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Energy and Water Consumption Behavior Model Based on Conservation and Efficiency on Green Building Concept: Bibliometric Analysis

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ABSTRACT

Green buildings mitigate the adverse effects of construction on the environment. Water conservation in housing is a criterion significantly affected by residents' behavior. The inhabitants' behavior influences the extent of water conservation and energy efficiency implemented in the building. This study conducts a comprehensive bibliometric analysis of the scholarly literature on water usage and energy efficiency behaviors in sustainable buildings. The study utilizes data from Scopus, spanning the years 1996 to 2024. The study identified collaborations across many institutions and countries, emphasizing significant research accomplishments. The network visualization study was performed utilizing R Studio Biblioshiny software version 4.4.1. The findings of this study offer substantial insights for academics, professionals, policymakers, and funding entities pursuing a thorough understanding of contemporary trends and goals in this domain. The findings of this study establish a significant framework for future research initiatives and highlight the necessity of ongoing investment in energy efficiency and water conservation efforts moving forward.

1. INTRODUCTION

Currently, humans are facing a very urgent environmental and energy crisis [1]. With the increasing population, the demand for natural resources, including energy, is increasing significantly [2, 3]. At the same time, the increase in the cost of living is often influenced by the increasing cost of basic necessities such as water and energy [4]. Indonesia is one of the countries that produces the most gas emissions in the world, in eighth position, with the most significant contributor of gas emissions coming from buildings [5]. The projection of Indonesia's electricity use with a population of 268,583,016 people until 2050 is estimated to be still dominated by the household sector [6]. In addition, there has been an increase in energy use and water consumption in East Java by more than 30% from 2018-2021 [7]. Optimizing energy use effectively is an important step to face the challenges of the energy and environmental crisis, as well as to increase the efficiency and sustainability of energy resource use [8]. Green buildings are the solution to reduce emissions, so the Green Building Council Indonesia (GBCI) has set a green building measurement standard called Greenship [9]. Greenship criteria for environmentally friendly homes in Indonesia consist of 6 criteria: Land Use, Energy Efficiency and Conservation, Water Conservation, Material Sources and Life Cycles, Health and Indoor Comfort, and Building Environmental Management. These criteria are to ensure that every certified home not only reduces negative impacts on the environment but also improves the quality of life of its occupants [10].

Green buildings are designed to reduce negative environmental impacts through energy efficiency, sustainable materials, or water resource management. In addition to reducing negative environmental impacts, green buildings also focus on improving the quality of life and human well-being [11]. By integrating the principles of energy efficiency, use of sustainable materials, and good water resource management, green buildings play an essential role in creating a healthier and more environmentally friendly environment and contributing to climate change mitigation and natural resource conservation [3, 12]. Previous research related to the application of Greenship to the millennial generation who live in green-concept homes shows that the lowest awareness of efficiency is in the use of clean water and electricity consumption [1, 13, 14]. These results show that although many buildings are claimed to be environmentally friendly, many of them have not achieved the expected design performance criteria [15]. The influence of human habits and behavior is often simplified and ignored in building design, construction, and operation. Several previous studies have shown that energy-conscious human behavior is a significant positive factor in improving the indoor environment while reducing energy use in buildings.

Many studies on the development of human behavior models for consuming water and energy have been conducted in buildings but are limited to buildings that are not green-concept [1, 16-19]. So, it is crucial to measure human behavior in green building residences by forming a model of occupant behavior based on water conservation and energy efficiency to evaluate the effectiveness of green-concept building performance. This research is expected to provide behavioral recommendations that support energy conversion and efficiency and recommend preferences for water and electricity sources in green building concept residences in Malang and Surabaya.

2. LITERATURE REVIEW

2.1 Energy efficiency and conservation

Energy efficiency and conservation are forms of efforts to save energy. The Government's target regarding energy efficiency in 2025, based on PP 22/2017 concerning RUEN (National Energy General Plan), is that there will be final energy savings of 17%, a decrease in energy intensity of 1% per year and energy elasticity of less than 1 [20]. One of the key pieces of information for developing energy efficiency projects is campaigning to implement green building standards (Greenship) to increase energy efficiency, especially in building structures. Water and energy consumption in building construction is a significant part of the demand for water and energy in urban areas, which is in line with population growth and increasing urbanization, but faces a drastic decline in the quantity and quality of available water [21].

Energy efficiency is defined as low energy consumption while simultaneously producing a total consumption value equal to or greater than the previous value [22]. "Energy conservation" refers to consuming less energy while simultaneously creating less energy [23]. The level of knowledge a user has regarding their energy consumption is directly proportional to the efficiency of energy consumption in buildings. Several studies have investigated how occupant behavior might influence energy consumption in buildings and evaluated how various patterns of behavior affect the quality of the interior climate and smart energy usage [24, 25]. Therefore, this study develops an occupant behavior model based on energy conservation and efficiency, such as turning on lights, opening and closing windows, and using clean water.

