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A Bibliometric Approach to Enhancing Energy Efficiency in Residential Buildings: A Review of Traditional Insulation Materials and Simulation-Based Integration for Optimal Design

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Abstract: Efficiency in Energy in residential building is very important on sustainable development and combating climate change. The requirements for heating and cooling the structures take a considerable part of energy, proving that modern techniques in this aspect are crucial. The current work is a bibliometric review of conventional types of insulation and the use of simulation as a form of integration in the improvement of energy efficiency. Common materials such as wool, cork, and cellulose assess with regard to thermal conductivity, cost, and environmental impact, and novelties with regard to efficiency at the cost of their detrimental environmental impact. Specific technological tools, Building Information Modeling (BIM) and EnergyPlus are discussed in assessing the potential of a simulation tool to determine the appropriateness of materials and design strategies. The research acknowledges deficiencies in the approach to introducing traditional materials into simulation technologies, the deficit of unified databases and cooperative collaboration among specialists of various fields. Some of the observations made are research activities are assuming growing importance in energy efficient design, novel materials, computational tools play a pivotal role in energy related concepts. Specific suggestions for practice are the implementation of regional adaptations of the insulation concept and the use of optimization through simulation right from the first design step to make cost-efficient solutions possible. In theoretical propositions, the activities require enhanced frameworks which entail both a material science and computational modeling. In future work thrusts are described in terms of expanding the application of new materials, advanced sensing and modeling with AI, and active performance assessment throughout the lifecycle. It will be useful for researchers, policymakers as well as practitioners involved in the development of sustainable residential construction.

Keywords: *Energy efficiency, Residential buildings, Insulation materials, Simulation-based design, Sustainable construction.*

1. Introduction

Efficiency in using energy in residential buildings has emerged one of the biggest foundations of sustainable development and fight against climate change across the world. Heating and air conditioning are the biggest energy loads in residential buildings, implying the importance of energy efficiency enhancements in cutting greenhouse gas emissions and running expenses (Morsy, et al., 2018). The following is a list of many strategies that are being pursued to achieve the goal, for insulating materials and for advanced design simulations have being identified as critical enablers of energy-efficient construction in the residential sector. In the context of increased speed of urbanization and advancement in technologies, hierarchy of more and more conventional insulations and simulation-based integration has become necessary to know while define building optimum designs (Zhou and Liu, 2024).

This systematic literature review analyses the scientific literature on energy efficiency in dwelling houses contemplating the role of existing insulation materials and models. New materials which have replaced the earlier used complex organic one includes wool, cork, foam, polyurethane among others have been helpful in minimizing heat transfer and improving the comfort level of the available structures (Allafi et al. 2022). At the same time, advances in simulation technologies have dramatically shifted the process of building design, allowing for a much better estimation of a building's thermal characteristics, energy efficiency, and environmental footprint. However, the issues how to combine conventional materials with state-of-art simulations to provide optimum, climate and socioeconomic context-appropriate, low cost yet high-performance building designs still remain critical (Schiuma and Santarsiero, 2023).

One of the major concerns in the field of design for energy efficient buildings is the lack of a systematic approach to applying conventional insulation materials combined with advanced simulation tools (Gan et al. 2020). Although longstanding materials provide localized thermal resistance and sustainability enhancement assurances, their full potential is mitigated by the inability of properly integrate them into simulation practices that dominate the modern material landscape (Mainini et al. 2024). In the same respect, simulations themselves may represent systems of buildings, however, such representation's precision and value depend on the first-class data feed in regard to properties of materials and condition of the environment.

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This paper will attempt to fill this gap by making the following contributions: bibliometric review of insulation materials and simulation-based optimization literature, highlighting findings about the topic, and presenting research perspectives for improving the efficiency of residential buildings.

Although the literature on energy-efficient construction of houses is increasing, bibliometric research studies that systematically review the combined strategy of traditional insulation materials and simulation technologies are still limited (Omrany et al. 2022). The related reviews of computational methods generally follow two directions: either the analysis of material properties or the discussion of simulation methods excluding the potential use synergistically of both. Therefore, there is a call to undertake detailed bibliometric analyses of these areas and their trends and possibilities for development, which will provide valuable recommendations for architects, engineers, civil and structural policy makers, and researchers (Sharma et al. 2022).

