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A Comprehensive Bibliometric Review on Enhancing Residential Energy Efficiency: Focusing on Traditional Insulation Materials and Simulation-Driven Design Optimization

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ABSTRACT

Efficiency in Energy efficiency in residential buildings is critical for sustainable development and combatting climate change. Heating and cooling the structures requires a significant amount of energy, demonstrating the need of current solutions in this area. The current study is a bibliometric evaluation of common kinds of insulation, as well as the use of simulation as a form of integration in energy efficiency improvement. Common materials such as wool, cork, and cellulose are evaluated for heat conductivity, cost, and environmental effect, whereas innovations are evaluated for efficiency at the expense of a negative environmental impact. Specific technical tools, such as Building Information Modeling (BIM) and EnergyPlus, are examined while evaluating the potential of a simulation tool to establish the suitability of materials and design techniques. The study recognises flaws in the method of incorporating traditional materials into simulation technologies, a lack of unified databases, and coordinated communication among specialists from many sectors. Some of the discoveries observed include research efforts becoming increasingly important in energy efficient design, innovative materials, and computational tools playing a critical part in energy-related ideas. Specific recommendations for practise include the use of regional adaptations of the insulation concept and the use of optimization through simulation from the first design phase to enable cost-effective solutions. In theoretical propositions, activities necessitate expanded frameworks that include both material science and computer modelling. Future work thrusts include extending the use of novel materials, improved sensing and modelling with AI, and active performance evaluation throughout the lifespan. It will be valuable to scholars, policymakers, and practitioners interested in the development of sustainable home building.

1. Introduction

Efficiency in energy consumption in residential structures has emerged as one of the most important foundations of sustainable development and the battle against climate change across the world. Residential buildings rely heavily on heating and air conditioning, making energy efficiency

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improvements crucial for reducing greenhouse gas emissions and operating costs [5]. The following is a list of numerous ways being tried to attain the aim. Insulating materials and sophisticated design simulations have been highlighted as significant facilitators of energy-efficient home building [12]. In the context of rising speed of urbanisation and technological improvement, a hierarchy of more and more traditional insulations and simulation-based integration has become vital to know while defining building optimal designs [35].

This systematic literature study examines the scientific literature on energy efficiency in residential buildings, including the impact of present insulating materials and models. New materials that have replaced the previously employed complex organic ones include wool, cork, foam, polyurethane, among others, have proven useful in decreasing heat transmission and enhancing the comfort level of the existing buildings [3]. Simultaneously, developments in simulation technology have radically altered the building design process, allowing for far more accurate estimates of a structure's thermal properties, energy efficiency, and environmental impact. However, the challenge of combining traditional materials with state-of-the-art simulations to offer optimal, climate and socioeconomic context-appropriate, low-cost yet high-performance building designs remains essential [31].

One of the biggest challenges in the field of energy-efficient building design is the absence of a systematic method to using conventional insulating materials paired with modern modelling technologies [15]. Although long-established materials give localised thermal resistance and sustainability enhancement assurances, their full potential is hampered by the inability to adequately incorporate them into modelling procedures that dominate the present material environment [22]. Similarly, simulations may describe building systems; however, the precision and utility of such representations are dependent on first-class data feeds for material attributes and environmental conditions. This work will seek to address this vacuum by providing the following contributions: a bibliometric assessment of insulating materials and simulation-based optimization literature, emphasising relevant findings, and giving research prospects for enhancing residential building efficiency [14].

Although the literature on energy-efficient house construction is rising, bibliometric research studies that thoroughly analyse the combined approach of traditional insulating materials and simulation technologies remain scarce [26]. The associated reviews of computational techniques mainly take two directions: an examination of material qualities or a discussion of simulation methods, ignoring the possibility of using both together. As a result, there is a demand to conduct extensive bibliometric assessments of these sectors and their trends and opportunities for development, which will give helpful advice for architects, engineers, civil and structural policy makers, and academics [32].

The fundamental goal of this research is to undertake a bibliometric analysis of the scholarly literature on conventional insulating materials and simulation-based integration for home energy efficiency. Because only the most recent and relevant academic publications, such as articles, conference proceedings, and technical reports, will be reviewed, this research attempts to outline important trends, identify prospective areas within the discipline, and determine the current state of the art. Furthermore, the research aims to determine the regionality of the given studies, the interdisciplinary of the works, and the role of major sources in shaping the present study agenda.

The study's findings have substantial implications for practitioners, policymakers, and academics looking to improve energy efficiency in residential structures. As a result, this study will analyse existing literature to develop techniques that give a road map and regulatory framework for more sustainable and efficient home building. Furthermore, the findings will help to improving the knowledge base for merging old and modern methodologies in RES research, and developing ideas for new advances in home energy efficiency design.

2.1 Literature Review
2.1.1 Energy efficiency in residential buildings

Research on how to enhance energy efficiency in residential buildings has emerged as a significant way to combating climate change and promoting sustainable development. Therefore, the goal of this study is to understand the role of domestic lighting energy consumption and the influence of greenhouse gas emissions in the housing sector, which is the greatest consumer of energy in the world [8]. Improving energy efficiency not only has fewer negative consequences on the environment, but it also saves money for homeowners, making it a cost-effective strategy. Buildings have lengthy usable lifetimes; thus, efficient building designs and the execution of efficiency improvements provide long-term benefits in terms of decreased energy consumption and resource use. Energy efficiency is getting attention from governments and international organisations due to its ability to make an instant beneficial impact on the environment. National and international rules and incentives for efficient energy usage in home construction are progressively emerging [23].

