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Global publication trends and hotspots of building energy simulation based on bibliometric analysis: 1982-2022

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Abstract

Buildings have a significant impact on climate change through their resource and energy consumption. This paper focuses on the importance of building energy simulation in reducing energy consumption and enhancing building sustainability. The study followed a systematic research plan, which involved extracting, preprocessing, and categorizing citation data from Scopus covering the period from 1982 to 2022. Utilizing the PRISMA Algorithm, a total of 3,049 studies were analyzed. The research objectives included descriptive, network, and quantitative content analysis. The study successfully identified influential documents, authors, journals, organizations, and countries. Additionally, scientific maps were created to visualize the research landscape and identify gaps in the field. The analysis of studies identifies emerging research areas like artificial neural networks, NZEB, genetic algorithms, machine learning, and retrofitting, which hold potential for future research.

Keywords: building energy simulation, bibliometric analysis, thematic mapping, citation analysis, Scopus, vosviewer

2020 MSC: 74G65, 94C60

1 Introduction

Climate change is a pressing global concern. Buildings contribute significantly to environmental impacts through their extensive use of natural resources and energy consumption [81]. The construction industry was responsible for 36% of global energy consumption and 39% of carbon emissions in 2018, according to the IEA [114]. Building energy consumption can be categorized into embodied energy, which includes the energy used in material production, transportation, construction, maintenance, reconstruction, and demolition, and operational energy, which is the energy used for heating, cooling, lighting, and operating appliances [42, 43, 41]. To address this issue, researchers are developing energy simulation models for buildings [38]. Energy simulation models have become crucial for predicting a building's operational energy and improving the design process to reduce energy consumption [71]. In short, energy simulation models in the building are prognosis and law-driven. However, building energy simulation models use a set of rules to forecast the system's actions [32]. There are different approaches to energy modeling, including the

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White, Grey, and Black Box methods, each with its advantages and disadvantages [74, 97, 67]. Several organizations, such as IBPSA, ASHRAE, and IEA, have established energy simulation standards for buildings. Additionally, there are various simulation and modeling programs available, each with its strengths and weaknesses. Building energy simulation techniques have been developed since the 1960s, with programs like BLAST, DOE-2, and Energy Plus playing significant roles in advancing the field [35, 34]. Other programs and plugins, such as BSIM, DEST, Ecotect, Equest, HAP, HEED, TRACE, TRYNSYS, Grasshopper with Honeybees, MR-Comfy, Tortuga, ICE Bear, Dynamo, and Generative Components, have also emerged [87].

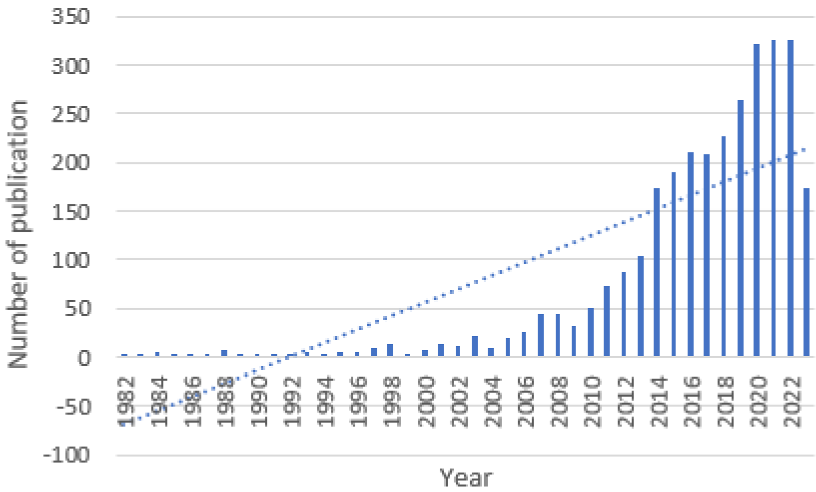

Figure 1: Evolution of the publication over the period 1982-2022 [Extracted from the Scopus citation database]

Building energy simulation literature has experienced significant growth and development in recent years. After thoroughly searching the Scopus Citation Database and using the PRISMA algorithm, we found 3049 studies on the topic from 1982 to 2022. Figure 1 displays the annual scientific production related to energy simulation in buildings. The chart shows a consistent upward trend in scientific production in building energy simulation, with minor fluctuations. The growth rate over the past 40 years has been significant, averaging 13.41%. Figure 2 illustrates that this study area is interdisciplinary, with most research conducted in engineering, energy, and environmental science. Energy simulation techniques used in buildings require accurate calculations, but there is a need for comprehensive and precise energy models [49]. Scholars have studied the verification of different energy models in building construction [46]. It is worth noting that various programming languages are utilized in energy simulation programs. Additionally, it is essential to mention some controversy surrounding validating results from different simulation programs [34]. Articles have compared energy simulation tools, highlighting their limitations and the need to enhance their "Architect Friendly" capabilities [17, 58]. A unified standard for evaluating energy simulation programs across different tools is also lacking, and requirements for these tools are still debated [16]. Greater precision and resolution are needed in simulation programs to implement Thermal Comfort Theory [90], and accuracy testing for PCM is essential [106]. Occupant behavior is a challenging factor in building energy simulation, and differences between predicted and actual energy performance are often attributed to it [18, 57]. Occupant behavior can lead to a 50% increase in heat, and efforts have been made to define occupant behavior in energy simulation programs [7]. Meteorological data, significant input parameters in simulation programs, can be inaccurate and vary each year [29]. Solutions such as calibration have been proposed to improve the accuracy of energy simulation programs in predicting actual energy consumption [30, 121]. Calibrated simulation involves adjusting program inputs in a building to ensure more reliable results [8].