The primary objective of this study is to conduct a bibliometric analysis of the scholarly literature on traditional insulation materials and simulation-based integration for residential energy efficiency. As only the most recent and relevant academic publications such as articles, conference proceedings, and technical reports will be considered, this study aims at outlining major trends, finding promising areas within the field, and determining the state of the art. Further, the research intends to identify the regionality of the offered studies, interdisciplinarity of the works, and the impact of the key sources for forming the modern agenda of studies.

The findings of this study therefore have important implications to practitioners, policy makers and researchers who seek ways of improving energy efficiency in residential buildings. Thus, this research will review available literature to design approaches that provide a roadmap and policy framework for more sustainable and efficient residential construction. In addition, the findings will contribute to expanding the knowledge base for integrating traditional and modern approaches in RES research and develop ideas for new improvements in residential energy efficiency design.

2. Literature review

2.1 Energy Efficiency in Residential Buildings

A study on residential building improves energy efficiency has developed into an important approach to responding to climate change and promote sustainable development. Therefore, the purpose of this study is to understand the role of residential lighting energy consumption and the impact of greenhouse gas emissions in the housing sector because it is the largest consumer of energy in the world (Chel and Kaushik, 2018). Improving energy efficiency means less negative effects on the environment but also, less expenses for the owners of houses, which means cost effective policy (Gabr & Ibrahim, 2024). Because buildings have long useful lives, efficient building designs and the implementation of efficiency upgrades have long-lasting positive characteristics related to reduced energy consumption and resource use. Energy efficiency is gaining the attention of governments and international organizations due to its potential to make an immediate positive impact on the environment: national and international policies and incentives for efficient energy use in dwelling construction are gradually emerging (Mondejar et al. 2021).

Residential energy demand patterns are general not static around the world and influenced by climate, income, and population densities among others. There remains a problem in developed regions where the stock of residential buildings is old and/or inefficient and can only be improved gradually usually at a high cost; and in the developing regions it was remain a problem to integrate efficiency into newly constructed buildings mainly due to financial and technical constraints. Despite these challenges, it means there are innovation and opportunities for collaboration on the part of the technologists (Ellsworth-Krebs, 2020). New materials, increased use of renewables, and developments in smart control systems translate into affordable solutions suited to climate and cost disparities. Based on the challenges highlighted above, this paper presents recommendations to stakeholders that will ensure that energy efficiency in houses turns these residential units to some of the most sustainable (Wang et al. 2020).

2.2 Traditional Insulation Materials: Characteristics and Applications

Insulation materials for residential application has evolved over years in an effort to enhance peoples comfort while at the same time been conserve on energy. Traditional insulation materials are simple, cheap and could be found in early dwelling spaces where they major in the use of straw, wool and cork among others (Abu-Jdayil et al. 2019). During the course of industrialization, people required technical and long lasting solutions which then gave rise to synthetic materials like polystyrene and polyurethane foam materials. These modern options provided improved thermal performance, installation convenience and again cost advantages that led to widespread use in House building. However, there is still a demand for traditional insulation, especially in areas where concerns on sustainability of the product and the local content are critical (Klemczak et al. 2024).

Classification of conventional insulation materials can be made based on their source into natural and synthetic products and each of them possesses its specific attributes. Materials like wool, cork and cellulose are renewable, biodegradable and possess the characteristics of thermal resistance, another good reason for them to be used in construction. But it may have shorter lifetime and can be affected by insect and water damage when the treatment is not done properly (Rafiq et al. 2020).

Looking at natural insulation materials, straw, cellulose and loose wood have low thermal conductivity, but poor moisture resistance for extreme climates, while synthetic insulation materials such as expanded polystyrene and polyurethane foam, have better thermal efficiency and moisture resistance (Petcu and Vasile, 2022). However, there is a variety of drawbacks associated with synthetic fabrics, for example, in manufacturing they consume a great deal of energy and there are some concerns with recycling and environmental effect. These strengths and weaknesses must be managed properly especially with different climactic conditions requiring materiality performance, cost, and environmental impacts, to be compatible with general or regional requirements and sustainability (Sandin and Peters, 2018).