Residential energy consumption patterns vary across the world and are impacted by climate, income, and population density, among other factors. There is still a problem in developed regions where the stock of residential buildings is old and/or inefficient and can only be improved gradually and at a high cost; in developing regions, it is still difficult to integrate efficiency into newly constructed buildings, owing to financial and technical constraints. Despite these limitations, there is innovation and opportunity for collaboration on the side of technologists [11]. New materials, increasing use of renewables, and advancements in smart control systems result into economical solutions that address climate and cost inequities. Based on the problems described above, this study gives recommendations to stakeholders that will ensure that energy efficiency in homes transform these residential units into some of the most sustainable [34].

2.1.2 Traditional insulation materials: characteristics and applications

Insulation materials for residential applications have changed throughout the years in an effort to improve people's comfort while conserving energy. Traditional insulating materials are basic, cheap, and may be seen in early housing spaces where they mostly used straw, wool, and cork, among others [1]. People demanded sophisticated and long-lasting solutions throughout industrialization, which resulted in the development of synthetic materials such as polystyrene and polyurethane foam. These new choices provided increased thermal efficiency, installation convenience, and cost savings, which led to their widespread adoption in house construction. However, conventional insulation is still in demand, especially in locations where concerns about product sustainability and local content are crucial [19].

Conventional insulating materials can be classified as natural or synthetic, with each having its own set of characteristics. Wool, cork, and cellulose are renewable, biodegradable, and thermally resistant materials, making them ideal for building. However, if not properly treated, it may have a shorter lifespan and be susceptible to pest and water damage [28].

Natural insulation materials like straw, cellulose, and loose wood have low thermal conductivity but poor moisture resistance in harsh climes, whereas synthetic insulation materials like expanded polystyrene and polyurethane foam offer superior thermal efficiency and moisture resistance [27]. However, synthetic textiles have a number of problems, including the fact that they require a lot of energy during manufacture, and there are some worries about recycling and the environment. These strengths and limitations must be controlled effectively, especially with diverse climactic circumstances needing materiality performance, cost, and environmental implications that are compatible with general or regional needs and sustainability [29].

2.1.3 Simulation-based integration for energy optimization

Because of the improved capabilities of simulation studies to examine and improve energy performance, digital technologies are one of the most important sources of innovation in building design today. Building Information Modeling (BIM) is a technology that includes many features to create a construction model. It helps architects and engineers to construct designs, analyse material properties, and even include energy performance into their plans [25]. Energy modelling in combination with BIM is made simpler by tools like EnergyPlus and TRNSYS enabling a more detailed study of the building's energy [15]. These technologies measure thermal behaviour, energy consumption, and the impact of these changes, and are thus critical in improving energy efficiency for residential structures. However, such integration of simulation technologies may be done in the early phases of the design process in order to bring about a superior result in terms of performance and sustainability [24].

The authenticity and believability of the data and parameters utilised in the simulation have a significant impact on its correctness. Such data is thermal conductiveness, density, specific heat capacity, and climatic data that takes into account temperature changes, degrees of sun exposure, and humidity [21]. Other important elements are the direction of the structure, its occupant density, and the mechanical system features. These elements allow simulations to assess, in addition to thermal properties and energy demand, the cost-effectiveness of various options. Simulations provide valuable information for planning, constructing, and monitoring energy-efficient residential structures while minimising expenses for sustainability [17].

2.1.4 Synergies between insulation materials and simulation tools

The combination of traditional insulating materials with simulation technologies has gained recognition as a method of enhancing energy efficiency in residential constructions. This technique allows designers to investigate the thermal properties of wool, cellulose, and cork, as well as environmental considerations, utilising analytical tools like BIM and energy models. Simulation technologies provide for more accurate testing since virtual models incorporate the features of the conventional material [1]. Material coefficients like thermal conductivity and moisture content may be supplied into EnergyPlus or TRNSYS simulation programmes to demonstrate the practical advantages of reducing energy waste while preserving comfort conditions within the structure. However, it is important to emphasise that full integration has not yet been realised, and there are a limited number of publications that claim of total integration of these technologies into practise [6].

Some particular evaluations provide compelling evidence of the efficacy of integrating techniques. For example, an ASU home retrofit project can use modelling tools to optimise the thickness of cellulose insulation, performance/price ratio [20]. Nonetheless, several key impediments remain in existence when combining conventional material attributes with simulation techniques [9]. Many natural materials' porosity changes in density and moisture content, making it difficult to replicate them in simulation [13]. Furthermore, several of these conventional materials lack standardised data, making it difficult to integrate them effectively into energy modelling techniques. These are widely known, with material scientists, software developers, and designers working together to create macro-level datasets and fine-tuned algorithms that integrate material characteristics and simulation technologies [7].

2. Methodology

2.1 Data Collection

The initial step in this bibliometric analysis is to identify scientific works on energy efficiency in residential structures, focusing on traditional insulating materials and modelling for incorporation into building designs. Abstracts will be searched throughout key scientific databases including Scopus, Elsevier, and Google Scholar [4]. The main articles will be chosen based on keywords and search phrases linked with the research subject, which includes energy efficiency, residential buildings and insulation materials, thermal performance, building energy modelling, and other relevant issues. The search will also contain articles, conference papers, books, book chapters, and other scholarly works in English, covering disciplines such as energy engineering, architecture, environmental science, materials science, and computer modelling [10].