Several review studies have examined various aspects of energy simulation in buildings, including sensitivity analysis methods [109], matching simulation models with measured data [32] modeling energy systems in buildings [49], building sustainability through BIM [116], occupants' behavior impact on energy consumption [39], radiant heating and cooling systems [98], building energy estimation [46], and convective heat transfer coefficient models in simulation programs [76]. However, a comprehensive bibliometric review is still needed. A bibliometric review is necessary due to the vast amount of knowledge, diverse study results, citations, and varying impact factors of journals across different

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phase Change Materials

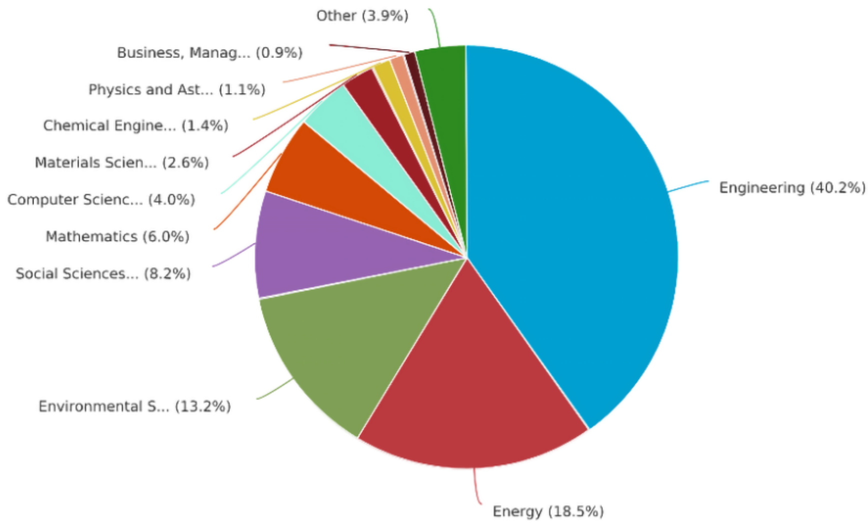

Figure 2: Subject area of documents [Extracted from the Scopus citation database]

geographical locations. The bibliometric approach has become increasingly popular in architectural and construction research; This is evident through various examples, such as the bibliometric review of green buildings [66], BIM [19, 68], building life cycle\cite [21], embodied energy in buildings [56], and the review of zero energy buildings [82].

The upcoming bibliometric review will examine various aspects of energy simulation in buildings through descriptive and network analysis, as well as quantitative content analysis.

The review utilizes the Scopus citation database to advance scientific knowledge in the field. It starts by introducing the research field and discussing the relevant literature. Then, a systematic and step-by-step methodological section is presented, employing a bibliometric approach [120]. This approach consists of seven steps. The results are objectively analyzed to enhance understanding of each research question. Finally, the review highlights the research's strengths and weaknesses, providing relevant suggestions for improvement.

2 Methodology

The review of literature is an essential aspect of scientific research [110]. A systematic literature review is an effective way to analyze past research and better understand a particular field [20]. Through a systematic literature review, the bibliometric analysis aims to provide an overview of previous studies [69]. The bibliometric method is quantitative and issued from philosophical conventions and positivist paradigms [40, 33]. Bibliometrics is a dependable and precise technique for systematically exploring and analyzing vast citation data. This approach has recently gained popularity thanks to advancements in bibliometric software and scientific citation databases [44]. We utilize statistical tools and theoretical diagrams to analyze citation data and draw meaningful insights [62]. Scholars use bibliometrics to control their research, identify gaps in their knowledge, and generate new research ideas [44].

This study uses a systematic review methodology, following the phases shown in Figure **??** [78] as a protocol [112].

2.1 Problem statement and field of study

The literature review was conducted using the "Publish or Perish" software [83], collecting the top scientific documents. Firstly, the accumulation of knowledge in the field of energy simulation in buildings is observed. Additionally, there is a need for a comprehensive bibliometric study, which motivated the researcher to conduct this study.

2.2 Determination of research objectives

The bibliometric method provides an approach to expressing qualitative features [123]. According to Moradi, the Researcher has categorized the objectives of this study into descriptive, analytical network, and quantitative content analysis [78].

2.2.1 Descriptive objectives

Descriptive objectives include identifying the most influential:

- Authors
- Journals
- Institutions or universities
- Countries

2.2.2 Analytical networking objectives

Analytical networking objectives include identifying the most effective:

- Co-citation patterns
- Bibliographic coupling patterns
- Countries' collaboration patterns

2.2.3 The quantitative content analysis objective

The content analysis objective includes identifying:

- The most frequent keywords

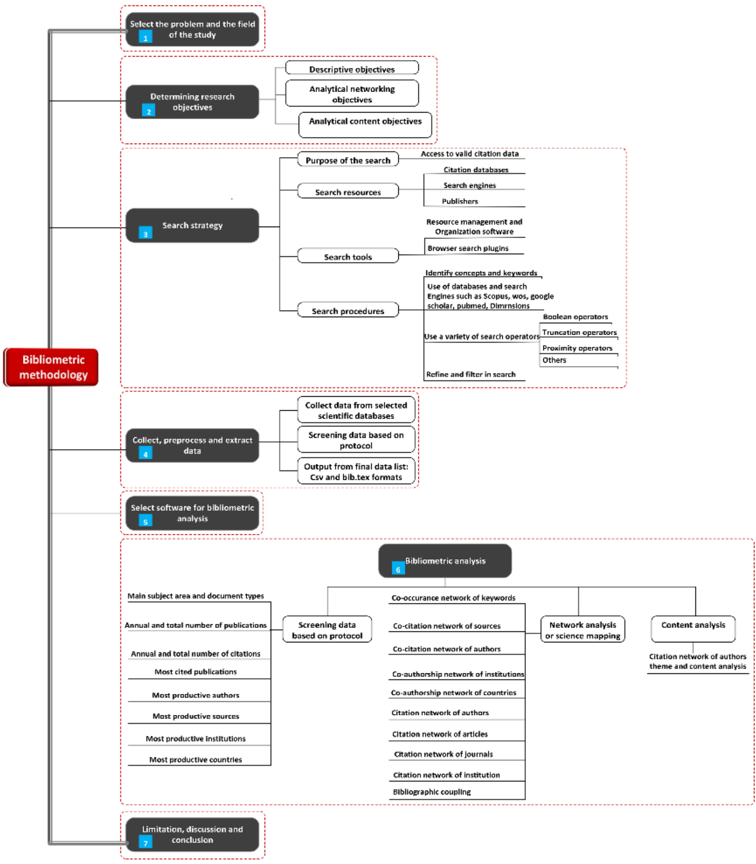

Figure 3: Bibliometric methodology [78]