2.2 Occupant behavior model on building energy performance

Occupant behavior greatly influences energy conservation, especially in buildings or households using electricity, heating, cooling, and other equipment. Energy conservation can be done by reducing energy consumption in cities so that sustainable urban development is achieved [26]. Occupant behavior related to energy includes the calculation of individual and group occupants and their interactions with building energy systems, equipment, and service facilities that aim to provide a standardized description of a complete set of human behaviors related to energy, consisting of four main components [19], namely, the drivers behind occupant behavior related to energy. Occupant needs should be based on physical or non-physical satisfaction criteria, actions taken by building occupants when unmet, and systems where occupants can interact to meet their needs.

The interactions that occupants have with building systems have a substantial impact on the energy performance of the structure as well as the comfort of the occupants throughout their stay [27]. Previous research has demonstrated that enhancing the behavior of building occupants can result in potential energy savings that range from five per cent to thirty per cent of the total energy consumption. These savings can vary depending on the type of building (residential or office buildings) and the building systems (air conditioning, lighting, and equipment) [19]. To optimize building design and minimize performance gaps, occupant behavior models are created to forecast and depict human behavior in building performance simulations [21]. Therefore, occupant diversity can contribute to reducing peak energy demand. Previous studies have identified the main steps to represent an occupant behavior modelling approach [19] The first step in gathering information involves data validation, system observation, and occupant monitoring. Step two consists in creating and testing an occupant behavior model to see how well it can anticipate how people would act within the structure. Ultimately, it's all about putting the occupant behavior model into action, which means combining it with other modelling tools and applications already used for buildings.

Related to previous research that has been conducted and under the focus of ITN Malang's research, namely Green and Sustainable Technology. Measuring the behavior of the millennial generation in buying and occupying environmentally friendly housing can be done using several methods and specific indicators. This measurement process aims to understand the extent of their interests, preferences, and decisions in choosing housing that supports environmental sustainability. Previous research conducted on the millennial generation in the cities of Malang and Surabaya stated that there was still a lack of understanding of green buildings [14], so prospective consumers needed to be educated about green buildings. By increasing awareness and knowledge, the millennial generation can become more active agents of change in supporting and implementing the principles of green buildings in the future. Environmental factors also influence buying green housing because of knowledge about the importance of maintaining and preserving the environment [12, 13]. This is reinforced in further research where three factors (attitudes, subjective norms, and behavioral control) influence the millennial generation's behavior to save energy. Overall, the environment from family and friends is a catalyst that can increase the millennial generation's awareness, motivation, and involvement in energy efficiency actions in environmentally friendly homes. Thus, this suggests that collective efforts and a supportive social environment can strengthen and expand the impact of energy-saving measures [9, 28]. By understanding the factors influencing their decisions, builders, property developers, and policymakers can develop more effective strategies to encourage millennials to adopt green housing.

According to research on 200 millennials in Malang and Surabaya [9], perceived behavioral control and energy efficiency intents partially favorably influence energy efficiency behavior. This finding is relevant to resident perception and Greenship implementation's success.

Subjective norms and attitudes, together with perceived behavioral control, significantly impact millennials' intentions to be energy efficient, according to the analysis and hypothesis testing results.

This research is expected to be developed into applied research and development research in Civil Engineering, concentrating on construction project management related to energy management in green buildings based on conservation and efficiency. This research is also expected to provide a better understanding to all project stakeholders to develop green concept buildings by building a Model of Water and Energy Consumption Occupant Behavior based on conservation and energy efficiency in Green Building residences.

3. RESEARCH METHODOLOGY

This study uses the quantitative perspective of the research landscape, deploying bibliometric analysis to gain insight into the existing literature on green building energy and water usage patterns, conservation efforts, and efficiency [29]. Data cleaning and standardization preceded bibliometric analysis. To avoid redundancy, duplicate items were removed from the search results. We have also standardized data formats (author names, journal titles, etc.) for consistency. Typos and different spellings of the same name were automatically and manually corrected. They were combined to prevent the fragmented or set-apart meanings of words and phrases, as the case may be in the analysis. Beyond that, the terms were assembled into broader categories to allow ease of thematic analysis and were then graphed. A list of documents was produced by removing crucial metadata such as author names, affiliations, keywords, and references to get additional information. The last thing was that the checks on the sample data were done manually to ensure the data cleaning and standardization processes were correct. A combination of bibliometric software and manual analysis efforts was required to ensure the quality and consistency of the data before further analysis.

The data collection process involved conducting a comprehensive search of the Scopus database using a carefully crafted query: TITLE-ABS-KEY ("energy consumption" OR "water consumption" OR "consumption behavior") AND ("conservation" OR "efficiency") AND "green building") AND PUBYEAR >1995 AND PUBYEAR <2025 AND (LIMIT-TO (SRCTYPE,"j") OR LIMIT-TO (SRCTYPE,"p")). Scopus is often chosen as a source of scientific journal reference databases because of its broad coverage, covering approximately 84 million records from more than 27,000 active titles and more than 8,000 publishers worldwide in a variety of scientific fields, which is wider than the Web of Science (WoS) [30-32]. Scopus also applies high-quality standards in the indexed journals' selection and evaluation process, thus ensuring better quality and integrity of content than Google Scholar, which has a less stringent selection process [33]. In addition, Scopus provides sophisticated citation analysis, allowing researchers to track the number of article citations, researcher h-index, and journal impact metrics such as CiteScore, SNIP, and SJR, which are more comprehensive and sophisticated than Google Scholar. Scopus also periodically updates its database by adding new content and removing journals that no longer meet its quality standards, thus ensuring that the content is always up to date [34]. This search strategy ensured the retrieval of relevant documents published between 1996 and 2024, focusing on journal articles and conference proceedings, with no specific fields and other filters applied. The absence of a particular restriction on the publication date filter between 1996 and 2024 aims to ensure comprehensive coverage of the research landscape, identify long-term trends, and provide a better understanding of the progress and development of the research domain over time.