2.2 Data Screening and Selection

Once the initial dataset has been created, the screening technique will utilise a stringent criterion to guarantee that only acceptable articles are included in the bibliometric analysis. Some of the detected entries will be duplicates and thus be eliminated, while the remainder will match the following inclusion and exclusion criteria [30]. Inclusion criteria may include the studies' relevance to topics such as energy efficiency in residential buildings, traditional insulation materials, simulation-integrated design for the best results, the empirical and theoretical nature of the studies, and publication in scholarly, peer-reviewed journals or reputable conference proceedings. By exclusion criteria, we mean papers published in languages other than English, grey literature: reports and policy briefs, articles not linked to the issue of the present research, articles published within the time period that is not included in the study period.

2.3 Data Extraction and Coding

After identifying all publications, the metadata and bibliographic information for the papers to be submitted will be extracted and coded methodically. Such information may include publication year, authorship, details of the journal or conference proceeding, keywords, abstracts, and citations [33]. Furthermore, a content analysis method might be used to identify key topics and concerns covered in the selected publications, theoretical frameworks and models, methodologies and approaches, and research outputs and findings. To ensure the validity of the results, the data extraction and coding method will be consistent, and different researchers will carry out the process to avoid the researcher's intervention [18].

2.4 Bibliometric Analysis

The gathered information will be evaluated statistically using a bibliometric technique to study varied aspects of scholarly publications in the subject of microfinance and economic development [2]. Additional quantitative data, such as the temporal distribution of publications, citation profiles, and author collaboration networks, will be generated to show the field's features. Co-citation analysis and bibliographic coupling may be used to identify notable authors, pioneering books, and thought communities within the literature. Furthermore, thematic analysis and keyword co-occurrence analysis will be performed in order to uncover major topics, theories, and trends in the area [16].

3. Results

3.1 Research Data Matrix

Table 1
Research data metrics

Publication years	: 2014-2018
Citation years	: 5 (2014-2018)
Paper	: 196
Citations	: 9273
Cites/year	: 285.0
Cites/paper	: 49.78
Cites/author	: 12.52
Papers/author	: 0.28
Author/paper	: 3.57
h-index	: 63
g-index	: 91
hI,norm	: 16.1
hI,annual	: 1.5
hA-index	: 18.3
Papers with ACC	: 65

From the data presented in the Table 1, the bibliometric analysis considering only the last five years (2014–2018) provides substantial findings regarding the research trends exploring energy efficiency in residential buildings, the main focus of which is paid to the traditional insulation materials and simulation-based integration. The dataset includes 196 papers, which received 9,273 citations throughout the course of 5 years, meaning an average of 285.0 citations per year. The papers in aggregate have been cited forty-nine point seven eight times, and the individual authors have been cited twelve point five two times. The publication trend returns a clear uptrend of papers from 25 in 2014, to 51 in 2018, affirming the increased interest in this research area.

These collaboration metrics provide an indication that this field is highly collaborative with an average of 3.57 authors per paper and an indication of the level of contribution of each author where he or she publishes 0.28 papers on average. The number of citations has a high h index of 63 this is a confirmation that the impact of 63 papers that has been published and written on this journal has a citation of at least 63 and above. A g-index of 91 further supports the diverse reach of such popular papers in this field. Additional measures that also support citation normalization reveal the normalized h-index hI,norm = 16.1 and the annual h-index hI,annual = 1.5. The hA-index of 18,3 gives an idea of the forthcoming papers while sharing the number of authors including their influence of papers.

Of most interest is the fact that 65 papers have been found with the ACC meaning that such research has received considerable attention within the scholarly domain. This explains the extent to which research on energy performance in residential buildings, especially in those that use a combination of new traditional insulation and simulated design methods, has brought about considerable change as a result of accumulated knowledge in the field. The continuous and enhanced number of publications and cited documents throughout the study period affirms the emergence of energy efficiency research in the building sector and its value in supporting sustainable development frameworks.

3.2 Network Visualization

The Figure 1 presents a comprehensive network visualization of terms related to "energy efficiency," which serves as one of the central nodes alongside "thermal insulation" and "housing." The network map illustrates the interconnected nature of research themes in building energy efficiency and insulation materials. Here is a breakdown of the major thematic clusters as they appear in the network:

i. Central Cluster (Purple) - Energy Efficiency and Housing Core: This cluster centers around the fundamental concepts of "energy efficiency," "housing," and "air conditioning." It includes key terms related to the basic principles of energy-efficient building design and operation.
ii. Red Cluster (Thermal Materials) - This prominent cluster focuses on "thermal insulation" and "walls (structural partitions)." It encompasses terms like "heat flux," "thermal bridges," and "insulation materials," reflecting the technical aspects of building insulation and heat transfer.
iii. Green Cluster (Environmental and Policy) - Located in the lower right portion, this cluster contains terms such as "carbon dioxide," "renewable energy resources," and "building energy management." It represents the environmental impact and policy aspects of energy efficiency.
iv. Blue Cluster (Climate and Conditions) - This cluster includes terms like "climate models," "natural ventilation," and "comfort conditions," indicating research focus on climate-responsive design and indoor environmental quality.
v. Orange Cluster (Life Cycle Analysis) - Positioned on the right side, this cluster features terms such as "life cycle," "life cycle cost," and "environmental impact," suggesting research emphasis on sustainability assessment and long-term performance evaluation.
vi. Yellow Cluster (Optimization and Technology) - Terms like "optimization," "genetic algorithms," and "machine learning" indicate the technological and computational aspects of energy efficiency research in buildings.