2.3 Search for citation data

The WOS and Scopus citation databases are highly regarded sources for collecting citation data. While there is some overlap between the two, Scopus covers a broader range of content than WOS [93]. Scopus, introduced to the information market by Elsevier in November 2004, is officially known as Sciverse Scopus [28]. Therefore, given the better coverage and better quality for bibliometrics, the researcher extracted 3081 studies from the Scopus citation database on June 30, 2023. See Table 1 for more details.

Table 1: Search for citation data [Source: Collected by the authors]

Items	Description
Citation Database	Scopus
Keywords	Energy simulation, energy performance simulation, building, construction.
Search fields in libraries	Title, Abstract, Keywords
Search Script	TITLE-ABS-KEY (("energy simulation*" OR "energy performance simulation*") AND (building OR construction)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBSTAGE, "final"))
Citation type	Journal and Review Articles
Search Date	1982-2023
Language	Refers to All (English Citation Sections)

2.4 Collect, pre-process, and extraction of data

A systematic review should be based on a protocol that describes the logic, hypothesis, and programmed methods [77]. The researcher uses the PRISMA protocol as high-quality guidance [2] updated in 2020 [85]. Based on the PRISMA protocol checklist, duplicate and irrelevant studies, non-English titles, abstracts, and keywords are removed from the list of studies. Figure 4 shows more details.

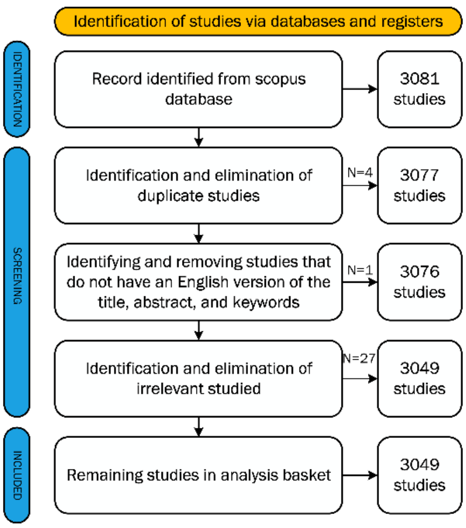

Figure 4: The contract selection of studies based on the developed PRISMA protocol [85]

2.5 Select software for bibliometric analysis

To conduct bibliometric studies, it is crucial to choose the right software. Some commonly used software include Bibexcel, Biblioshiny, Bibliomaps, CiteSpace, Citnetexplore, SciMat, SciTool, and VosViewer [79]. This study used Publish or Perish software to assess valid literature. To screen citation data, we followed the standard PRISMA protocol using Excel. We employed Bibliometrix software in R for performance analysis and VosViewer for network analysis. Table 2 shows more details.

Table 2: Information of selected bibliometric software [Source: Collected by the authors]

Tools	Analyzed version	Year	Developer	Operative system	User interface
Publish or perish	8.6.4198.8332	2022	Anne-Wil Harzing	Win	Desktop
Excel	2304	2019	Microsoft Corporation	win	Desktop
Biblioshiny	4.0	2023	The University of Naples Federico II(Italy)	win	Web
Vos viewer	1.6.18	2022	Leiden University (The Netherlands)	Win	Desktop

2.6 Examining the results

At this stage, following the research objectives mentioned in 2.2, the researcher will analyze the descriptive analysis, analytical networking analysis, and quantitative content analysis.

2.7 Discussion and conclusion

Based on the results, the main research questions are answered. Additionally, the limitations are stated, and the strengths and weaknesses are examined. Finally, the implications and suggestions for future research in the field are provided.

3 Result

Phase 6 of the Research Methodology, as shown in Figure 3, involves the researcher conducting a descriptive, network, and quantitative content analysis. Firstly, a general analysis of documents is conducted. Then the rest of the results are presented.

3.1 Overall information of extracted data

Table 3: Overall information of extracted data [Extracted from the R software]

MAIN INFORMATION ABOUT DATA	
Timespan	1982:2023
Sources (Journals, Books, etc)	396
Documents	3049
Annual Growth Rate %	13.41
Document Average Age	6.55
Average citations per doc	31.37
References	106685
DOCUMENT CONTENTS	
Keywords Plus (ID)	10924
Author's Keywords (DE)	6739
AUTHORS	
Authors	6437
Authors of single-authored docs	151
AUTHORS COLLABORATION	
Single-authored docs	176
Co-Authors per Doc	3.58
International co-authorships %	25.39
DOCUMENT TYPES	
article	2931
review	118

Table 3 shows that energy simulation in buildings has experienced an annual growth rate of 13.41% over 40 years. The 3049 records were published in 396 scientific journals and have been cited in other studies 106685 times. Most 96% of the studies were journal articles, with only 4% being review articles. Of these records, 5.8% were written by single authors, while co-authors wrote 94.2%. About 25.39% of the records were produced through international collaboration, with an average collaboration rate of 3.58. A total of 2873 records were published through collaboration with other researchers.