The initial search yielded a total of 1008 documents, which formed the basis for the subsequent bibliometric analysis. The potent R Studio Biblioshiny software version 4.4.1 was employed to conduct the bibliometric analysis. This tool enabled the extraction and visualization of key bibliometric indicators, providing valuable insights into the research landscape, collaboration patterns, and influential actors within the field. The analysis focused on various aspects, including the annual scientific production, most relevant institutions and countries, citation patterns, and the thematic structure of the research domain. The bibliometric analysis in this study relies on data from the Scopus database, which, despite its extensive coverage, may have some limitations. One potential limitation is excluding non-English literature, as Scopus primarily indexes English-language publications. This may result in underrepresenting research conducted and published in other languages, potentially overlooking valuable contributions and perspectives from non-English speaking researchers and regions. Additionally, while Scopus is a comprehensive database, it may not index all relevant sources, particularly those from smaller or regional journals, conference proceedings, or grey literature. This could lead to an incomplete picture of the research landscape, as some studies and findings may not be captured in the analysis. Recognizing these limitations is crucial for interpreting the results and understanding the potential gaps in the data. Future research could explore ways to incorporate non-English literature and expand the data sources to provide a more comprehensive and inclusive field analysis. By examining these indicators, the study aimed to identify the growth trajectory, leading contributors, and emerging trends in energy and water consumption behavior, conservation, and efficiency within green buildings.

4. RESULTS AND DISCUSSION

4.1 Main information data

Figure 1. Main information

This study database spans from 1996 to 2024, with 1008 documents from 516 sources, as illustrated in Figure 1. The annual growth rate of 19.15% and an average of 14.99 citations per document signify a robust and influential body of work. The 18.06% international co-authorship rate and average of 3.45 co-authors per document indicate a strong collaborative dynamic within this scientific community. These insights can assist researchers, institutions, and funding agencies in comprehending the landscape, identifying possible collaborators, and making educated decisions to advance this field of study. This study domain's consistent expansion and influence suggest it is a promising sector with the potential for transformative discoveries and inventions that may benefit society shortly.

4.2 Annual scientific document productions

Figure 2 depicts the annual scientific output from 1996 to 2024, exhibiting a consistent rising trajectory with intermittent variations. The yearly publication of papers has markedly escalated over the previous thirty years, rising from a handful in the late 1990s to around 100 in recent years. The increased scientific output is advantageous as it signifies a flourishing research community actively enhancing knowledge across diverse disciplines. This trend indicates that the scientific landscape is becoming more competitive as researchers and institutions endeavour to distinguish themselves by publishing high-quality, influential work and fostering innovation and advancement across several disciplines.

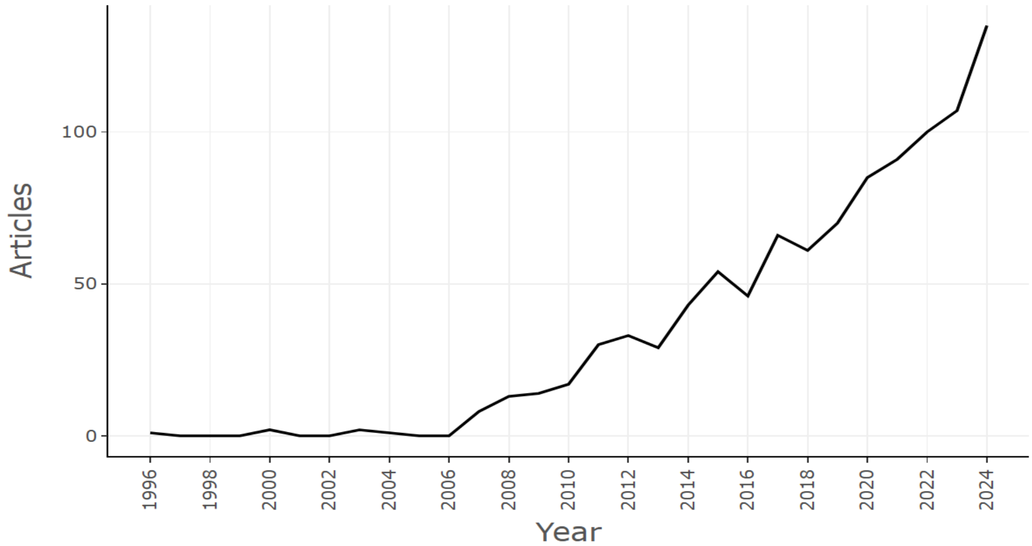

Figure 2. Annual scientific production chart

4.3 Based on institutions

Figure 3 illustrates the most significant institutions according to the volume of documents they have supplied to the research database. Energy and Buildings has 17 documents, while IOP Conferences Series: Earth and Environmental Science has 15 papers. The data demonstrates that these universities lead research in this domain, consistently publishing and disseminating their findings. This information aids researchers, students, and industry professionals aiming to collaborate with or acquire knowledge from the foremost universities in this field. This evidence suggests that these institutions will likely persist in fostering innovations and influencing future research trajectories, rendering them valuable collaborators and reservoirs of information for those engaged in this domain.