Other important nodes, while not clearly belonging to a specific cluster, include terms related to specific locations like "Japan," "Germany," and "Chile," suggesting the international scope of research in this field, as well as specialized terms like "parametric analysis," "social housing," and "historic preservation" that bridge multiple research themes.

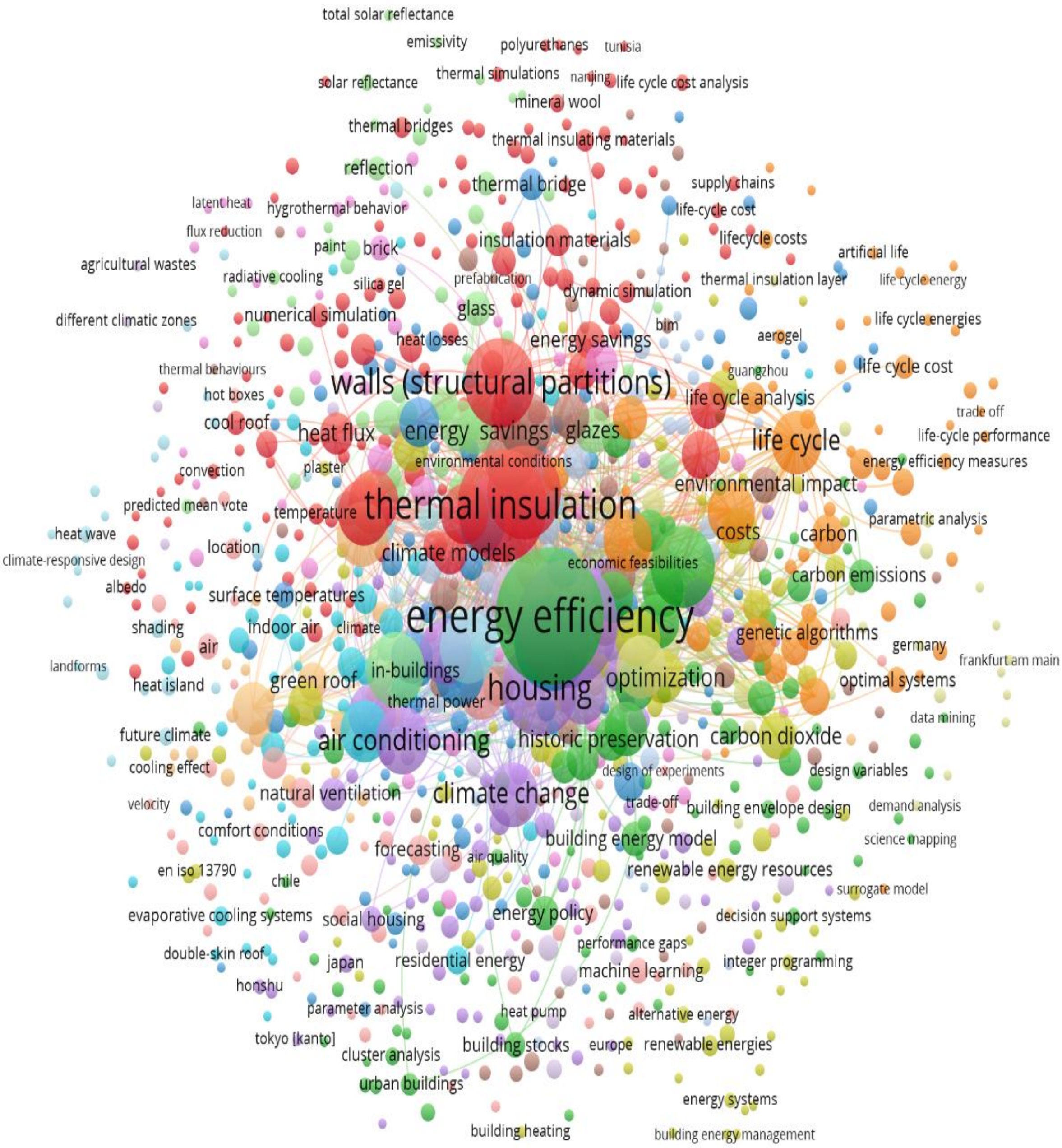

Fig. 1. Network visualization

3.3 Overlay Visualization

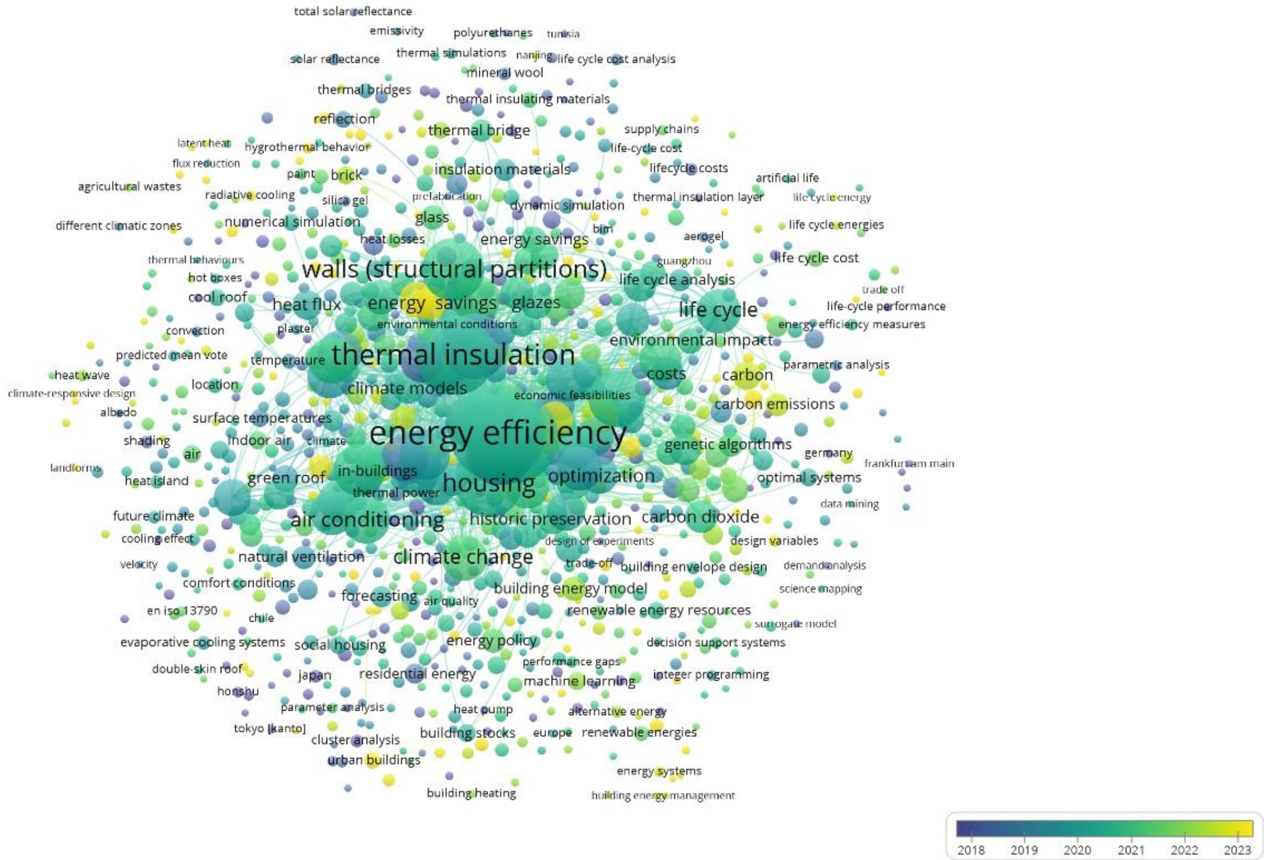

Fig. 2. Overlay visualization

Figure 2 is a bibliometric visualization with a temporal overlay that depicts the chronological progression of research subjects in energy efficiency and building insulation. Each node (subject) represents a study issue, with the color reflecting when the topic was most often addressed in the literature. The color gradient ranging from blue (2018) to yellow (2023) represents the chronological evolution of phrases in the literature. The color caption at the bottom of the picture, which covers from 2018 to 2023, identifies key research trends:

i. Early Period Nodes (2018-2019, Blue): These nodes represent the foundational research topics that were prominent at the beginning of the period. Terms like "thermal insulation," "walls," and "heat flux" appear in blue, suggesting that early research focused on basic building physics and traditional insulation methods. This period established the core technical understanding of building thermal performance.
ii. Middle Period Nodes (2020-2021, Green): The terms in this period, shown in green, demonstrate an evolution toward more sophisticated concepts. Topics like "energy efficiency," "optimization," and "climate change" gained prominence. This period marks a shift toward integrating environmental concerns with technical solutions, particularly focusing on climate-responsive design and energy savings.
iii. Recent Nodes (2022-2023, Yellow): The yellow nodes represent the most recent research trends, clustering around terms such as "life cycle analysis," "carbon emissions," and "machine learning." This indicates a transition toward more advanced analytical approaches,

sustainability assessment, and the integration of artificial intelligence in building design and operation.

This research trend suggests an evolution from fundamental technical studies of building materials and thermal performance, through the integration of environmental and climate considerations, to the current focus on advanced computational methods and comprehensive sustainability assessment. The progression reflects the field's response to growing environmental concerns and technological advancement, while maintaining the core focus on energy efficiency in buildings.