3.2 Descriptive Analysis of Documents and Authors

The top 10 documents in building energy simulation are prioritized based on their quality index according to more citations in Table 4. The article of Crawley and his colleagues in 2001, which has received the most citations, introduces Energy Plus Simulation Software. He explains that this program is a combination of two DOE-2 and BLAST software that are based on their strengths. Also, this document compared the features and capabilities of 3 software. In short, one of the most important benefits of this software over other energy simulation software is:

- Remove BLAST and DOE-2's inherent restrictions by presenting a new structure in Energy Plus;
- The capability of integrated simulation and balance in heat transfer and mass combination and multi-zone airflow and simulation of plants;
- User-friendly, faster analysis power and expansion [35]

In 2008, Crawley and his colleagues published a second widely cited document. The document compares 20 common and primary tools for energy simulation in buildings. The authors' purpose is to promote using a set of tools that cater to a wide range of energy simulation needs. However, the document notes that there is no shared language between this software and that the accuracy of the models is questionable in some instances []. According to research, Tian's 2013 article is highly regarded in energy performance analysis in buildings, with 560 citations and ranked third. The study investigates sensitivity analysis methods, specifically Global and Local methods, for analyzing energy performance. Four regression approaches based on screening and meta-variance are introduced for the Global method, with each method being chosen based on objectives, computing costs, energy models, number of inputs, and time.

Table 4: Top 10 most globally cited documents [Extracted from the R software]

Paper	**DOI**	**Title**	**Total Citations**	**SO**
CRAWLEY DB, 2001	10.1016/S0378-7788(00)00114-6	EnergyPlus: creating a new-generation building energy simulation program [35]	1740	Energy and buildings
CRAWLEY DB, 2008	10.1016/j.buildenv.2006.10.027	Contrasting the capabilities of building energy performance simulation programs []	1138	Building and environment
WEI T, 2013	10.1016/j.rser.2012.12.014	A review of sensitivity analysis methods in building energy analysis [109]	9	Sustainable energy reviews
CRAWLEY DB, 2000		Energy Plus: energy simulation program [36]	580	Ashrae journal
COAKLEY D, 2014	10.1016/j.rser.2014.05.007	A review of methods to match building energy simulation models to measured data [32]	554	Sustainable energy reviews
PAGE J, 2008	10.1016/j.enbuild.2007.01.018	A generalized stochastic model for the simulation of occupant presence [86]	519	Energy and buildings
SAILOR DJ, 2008	10.1016/j.enbuild.2008.02.001	A green roof model for building energy simulation programs [101]	500	Energy and buildings
RATTI C, 2005	10.1016/j.enbuild.2004.10.010	Energy consumption and urban texture [96]	426	Energy and buildings
HARISH VSKV, 2016	10.1016/j.rser.2015.12.040	A review on modeling and simulation of building energy systems [49]	409	Renewable and sustainable energy reviews
WONG JKW, 2015	10.1016/j.autcon.2015.06.003	Enhancing environmental sustainability over building life cycles through green bim: a review [116]	383	Automation in construction

This part reviews the authors' ranking in the field. The total number of publications and the total number of citations received are crucial factors in bibliometric studies [24]. In 2005 the H-Index provided a numerical value representing a researcher's scientific output [50]. In 2006, L. Egghe proposed the G-Index as an enhancement to the H-Index [105]. Other indicators, such as the M-Index, consider the researcher's scientific life [113]. Experts consider the H-Index crucial for authors in reputable citation databases like WOS and Scopus [60]. Table 5 highlights the top 10 authors based on their publications, citations, and hybrid indicators. Ascione F. is the most influential author, with 32 scientific documents published since 2010, which have received 1678 citations. Hong T. ranked second with 29 documents and 1363 citations, while Bianca N. ranked third with 22 scientific documents and 1249 citations. It is worth mentioning that the publication index is a significant priority indicator for the authors. Table 5 indicates

NP indicator
TC indicator

that specific authors, such as Lam JC, have fewer scientific documents but receive more citations in higher ranks. In contrast, others, like Krarti M., have more publications but are ranked lower. Additionally, the number of years since the authors' first publication has been considered in prioritizing the top authors in the scientific community.

Table 5: Top 10 authors in building energy simulation field [Extracted from the R software]

Element	h_index	g_index	m_index	TC	NP	PY_start
ASCIONE F	21	32	1.5	1678	32	2010
HONG T	19	29	0.76	1363	29	1999
BIANCO N	17	22	1.417	1249	22	2012
LAM JC	15	17	0.484	1268	17	1993
LIU J	15	25	0.882	820	25	2007
SAELENS D	15	23	1.25	820	23	2012
VANOLI GP	15	21	1.154	1407	21	2011
HENSEN JLM	14	21	0.452	1532	21	1993
KRARTI M	14	24	0.519	1199	24	1997
SREBRIC J	14	15	1.167	616	15	2012

3.3 Descriptive analysis of journals and organization

In this section, the researcher emphasizes prioritizing journals and organizations that are actively involved in the field of building energy simulation. The top 10 journals in this area are listed in Table 6, ranked by the number of published documents [80].

The top scientific journal is the Journal of Energy and Buildings, publishing 658 articles. It has an impact factor of over seven and focuses on reducing building energy consumption and improving indoor environment quality. The Journal of Building and Environment is second with over 204 articles and an impact factor of over seven. It covers Building Science, Urban Physics, and Human Interaction with the Built Environment. The Journal of Energies ranks third with 184 scientific documents and covers Technology Development, Engineering, Politics, and Management.

Table 6: Top 10 most relevant sources in building energy simulation field [Extracted from the R software]

Sources	Articles
ENERGY AND BUILDINGS	641
BUILDING AND ENVIRONMENT	199
ENERGIES	175
APPLIED ENERGY	152
JOURNAL OF BUILDING ENGINEERING	103
BUILDING SIMULATION	91
ENERGY	90
SUSTAINABILITY (SWITZERLAND)	90
JOURNAL OF BUILDING PERFORMANCE SIMULATION	79
SOLAR ENERGY	66

According to Table 7, Tongji University is the leading institution in building energy simulation research. It is ranked 28th in China and 134th worldwide. The City University of Hong Kong is ranked second with 101 published scientific documents and holds a Q1 ranking according to www.scimagoir.com. The Lawrence Berkeley National Laboratory, affiliated with the University of California, is ranked third as a Q1 research and development center. It holds the 96th position in the US and 226th globally. The table highlights the remaining top seven organizations in the field of building energy simulation.