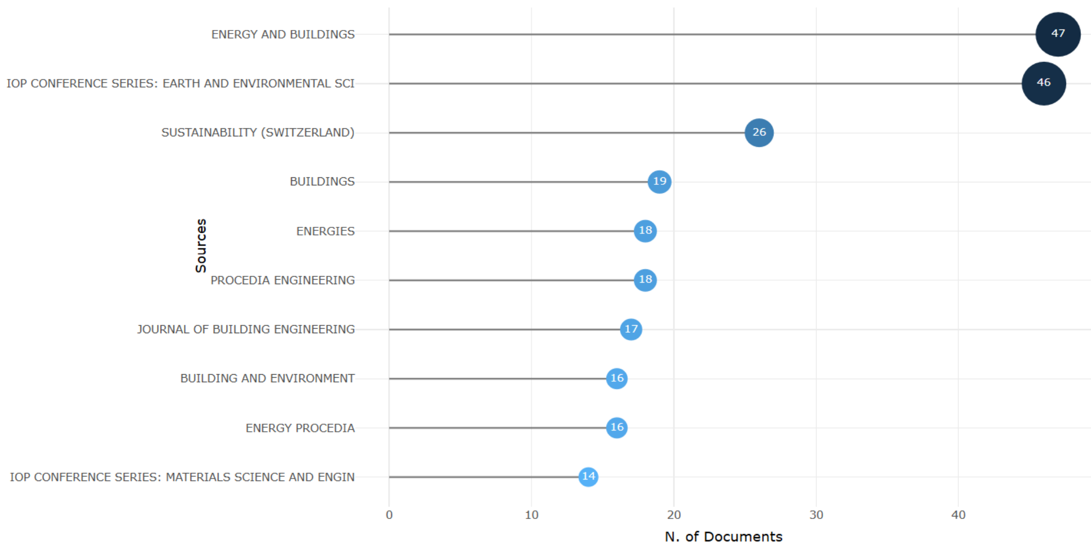

Figure 3. Most relevant affiliations graph

4.4 Based on countries

Figure 4 illustrates the countries with the highest citation counts in the research database, with China in the forefront, boasting 4206 citations. The United States and Italy have 2721 and 792 citations, respectively. This data benefits researchers by identifying the countries exerting the most substantial influence in this study area, suggesting possible collaboration and knowledge transfer hubs. This information indicates that nations with elevated citation counts are likely to be at the forefront of research, fostering innovation and establishing the agenda for future developments in this domain, rendering them appealing locations for researchers aiming to leave their imprint in the field.