3.4 Citation Analysis

Table 2
Most impactful literature review

Year	Title	Cited by
2015	A 50 year review of basic and applied research in radiant heating and cooling systems for thermal comfort	389
2016	An investigation of the impact of building orientation on energy consumption in a domestic building	291
2015	The early design stage of a building envelope: multi-objective search through heating, cooling, and lighting energy performance analysis	263
2017	Temperature and cooling demand reduction by green-roof types in different climates and urban densities	211
2016	Green roofs energy performance in Mediterranean climate	162
2020	Power-to-hydrogen as seasonal energy storage: an uncertainty analysis for optimal design of low-carbon multi-energy systems	158
2020	An artificial neural network (ANN) expert system enhanced with the electromagnetism-based heuristic optimization method for energy performance assessment of residential buildings	157
2015	Optimal design of residential building envelope systems in the Kingdom of Saudi Arabia	156
2020	Optimum insulation thicknesses and energy conservation of building thermal insulation materials	152
2016	Contribution of structural lightweight aggregate concrete to the reduction of thermal bridging effect in buildings	152

Table 2 lists the most significant articles in the subject of residential building energy efficiency, with a particular emphasis on insulating materials and simulation-based design optimization. The most referenced study is a thorough 50-year overview of radiant heating and cooling systems from 2015, which had 389 citations, illustrating the ongoing relevance of basic thermal comfort research. The second most referenced work, with 291 citations, studies how building orientation affects energy usage, emphasising the importance of passive design solutions in residential structures.

Several highly cited publications focus on early-stage design decisions and envelope optimization, such as a multi-objective study of heating, cooling, and lighting performance (263 citations) and research on optimum envelope systems in Saudi Arabia (156 citations). The appearance of several publications from 2020 with high citation counts, notably those on seasonal energy storage and artificial neural network applications, demonstrates the field's shift toward sophisticated computational approaches and new energy solutions.

The table also demonstrates a considerable research interest in green building technology, as seen by studies on green roof performance in diverse climates (211 citations) and Mediterranean settings (162 citations). The inclusion of research on structural lightweight concrete (152 citations) and optimal insulation thicknesses (152 citations) emphasises the significance of material selection and thermal optimization in meeting energy efficiency targets.

This collection of widely referenced papers includes both conventional approaches to energy efficiency and newer computational methods for optimization, demonstrating the field's evolution from fundamental concepts to more complex, simulation-based integrated strategies for optimal design.

