cluster as "Building performance optimisation," the blue cluster is "comprehensive building environmental performance," the yellow cluster as "environmental health in housing," the purple cluster as "integrated energy-efficiency strategies," the Turquoise cluster as "Environment Analysis," the orange cluster as "energy management" and brown cluster as "adaptive thermal comfort." For the frequency of keyword appearances, the keyword "energy efficiency" was one of the earliest outbreaks in 2012, which lasted with the highest burst strength value for four years and appeared in the same year with "building simulation," "energy use," "building performance," "thermal mass" and "energy saving."

The theme of climate is crucial due to the current worldwide environmental challenges linked to climate change. The need for sustainable and energy-efficient buildings has increased significantly to preserve the environment and climate. Thus, towards sustainable developments, it is essential to focus on improving energy retrofit technologies, energy efficiency, saving targets, indoor thermal comfort, optimizing passive design, and minimising energy demand.

## 5.2 Recommendations and Future Remarks

As follows are some of the relevant observations from the content review of the most cited publications in WoS to answer the question of O5:

- A holistic and collaborative approach is essential for developing climate-adaptive, resilient, and energy-efficient buildings.
- Emphasising the importance of developments for ventilation systems, envelopes, passive cooling systems, low embodied energy materials, and optimisation approaches, climate-adaptive high-performance solutions to mitigate the energy consumption of buildings and, therefore, improve energy security, equity, and environmental sustainability.
- Circular Economy (C.E.) is crucial for the building industry's sustainability, emphasising resource reduction, reuse, and recycling. Retrofitting existing residential buildings aligns with circular economy principles, proving economical and ecologically beneficial.
- Occupant behaviour significantly impacts building performance, influencing energy efficiency and comfort. In addition, understanding specific behaviours, incorporating Phase Change Materials (PCM), shifting to personalized air conditioning systems, advancements in Radiant Heating and Cooling (RHC), and adopting interdisciplinary approaches contribute to reducing energy demands.
- In residential buildings, like China, space heating and cooling are major energy consumers. Many factors, such as small family sizes, duration and location of occupancy, and lifestyles, can help save and consume less energy in residential buildings and, in return, reduce carbon and greenhouse gas emissions.
- In retrofit technologies, studies have investigated energy retrofit measures for multi-family residential and non-residential buildings to reduce operational phase energy consumption.
- Glazing materials, horizontal shading projection factors, and window-to-wall ratios remain unaffected by future climatic uncertainties. Moreover, energy retrofit strategies for a traditional house in a dry climate, for example, include increasing thermal insulation, improving solar control glazing, enlarging window size, and enhancing natural ventilation with ceiling fans.
- By using AutoBPS, a tool introduced by Deng et al. (2023), facilitates urban building energy modelling, calculates energy demands, and assesses retrofit and rooftop photovoltaic measures. Results suggest that window upgrades are most effective for residential buildings, while lighting upgrades excel for commercial buildings.

Based on the presented data and research, more uncovered areas will be advantageous for further study and future research. For example, the financial aspect consistently imposes constraints on ambitious decision-making. Therefore, evaluating cost-benefit analysis and long-term performance for retrofitting plans is crucial. This kind of evaluation helps identify the most economically efficient methods for enhancing the energy efficiency of residential buildings in regions with hot climates.

Future studies could explore the thermal characteristics of vernacular and traditional dwellings because vernacular architecture is fundamentally climate responsive. Residents in these dwellings may experience lower comfort demands and satisfaction levels compared to the urban areas. Thus, simple

interventions could significantly enhance the thermal comfort of occupants in such dwellings.

Moreover, one of the essential contributors in the building sector is the non-residential buildings (which are the buildings that do not serve as dwellings, such as educational, public, or office buildings, or have less than half of their total floor space designated for residential purposes). Non-residential buildings vary in functions and occupants; thus, they may need strategies, policies, and design methods that differ from those used with residential buildings. Moreover, architects focus more on the occupants' thermal comfort, work performance, and energy consumption in these buildings. The principles of climate-responsive and passive design can be extended to non-residential buildings to enhance occupant's thermal comfort and decrease energy demand for heating, cooling, and lighting.

In addition to the above, supplemental research may explore additional retrofit measures or various combinations of measures to attain more substantial energy savings and improvements in thermal comfort. The research could also concentrate on evaluating the effects of these retrofit measures on indoor air quality and the health of occupants. It is also recommended that further investigation, evaluation, and comprehensive analysis be conducted to explore the contributions of authors focused on this research field in their publications in different academic research databases rather than WoS, such as Scopus, and different languages.

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