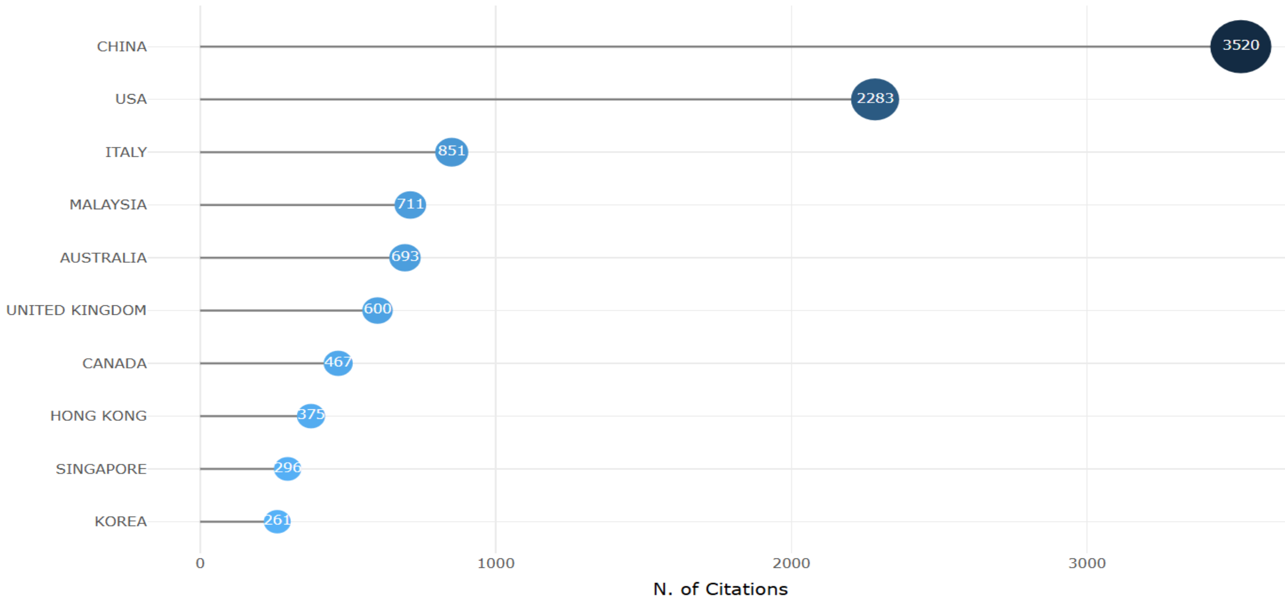

Figure 4. Most cited countries' graph

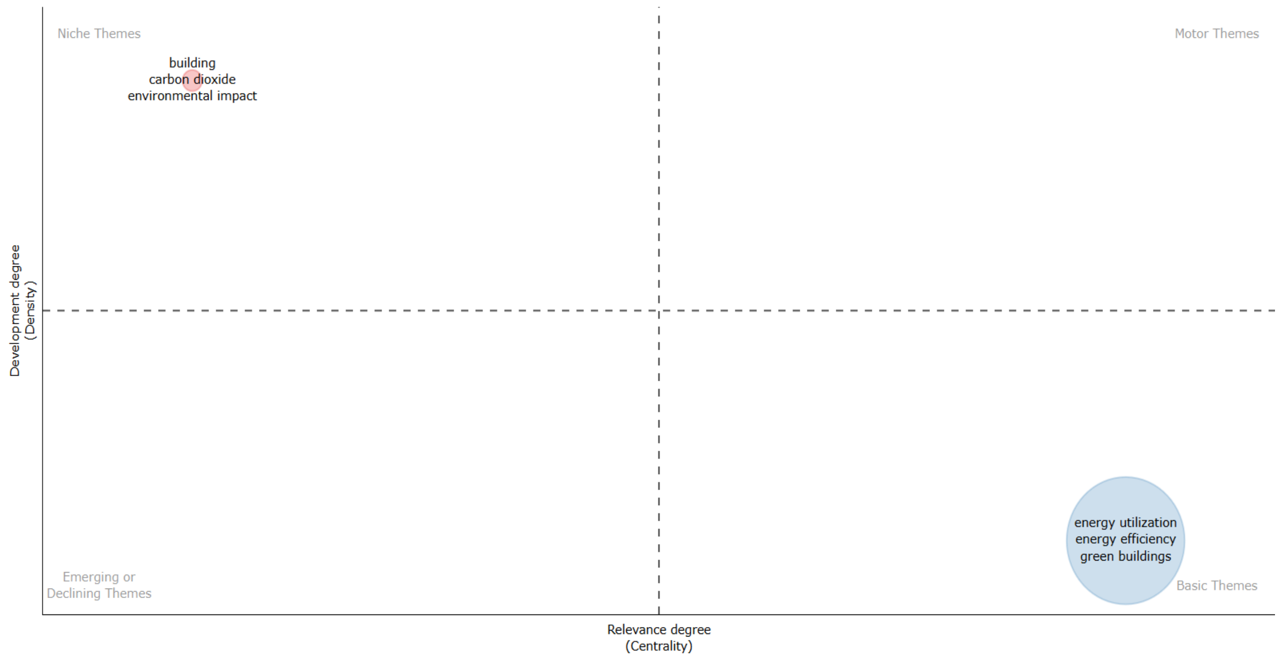

Figure 5. Thematic map

4.5 Thematic map

The thematic map visually illustrates the principal study themes inside the database, with "building" as the focal issue, as presented in Figure 5. This key theme is closely associated with notions such as "energy efficiency," "energy consumption," "thermal comfort," and "sustainable development," highlighting a significant emphasis on sustainable construction techniques and energy optimisation. This knowledge is essential for researchers as it enables them to discern the most significant and interconnected domains of study within the discipline, facilitating alignment with contemporary trends and contributions to critical concerns. This data suggests that forthcoming research will persist in examining these themes, enhancing our comprehension of sustainable construction practices and fostering innovation in energy efficiency, thermal comfort, and eco-friendly building materials, ultimately resulting in more sustainable and resilient built environments.

4.6 Word cloud

The word cloud visually represents the most prevalent terms in the study database, highlighting "energy," "buildings," "conservation," and "efficiency" as the most significant keywords, as presented in Figure 6. This depiction aids researchers by providing a swift and intuitive understanding of primary emphasis areas and trends within the discipline, facilitating the identification of potential research gaps and opportunities for additional investigation. This data indicates that the research community is significantly focused on optimizing energy consumption in buildings, fostering conservation, and enhancing overall energy efficiency. This suggests that these subjects will remain central to research initiatives in the forthcoming years, propelling advancements in sustainable building practices and technologies.

Figure 6. Word cloud

4.7 Co-Occurrence network

Figure 7 illustrates the co-occurrence network, depicting the interrelation of key phrases in the study database, with "energy utilisation," "energy efficiency," and "energy conservation" identified as central nodes. The network demonstrates robust connections across these ideas and associated phrases like "buildings," "sustainable development," and "architectural design," signifying a multidisciplinary strategy for addressing energy-related issues in the built environment. This information is essential for academics since it elucidates the intricate relationships between many facets of energy and buildings, facilitating the identification of potential synergies and collaborations across diverse disciplines. This data indicates that improving energy efficiency and conservation in buildings necessitates a comprehensive and collaborative strategy, engaging specialists from diverse fields to devise innovative solutions that will foster more sustainable and energy-efficient built environments in the future.