Table 7: Top 10 most relevant affiliations in building energy simulation field [Extracted from the R software]

Affiliation	Articles
CITY UNIVERSITY OF HONG KONG	101
LAWRENCE BERKELEY NATIONAL LABORATORY	99
TONGJI UNIVERSITY	98
YONSEI UNIVERSITY	86
UNIVERSITY OF NOTTINGHAM	82
NOT REPORTED	70
CONCORDIA UNIVERSITY	69
EINDHOVEN UNIVERSITY OF TECHNOLOGY	69
TSINGHUA UNIVERSITY	68
NATIONAL UNIVERSITY OF SINGAPORE	67

3.4 Descriptive analysis of countries

Building energy simulation studies in buildings are conducted in 82 countries across the five continents. Table 8 shows that the most cited countries are the US, Italy, China, the United Kingdom, and Hong Kong, spanning three continents. The US has received the highest number of citations, totaling 19313. However, Switzerland has the highest average number of citations due to its highly cited documents.

Table 8: Top 10 most cited countries in building energy simulation field [Extracted from the R software]

Country	TC	Average Article Citations
USA	14324	34.7
ITALY	10653	43.7
CHINA	6973	31.4
KOREA	3815	23.3
HONG KONG	3691	43.4
UNITED KINGDOM	3663	29.3
CANADA	2608	24.4
SWEDEN	2560	40
SWITZERLAND	1882	45.9
FRANCE	1801	33.4

3.5 Network analysis

3.5.1 Analysis of author co-citation network

Author Co-Citation Analysis is a method that counts the number of times an author's work is cited alongside another author's work in document citations. This helps to identify and analyze the intellectual structure of a particular field. It is advantageous in detecting authors who are frequently cited together in other documents [122]. The size of the nodes in the network indicates the extent to which the author has been co-cited [119]. Additionally, the relationships between the nodes illustrate how citation connections were formed among authors who share similar research interests [47]. The co-citation networks of the authors are shown in Figure 5, created using the VosViewer software.

Each author has at least 60 citations, resulting in 701 nodes of co-cited authors, forming five main clusters. Hong T. demonstrates the highest co-citation with other authors within the yellow cluster, particularly with Yan D., Chen Y., Robinson D., and O'Brien. In the blue cluster, D.B. Crawley and Chen Q. have the highest co-citation. The purple cluster is led by M. Santamouris and Hensen J.I. Li Y. and Y. Zhang are prominent in the green cluster, while F. Ascione and Krarti M. stand out in the red cluster. In Table 9, two authors were chosen as representatives for each cluster based on their significant connections and larger node sizes.

Table 9: Authors' co-citation cluster information [Source: Collected by the authors]

Cluster color	Representative authors
Yellow	hong, t- yan, d
Blue	Crawley, d.b.- chen q.
Purple	santamouris, m- hensen j.I.
Green	zhang, y- Li Y.
Red	ascione, f- krarti m.

3.5.2 Analysis of the author's bibliographic coupling network

The concept of bibliographic coupling means that two documents are connected if they both mention the same document [70].

In the Analysis of Bibliographic Coupling among authors, they are grouped based on their citations of a common author. When authors cite the same sources, they create a stronger connection, known as bibliographic coupling links [75]. The distance between nodes in a network corresponds to the content of documents. In contrast, the thickness of links indicates the level of bibliographic coupling and influence between them [92].

Figure 6 shows the authors' bibliographic coupling network. To create the network in VosViewer, each author was required to have at least two publications and fifteen citations. The network is categorized based on the relationships between nodes, consisting of 75 nodes representing authors and 13 clusters. Table 10 highlights authors with the biggest nodes and is presented as the cluster representatives.

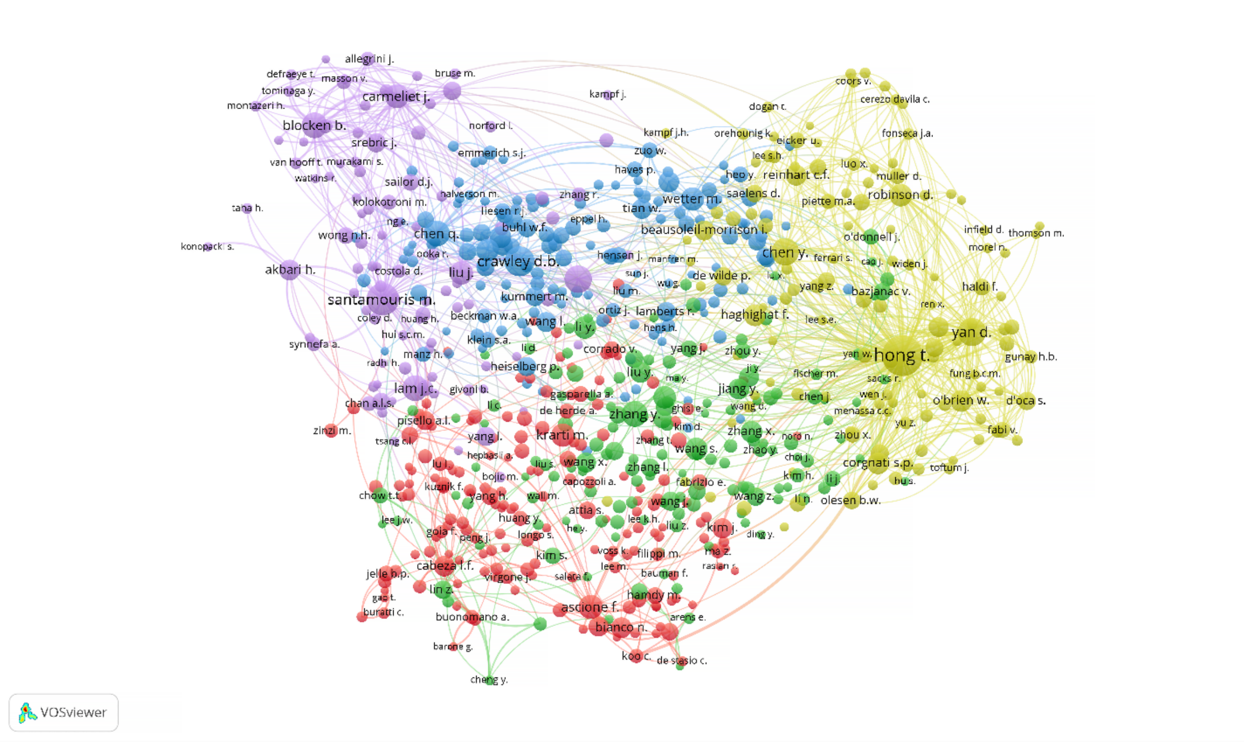

Figure 5: Co-citation of authors' network [Extracted from the Vosviewer software]