3.5 Density Visualization

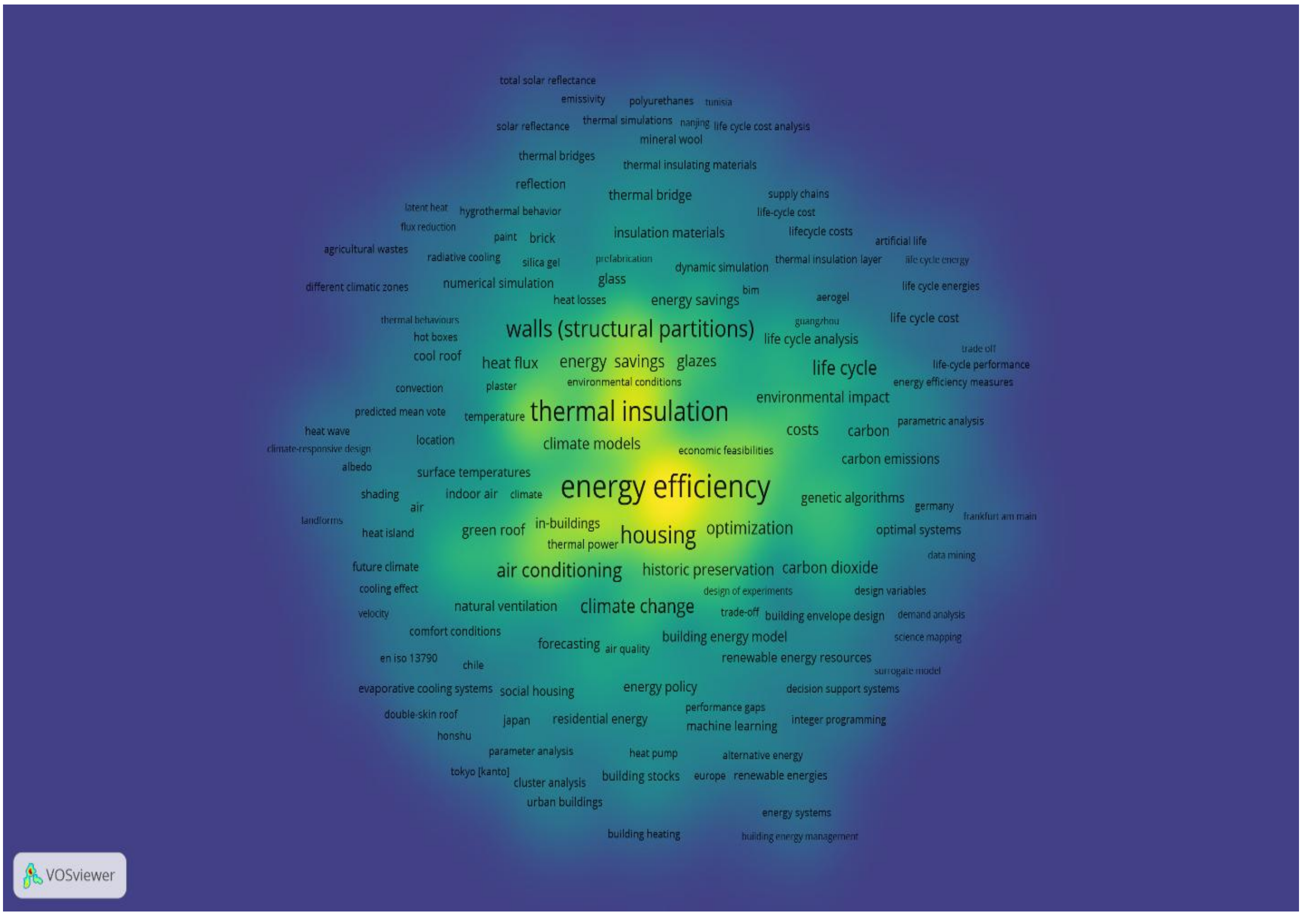

Fig. 3. Density visualization

The density visualization as shown in Figure 3, depicts an extensive map of research keywords and linkages in the subject of building energy efficiency. At its heart, the display uses a complex heat map technique, with a colour gradient that moves from a bright yellow centre to green-blue intermediate zones, and eventually to deeper blue peripheries. This colour scheme successfully depicts the various levels of term connections and their prevalence in the text.

At the centre of the graphic, "energy efficiency" emerges as the dominant notion, as seen by the brightest yellow hue and greatest word size. This centre hub is bordered by "housing" and "thermal insulation," making a triangle core of key ideas in the area. "Building envelopes" and "walls (structural partitions)" have a considerable representation around this centre cluster, demonstrating their importance in energy efficiency research.

Moving outward from the centre, the image exposes a central layer of significant phrases coloured green-blue. This intermediate zone encompasses key ideas like "climate change," "air conditioning," "energy savings," and "building energy models." These words show a strong connection to the main concepts while also branching out into more specific areas. "Architectural design" and "thermal comfort" exist in this medium range, implying that they serve as bridges between technical and practical applications.

The visualization's outer edge, which is coloured deeper blue, comprises more specialist or emerging words. These include technical terms like "evaporative cooling systems," "double-skin roof," and "mineral wool," as well as wider notions like "total solar reflectance" and "agricultural wastes." The inclusion of phrases such as "machine learning" and "parameter analysis" in these outer regions indicates developing technical techniques in the subject. The spatial arrangement of these phrases, while avoiding overlap, successfully communicates their links to more essential concepts while retaining visual clarity.

The visualisation, built with VOSviewer software, as seen in the bottom left corner, effectively depicts a complicated network of relationships in an understandable fashion. The varied font sizes create a new level of information, quickly emphasising the relative significance of distinct phrases while preserving legibility across the graphic.