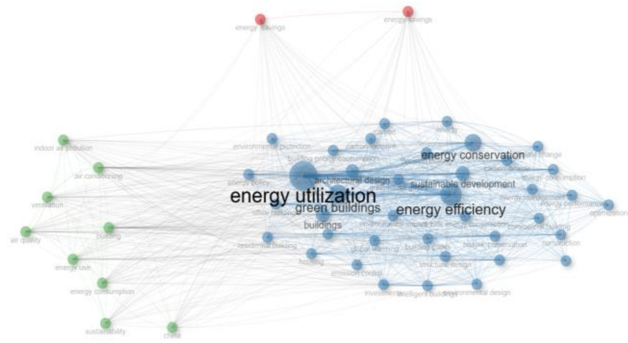

Figure 7. Word cloud

4.8 Most cited documents

According to Figure 8, which illustrates the most globally cited articles, YU W's 2015 publication in Energy Build ranks first with 352 citations, while FUMIO N's 2014 paper in Renewable Sustainable Energy Rev follows closely with 339 citations. The third most cited paper is GHAFFARIANHOSEINI A's 2013 publication in Renewable Sustainable Energy Rev, which has received 326 citations. A discernible pattern indicates that more recent publications (2015-2019) typically exhibit lower citation counts than older ones (2009-2015). This is logical, given that younger works have had insufficient time to garner citations. Publications in renewable energy and sustainability journals predominantly occupy the top ranks, underscoring the increasing significance of these disciplines in recent years. This citation analysis allows researchers and students to identify seminal works in the energy and sustainability domain that have profoundly influenced the scientific community. This data indicates that research on renewable energy and sustainable building design is becoming vital in academic discussions, reflecting a broader transition towards environmentally responsible development in the construction and energy industries.

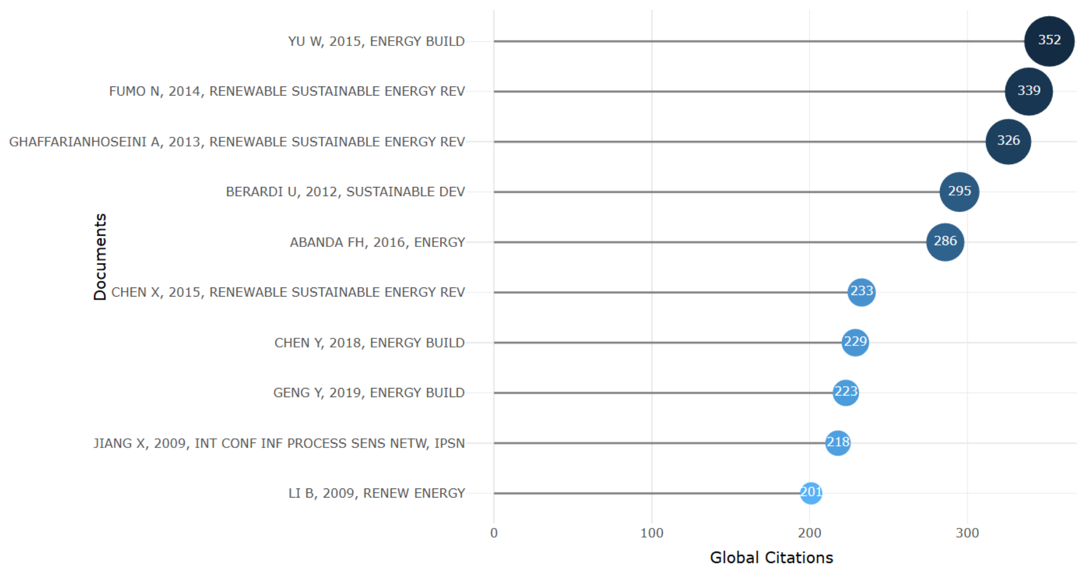

Figure 8. Most cited documents graph

4.9 Most productive author (Based on the number of publications)

Data from the most productive writers, as illustrated in Figure 9, indicates a notable discrepancy in the quantity of documents produced by the enumerated scholars. Wang Y is the most prolific author, having made 13 documents, while Li J and Liu Y have authored 8 and 7 documents, respectively. The majority of the authors have produced five or fewer documents. This information is essential for identifying the most active and potentially influential academics in the field, guiding readers, particularly novices, in researching significant literature and research trends. Nonetheless, the data underscores a possible concentration of research output among a limited number of writers, which could restrict the diversity of perspectives and methodologies within the discipline. Promoting a more equitable allocation of research contributions may cultivate a more prosperous and behavior-inclusive research environment, ultimately resulting in more thorough and innovative progress in comprehending energy and water consumption behaviors, conservation, and efficiency in sustainable buildings.