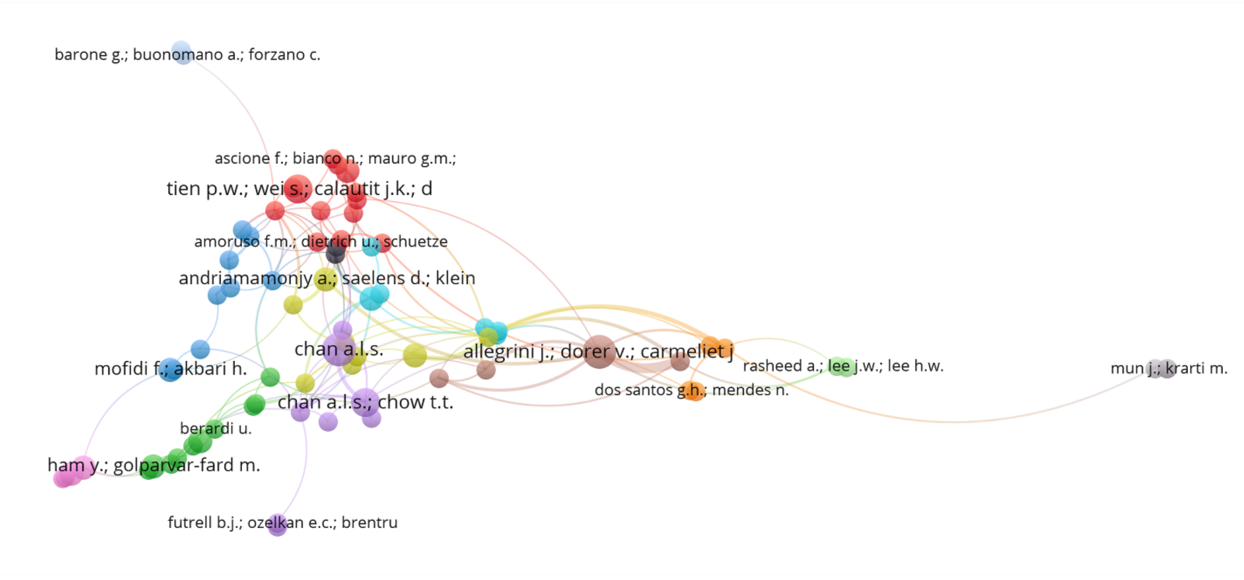

Figure 6: Bibliographic coupling of authors network [Extracted from the Vosviewer software]

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3.5.3 Countries' collaboration network

Figure 8 displays the International Cooperation of Countries (MCP) and Intra Country Collaboration (SCP). Table 11 shows the top ten most corresponding authors' countries. The US ranks highest on the table with MCP= 69 and SCP= 354, indicating significant collaboration with other countries in this area. Figure 7 shows that American researchers have collaborated the most with researchers from China, England, Italy, and South Korea. Table 11 reveals that Hong Kong, England, China, and Belgium have a higher international cooperation rate than other countries, as

Table 10: Authors' bibliographic coupling cluster information [Source: Collected by the authors]

Cluster color	Representative authors
Brown	allegrini j.; dorer v.; carmeliet j.
Purple	chan a.l.s.
Green	ham y.; golparvar-fard m.
Light blue	buonomano a.; calise f.; palombo a.; vicidomini m.
Blue	saffari m.; de gracia a.; ushak s.; cabeza l.f.
Light gray	park b.; Kranti m.
Red	ascione f.; bianco n.; de masi r.f.; mauro g.m.; vanoli g.p
Yellow	kamel e.; memari a.m.
Orange	laouadi a.
Black	bre f.; fachinotti v.d.
Pink	thomas a.; menassa c.c.; kamat v.r.
Light green	rasheed a.; lee j.w.; lee h.w.
Cyan	hosseini m.; bigtashi a.; lee b.

demonstrated by their MCP rate.

Table 11: Top 10 most corresponding authors' countries [Extracted from the R software]

Country	Articles	SCP	MCP	Freq	MCP_Ratio
USA	423	354	69	0.139	0.163
ITALY	256	192	64	0.084	0.25
CHINA	239	146	93	0.078	0.389
KOREA	169	121	48	0.055	0.284
UNITED KINGDOM	128	77	51	0.042	0.398
SPAIN	118	93	25	0.039	0.212
CANADA	110	90	20	0.036	0.182
HONG KONG	86	51	35	0.028	0.407
SWEDEN	65	60	5	0.021	0.077