3.6 Author Collaboration Network

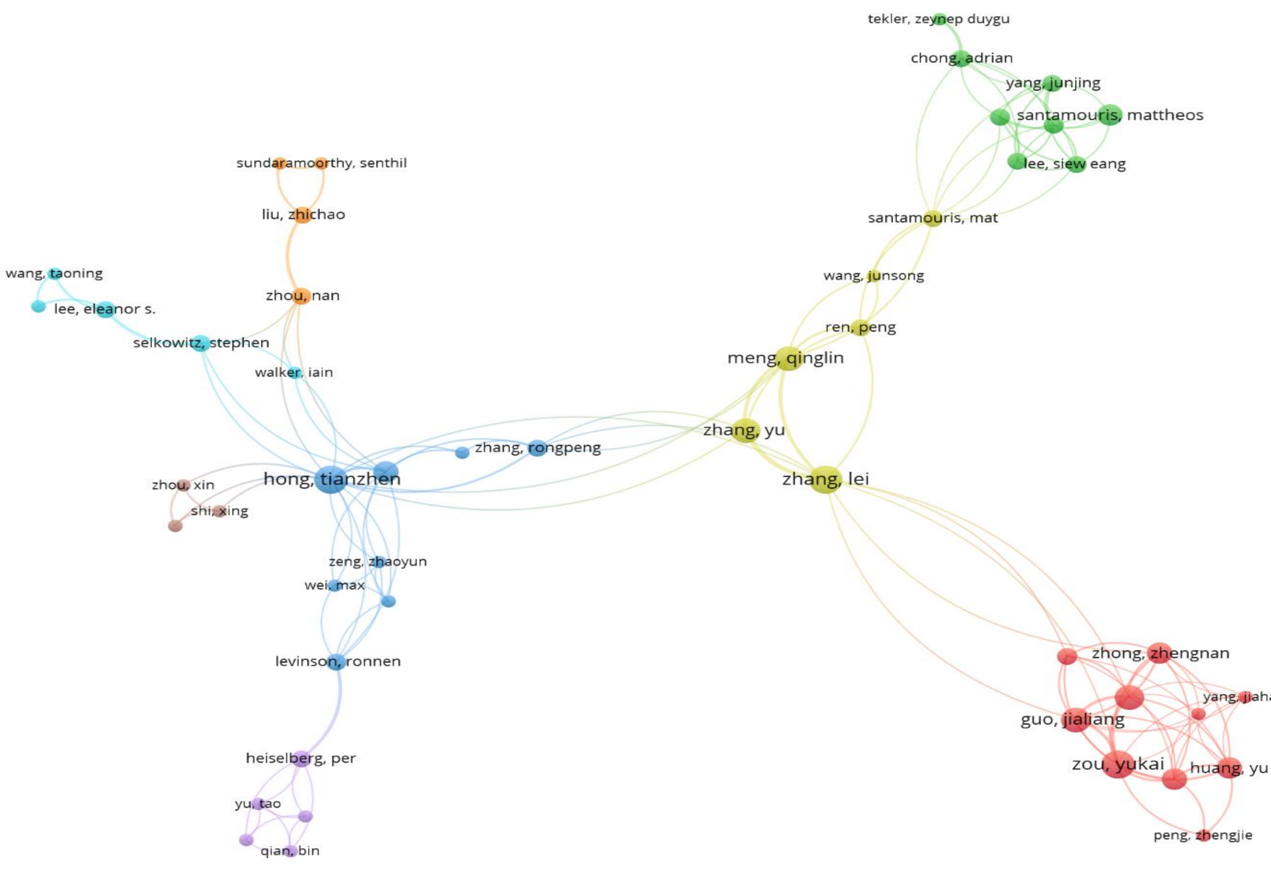

Fig. 4. Author visualization

The author cooperation map, as shown in Figure 4, depicts the range of co-authorship and the community of scholars in the topic. It is divided into four unique groups: green for the first cluster, blue for the second, red for the third, and yellow for the fourth. The colour markers indicate that it encompasses four diverse research communities, each with its own dynamics and issues. However, in the majority of these clusters, numerous writers may be identified as crucial to the field's accomplishments. Among the blue group hue, tianzhen has many cooperation relationships, and zhang, lei serves as a link between the various study groups.

Zhong/zhengnan is highly important in the red cluster at the bottom right, while the green cluster at the top right displays intense coupling among the researchers, which includes Chong Adrian, Yang Junjing, and Santamouris. The network represents several levels of collaboration intensity: a core of highly connected individuals and groups, as illustrated in the red component; blue links, which reflect more chained interaction; and researchers with few connections at the community's outskirts. Overall, while the research communities are fairly separate, a number of connections across the clusters indicate moderate cross-group contacts. The overall geographic design of the network can best represent all of the natural boundaries within and across a collection of study fields, while also mapping the connectedness that maintains the divides. This structure represents an area that combines more concentrated research within individual groups with targeted cross-organizational cooperation.

4. Conclusion

This study clearly demonstrates the need of boosting energy efficiency in residential buildings and highlights the differences between standard insulating materials and the simulation approach. These and other traditional materials, such as wool, cork, and cellulose, can be ecologically beneficial and cost-effective solutions for improving thermal comfort and saving energy. However, these materials have issues with strength, durability, and other environmental considerations. Available synthetic insulations may beat natural insulations in terms of thermal conductivity coefficient, but their manufacturing and use are associated with significant energy consumption and potentially detrimental environmental implications. At the same time, advanced simulation tools such as BIM or EnergyPlus enable realistic assessments of the building's material attributes and overall performance. However, additional study has been conducted on the use of conventional materials in simulation frameworks, which has been shown to be quite restricted, leaving potential for more investigation.

The research demonstrates that interest in this field's themes has gradually increased in recent years, as evidenced by an increase in the number of publications and citations. Such rise illustrates society's need to address energy efficiency on a larger scale, inspired by sustainability and climate change objectives. In that regard, this study is intended to be useful to researchers, architects, engineers, and policymakers because it supplies information about how traditional insulation techniques might work together with recent computational developments to augment the ongoing search for efficient, cost-effective, and effective approaches to constructing sustainable structures.

4.1 Recommendations
4.1.1 Practical implications

From a practical perspective, enhancing the integration of traditional insulation materials into simulation tools is essential. This requires the development of standardized datasets detailing the properties of these materials, enabling better compatibility with advanced modeling frameworks. For policymakers and industry professionals, prioritizing cost-effective simulation-based optimizations can guide the selection of insulation solutions tailored to specific climatic and socioeconomic conditions. Additionally, promoting the use of natural insulation materials in regions with abundant local resources can reduce environmental impacts while fostering sustainability initiatives. These steps collectively ensure that practical approaches to energy efficiency are accessible, scalable, and aligned with regional needs.

4.1.2 Theoretical implications

Theoretically, there is a pressing need to foster interdisciplinary research bridging material science, computational modelling, and architectural design. Such collaborative efforts can result in more robust frameworks for integrating traditional and modern approaches. Furthermore, policy-focused research should examine the role of government incentives in accelerating the adoption of energy-efficient practices in residential construction. Lastly, enhancing the validation of simulation models by incorporating experimental data on insulation materials' performance under diverse environmental conditions can improve model reliability and applicability. These theoretical advancements will support the broader implementation of integrated strategies for energy-efficient design.

4.1.3 Future Research Directions

For future work, there is future research needed to widen an understanding of how the traditional insulation materials can be combined with the efficiently designed simulations. They could help complete inefficient building designs by offering optimal strategies based on existing ones. Moreover, there is a possibility to develop new bio-based and recyclable materials for insulations in replacement of traditional and synthetic ones for further investigation as the idea for innovation. Longitudinal studies of the lifecycle performance of these integrated solutions offer important information about the solutions' lifecycle costs, energy savings, and environmental benefits.

Furthermore, regional research is also necessary to solve climatic, economic, and cultural peculiarities within regions that influence energy efficiency approaches. Such studies may be especially useful in identifying the best fit among standardised solutions within given environments so as to bring global solutions closer to local realities. Finally, utilizing artificial intelligence and machine learning for simulations enhances the prediction in designing and construction of residential buildings. All of these research directions combined will progress the field so that more adequate and permanent solutions for residential energy will be established.

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