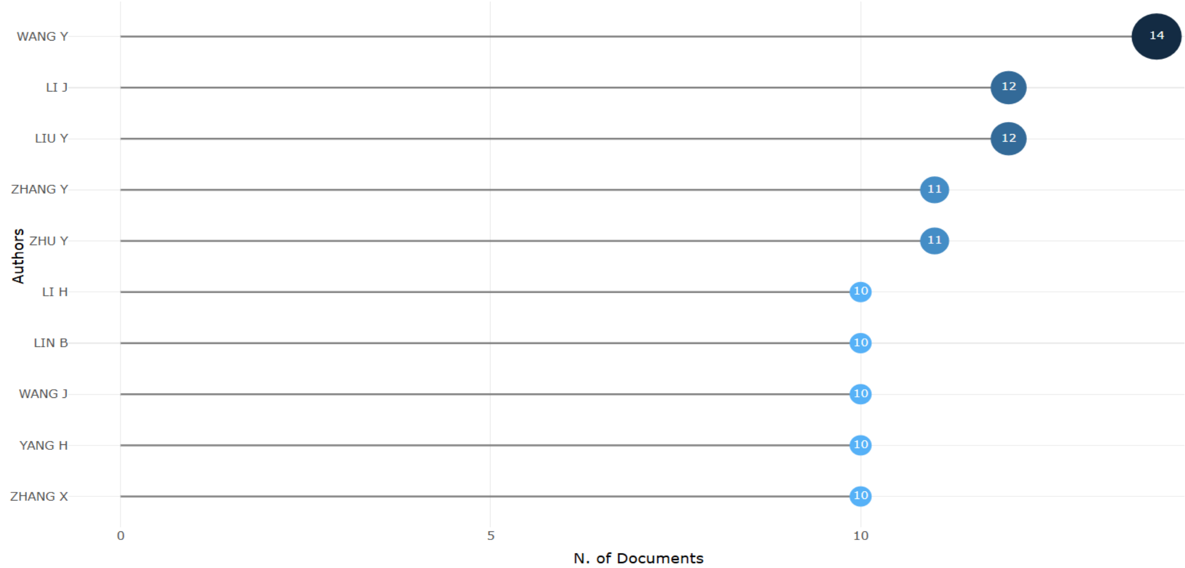

Figure 9. Most productive authors graph

4.10 Author's local impact

Figure 10 illustrates the author's h-index data, highlighting a notable discrepancy in local effect among the researchers, with Wang Y emerging as a distinct outlier, possessing an exceptional h-index of 5, signifying their considerable influence within the research community. Conversely, the majority of authors possess an h-index of 1, indicating a restricted geographical influence. This information can aid in identifying and recognizing prominent researchers, informing resource allocation and partnership choices, and emphasizing the necessity for activities that promote wider engagement and acknowledgment of various contributions. Nonetheless, it prompts significant inquiries regarding possible disparities or prejudices inside the research framework. It highlights the necessity of considering elements outside the h-index when assessing individual authors' contributions, eventually stressing the need for a more inclusive and equitable research environment that acknowledges the diverse contributions of all researchers.

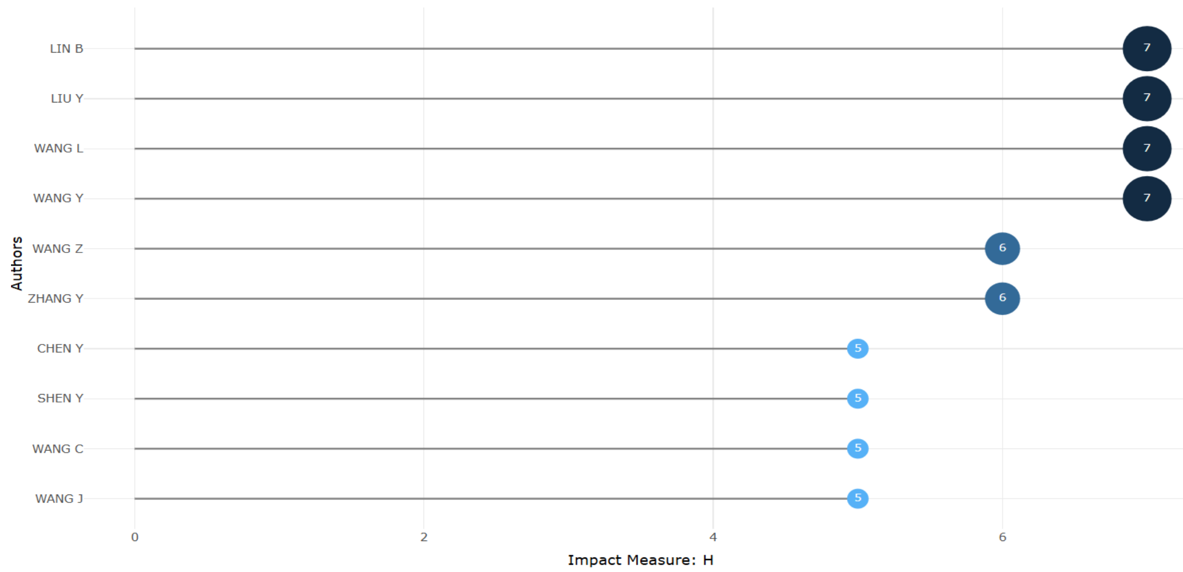

Figure 10. Author's local impact graph

4.11 Collaboration network

The collaboration network data illustrated in Figure 11 depicts a complex web of interactions among researchers, highlighting both regions of significant collaboration and potential isolation. The principal characteristic is a substantial, interconnected cluster centered on Wang Y, encompassing several researchers including Liu Y, Zhang Y, and Li Y, indicating a strong collaboration network where ideas, resources, and skills are presumably exchanged. Nonetheless, numerous smaller, isolated clusters and individual nodes dispersed throughout the network suggest that many researchers may operate independently or engage in minimal collaboration within this group. This fragmentation may result from geographic distance, disciplinary barriers, or restricted access to collaboration opportunities. Identifying these patterns can facilitate potential cooperation, knowledge sharing, and interdisciplinary research, highlighting the necessity for targeted strategies to connect disparate groups and cultivate a more cohesive and integrated research community. Neglecting to resolve these challenges may lead to lost possibilities for synergy, redundant efforts, and a decelerated rate of general advancement in the field.