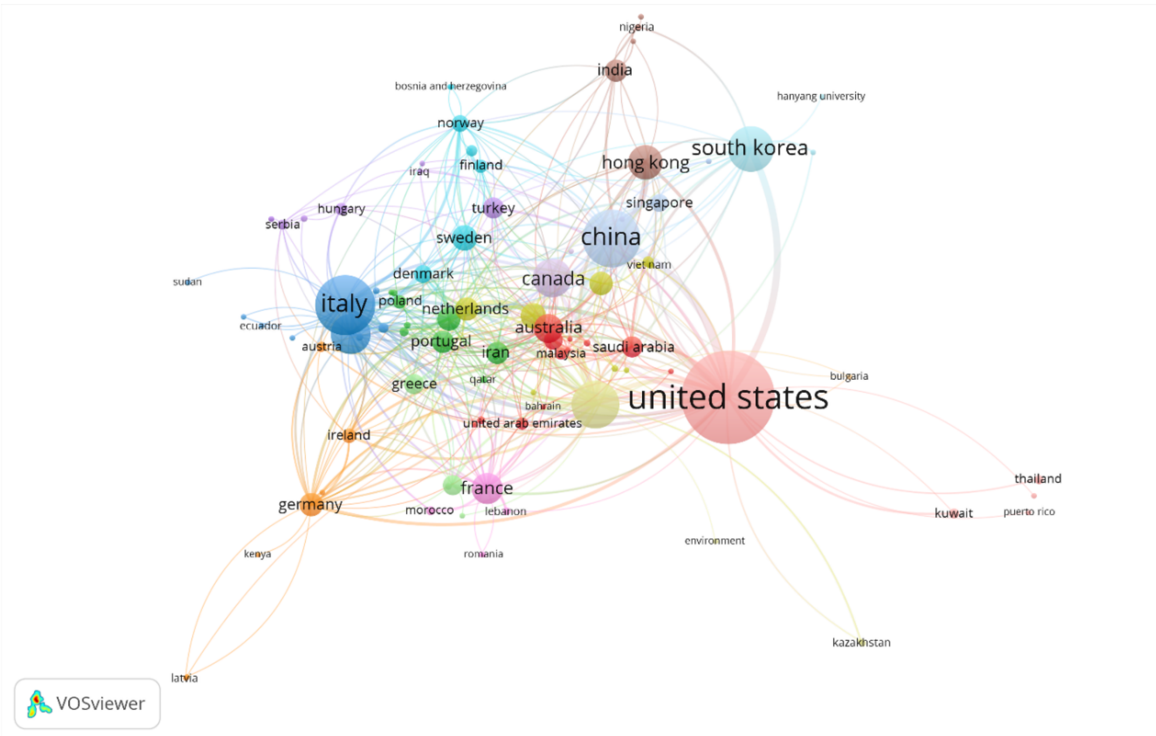

Figure 7: Countries' collaboration network [Extracted from the Vosviewer software]

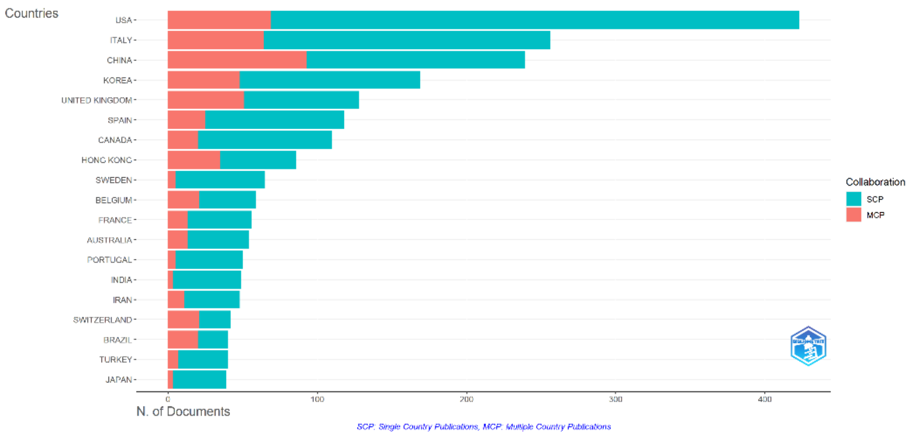

Figure 8: Corresponding author's countries [Extracted from the R software]

3.6 Quantitative content analysis of keywords

In bibliometrics, evaluation, and examination of the keywords are important for the approach [4]. To evaluate research trends and identify critical areas in this field, it is necessary to check the keywords and recognize the main domains [27]. Figure 9 is the word cloud graph that shows the 50 most frequent keywords in building energy simulation documents.

Figure 9: Wordcloud [Extracted from the R software]

The top 10 most frequently keywords are Energy efficiency ($F = 1230$), Energy utilization ($F = 1000$), Building energy simulation ($F = 807$), Buildings ($F = 788$), Energy conservation ($F = 613$), Energy simulation ($F = 521$), Architectural design ($F = 502$), Office buildings ($F = 487$), Air conditioning ($F = 457$) and Computer simulation ($F = 455$). These words are known as hot spots in studying energy simulation in building research.

4 Discussion

By 2050, with the increase in the global population, we can expect the construction of approximately 13,000 new buildings each day[79]. The simulation of energy usage in buildings is crucial for reducing environmental impacts and improving energy efficiency. Based on a bibliometric approach and analysis of 3049 studies from the Scopus citation database, this research focused on energy simulation in buildings over the past 40 years. The findings indicate that the field's scientific production is consistently expanding, and it is an interdisciplinary area of study. In particular, the high growth rate of scientific production in the last decade has emphasized three topics:

- The Importance of Studying this Field

- Researchers' Interest in Studying this Field
- The Challenging Topics in this field

Two challenging issues have been identified in the field related to energy simulation models in buildings. The first issue pertains to validating the accuracy of these models, while the second issue involves addressing discrepancies between the predicted and actual performance of occupants.

The validation of energy simulation models has received significant attention in recent studies conducted by Oraiopoulos and Howard [84], Abolhassani [1], and Prataviera [95]. These researchers have explored various approaches to validate the accuracy of energy simulation models and improve their reliability. The second issue, focusing on the discrepancies between predicted and actual performance of occupants, has also been investigated by researchers such as Panchabikesan [38] and C. Yu [118]. These studies delve into the factors contributing to the differences between predicted and actual performance and propose solutions to enhance the accuracy of building energy simulation models.

The top journals in the field are Energy and Buildings, Building and Environment, and Energies; These three journals are responsible for over 34% of all research publications. Building energy simulation is a field dominated by three leading countries: the US, Italy, and China. The US is the most internationally collaborative, cooperating with Italy, China, England, and Hong Kong. Developed countries have been at the forefront of this field for years, while underdeveloped countries continue to lag, with a smaller share of research output. It is worth noting that none of the top 10 countries in this field of study are African nations. This highlights the importance of African countries focusing more on this area of research to improve their understanding of energy simulation in buildings and to contribute to the advancement of the field.