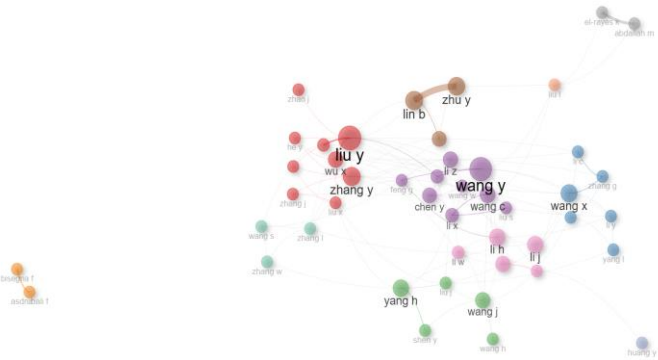

Figure 11. Collaboration network

4.12 Future research and practice

The bibliometric study's thematic map and co-occurrence network elucidate the research domain's knowledge structure, emphasizing principal themes and their interconnections. Contrasting the shown structure with expert assessments or recognized classifications in the domain may be beneficial for further validating and contextualizing these findings. The thematic map delineates "building," "energy efficiency," "energy consumption," "thermal comfort," and "sustainable development" as interrelated primary themes. Field experts may be consulted to evaluate the alignment with their comprehension of principal research domains and their interrelations. The findings may be juxtaposed with established taxonomies or classification frameworks in green building research to discern similarities, differences, or potential deficiencies. Such comparisons would contextualize the bibliometric findings within the wider research domain, offering a more thorough comprehension of the knowledge structure. Discrepancies between the visualized structure and expert assessments or established classifications may indicate the need for additional research or improvement of the bibliometric analysis. In contrast, concordance between the findings and expert opinions would bolster the validity and significance of the visualized knowledge framework.

Future research and practice in green buildings must prioritize geographically diversified studies to encompass underrepresented locations, addressing distinct challenges and opportunities in sustainable construction. Researchers ought to concentrate on uniting engineering, architecture, social sciences, and policy studies to formulate cohesive solutions for energy efficiency, thermal comfort, and sustainable development. A crucial domain for further investigation is the correlation between occupant behavior and energy performance, encompassing elements that affect behavior, the efficacy of treatments, and sophisticated modeling approaches for building simulation. Evidence-based methodologies ought to inform design and policy decisions, highlighting the necessity for collaboration between academia and industry to develop practical recommendations and instruments. Practitioners must implement user-centered solutions, emphasizing occupant comfort, well-being, and engagement while consistently utilizing input to enhance building performance. These initiatives will enhance the sustainability, efficiency, and functionality of green buildings following global climate action and resource conservation objectives.

5. CONCLUSIONS

The research environment on green building energy and water consumption behavior, conservation, and efficiency has been vibrant and influential, according to this bibliometric study of 1008 papers from 516 sources covering 1996-2024. The discipline seems to be heading in the right direction, with yearly scientific productivity, significant international collaboration, and the rise of influential institutions and nations. A multidisciplinary approach to solving energy-related difficulties in the built environment is centrally focused on sustainable construction practices, energy optimization, and the theme map, word cloud, and co-occurrence network. These findings highlight the importance of academics, institutions, and governments focusing on this topic. It promises to create sustainable and energy-efficient built environments by developing new solutions. There is a need for more study into the interplay between occupant behavior, building design, and energy performance, as well as the efficacy of different conservation and efficiency measures in diverse climatic, socioeconomic, and cultural settings.

Since research from just a handful of nations is so prevalent, this data shows how important it is to diversify researchers' locations. It would be beneficial for future research to deliberately seek out underrepresented regions' viewpoints and case studies on green building methods, as these areas can encounter different obstacles and possibilities. Researchers should work to close those gaps for solutions that address sustainable development, thermal comfort, energy efficiency, and the gaps between engineering, architecture, sociology, and policy studies. Investigating the variables that affect occupant behavior, the efficacy of interventions, and the use of sophisticated modelling methods in building simulations as they pertain to energy performance is an important subject for the future. Design and policy decisions should be based on evidence, emphasizing academic and industry collaboration to provide practical guidelines and tools. Building performance can be constantly optimized through feedback loops, but practitioners must prioritize occupants' comfort, well-being, and engagement by adopting a user-centric approach. These initiatives will improve green buildings' longevity, effectiveness, and practicality, which will help achieve worldwide targets for combating climate change and conserving natural resources.

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