Keywords Energy Efficiency, Energy Utilization, Building Energy Simulation, buildings, and Energy Conservation can be the hot spots in studying energy simulation in buildings. Furthermore, new subjects such as Machine Learning [55, 115] and Zero Energy Building [6, 37] have recently emerged in this field and have garnered the highest number of publications in 2020-1.

An analysis of co-citation network clusters indicates that T. Hong and D. Yan are the top authors in the yellow cluster. They have collaborated on outstanding research on occupants' behavior [53, 117, 52]. D. B. Crawley and Q. Chen examined the tools and software used in energy simulation for building design [35, 34]. M. Santamouris and Hensen J.L. have a strong connection in the purple cluster. They have highly cited studies in various fields such as green roofs [102], urban climate [103], urban heat island [104], occupant behavior [51], and uncertainly analysis [54]. Also, blocken B. and Carmeliet J. are two other authors in the purple cluster who have strong links, they have highly cited studies in the CFD field [22, 23].Y. Zhang and Z. Lin are the representative authors of the Green Cluster, who have studied in the field of sensitivity analysis [88], as well as building energy models, including calibration and gray box models [64, 65]. Finally, F. Ascione and Krarti. M has conducted studies in the field of artificial neural networks [10], artificial lighting [61], optimization [14, 15], PCM [12], green roof [13], retrofit [9], NZEB [14], and genetic-algorithm [108] within the red cluster. According to the co-citation network, it can be concluded that the yellow, blue, green, and purple clusters are larger clusters with larger nodes, and the topics extracted from them have a higher number of publications and have received more citations.

In contrast, the red cluster has smaller nodes and forms smaller clusters. This cluster represents topics such as artificial neural networks, artificial lighting, NZEB, genetic algorithms, retrofit can be considered as recent topics of interest or less explored topics.

The examination of the representatives of the authors' bibliographic coupling network clusters shows that the representatives of Clusters 1 to 13 have the following subject-oriented studies, respectively: CFD [3], photovoltaic collector [31], BIM [48], BIPVT and geothermal and solar energy [26], PCM [100, 73], energy performance analysis [89], optimization [11], BIM [59], software [63], artificial neural network [99, 25], NZEB and adaptive building simulation [107, 108], greenhouse design [94] and machine learning [55] Examining the bibliographic coupling network shows that clusters 1 to 9 are larger clusters that have larger and more nodes, and clusters 10 to 13 are smaller clusters with smaller nodes. Clusters 1 to 9 show the most important and discussed topics in the field, which include: CFD, BIM, BIPVTO, software, optimization, etc. Clusters 10 to 13 include newer and less explored topics in the field, including artificial neural networks, NZEB and adaptive building simulation, greenhouse design, and machine learning.

Computational Fluid Dynamics
Nearly Zero Energy Building
Building Information Modeling
Building Integrated Photovoltaic Thermal systems

By comparing the topics extracted from the clusters of the co-citation network and the bibliographic coupling network of the authors, it can be concluded that the following topics are the most discussed in the field of energy simulation in buildings: occupant behavior, tools, green roof, urban climate, urban heat island, uncertainty analysis, CFD, sensitivity analysis, calibration, BIM, BIPV, PCM, and optimization. On the other hand, topics such as artificial neural networks, NZEB, genetic algorithms, machine learning, and retrofit are less covered in the field and can be identified as research gaps.

Keyword analysis reveals that the term "Residential Building" appears in 191 instances, while "Office Building" appears in 487 instances. However, there is a noticeable lack of research on "Educational Building", highlighting a gap in the field. This gap calls for more research to be directed toward energy simulation in educational buildings to better understand and optimize their energy performance. While there has been a proliferation of energy simulation software programs released in recent years, it is interesting to note that most studies in the field still use Energy Plus as their primary simulation tool [72]. Investigating the frequency of keywords confirms this trend. This calls for more research into alternative energy simulation software programs to better understand their capabilities and potential benefits.

Most studies in the field have focused on developed countries, leaving a significant gap in knowledge in underdeveloped regions. Furthermore, while a quantitative approach is the most commonly used research method, only a few studies have employed a qualitative approach. Therefore, there is a need to incorporate qualitative research methods to gain a deeper understanding of the building energy simulation field. Additionally, research on energy simulation in buildings has mostly focused on urban buildings. Therefore, there is a need for stronger research on rural buildings in this field.

This study also has some limitations, including the fact that it is based solely on citation databases, specifically the Scopus Citation Database. While Scopus is a vast collection of citation data, it does not encompass all existing citation data. For future studies, it is recommended that researchers use alternative citation databases or a combination of databases to supplement their analyses. Additionally, it should be noted that the bibliometric approach used in this study is quantitative and has certain limitations [45]. Researchers are advised to use additional methods, such as qualitative content analysis or review, in combination with bibliometrics [5]. It is important to note that the analysis file used in this study only contains data from journals and review articles, while conference articles, books, and Ph.D. theses were excluded. Therefore, for future studies, researchers must have unrestricted access to citation databases that include a broader range of scholarly outputs, such as conference proceedings and dissertations. Another limitation of this study is that it only considered citation data in English. Therefore, it would be beneficial to examine research in other languages in the future to gain a more comprehensive understanding of the field.

5 Conclusion

This systematic review assesses global research on energy simulation in buildings from 1982 to 2022. The field has experienced significant growth, particularly since 2015, and encompasses multidisciplinary research conducted in various regions. The examination of studies identifies emerging topics like artificial neural networks, NZEB, genetic algorithms, machine learning, and retrofitting, which have garnered attention recently and hold potential as future research areas.

Despite its limitations, the current study effectively achieves its objectives as a review article by employing a bibliometric approach to analyze energy simulation in buildings.

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