2.3 Simulation-Based Integration for Energy Optimization

Digital technologies are one of the most significant innovation sources in building design due to advanced possibilities of simulation studies to analyze and enhance the energy performance. BIM stands for Building Information Modeling which acts as a tool that incorporates multiple attributes, to develop a model of construction. It enables architects and engineers to create a design, evaluate characteristics of material, or even consider energy performance factor in their plan. Energy modeling in tandem with BIM is made easier with the help of programs like EnergyPlus and TRNSYS for a more precise analysis of the building energy (Gan et al. 2020). These tools assess the thermal behavior, energy usage and effect from these changes, therefore are crucial in enhancing energy optimized for residential buildings. Such integration of simulation technology can however be done in the early stages of the design process in order to bring about a better result concerning performance as well as a sustainable one (Mourtzis, 2020).

The reality and credibility of data and parameters used in the simulation affect the accuracy of the simulations enormously. Such data is thermal conduciveness, density, specific heat capacity and climate data which takes into consideration temperature fluctuations, levels of solar exposure, and humidity (Law, 2022). Other parameters of significance also embrace the building's orientation, occupancy density, and mechanical system characteristics. These factors enable simulations to evaluate, in addition to thermal characteristics and energy demand, cost efficiency of selected solutions. Simulations offer the greatest value because they supplement decision-making with accurate and comprehensive information about designing, constructing, operating and managing innovative and energy-efficient residential buildings with the least costs for their sustainability (Ilgın and Aslantamer, 2024).

2.4 Synergies Between Insulation Materials and Simulation Tools

The inclusion of the conventional insulation materials with simulation technology has received acceptance as a technique of improving energy efficiency in residential structures. It means this approach enables designers examine thermal qualities of wool, cellulose, and cork, and environmental aspects using analytical tools such as BIM and energy models. Simulation technologies enable nearer accurate testing since the virtual models include the characteristics of the traditional material (Abu-Jdayil et al. 2019). Material coefficients of thermal conductance and moisture content can be fed to EnergyPlus or TRNSYS simulation tools to show realistic benefits of avoiding energy wastage and maintaining comfort conditions inside the building (Gabr, 2023). However, one must still note that full integration has not been achieved yet and there are a limited number of papers that boast about complete integration of these technologies into practice (Benachir et al. 2023).

The effectiveness of implementing integrated approaches is well illustrated in some special analyses. For instance, an ASU residential retrofit project can incorporate simulation software in optimizing the thickness of cellulose insulation, performance/price ratio (Kumar, 2024). Nevertheless, some critical barriers stay in place in matching the traditional material properties with simulation tools (Choi et al. 2021). Porosity in many natural materials varies in density and moisture content which pose a challenge to their depiction in the simulation. Furthermore, standardized data for some of these traditional materials is not well developed to enable effective integration in energy modeling procedures. These are well understood with material scientists, software developers and designers joining forces to build macro level datasets and fine-tuned algorithms that connect properties of materials and simulation technologies (Busser et al. 2019

3. Methods

3.1 Data Collection

This bibliometric study's first process is the identification of scholarly articles on energy efficiency in residential buildings, with focus on traditional insulation materials and simulation for integration into building designs. Abstracts will be searched covering leading scientific databases such as Scopus, Elsevier, and Google Scholar (AlRyalat et al. 2019). The key publications will be selected using keywords and search terms associated with the study topic encompassing energy efficiency, residential buildings and insulation materials, thermal performance, building energy simulation, and other related topics. The search will also include articles, conference papers, books, book chapters, other scholarly documents that will be in English and covers discipline such as energy engineering, architecture, environmental science, materials science and computational modeling (Cristino et al. 2018).

3.2 Data Screening and Selection

The method of screening that will be used once the initial dataset has been compiled involves a carry out strict criterion to ensure that only eligible publications end up being used in the bibliometric analysis. Some of the records identified will be duplicates and will therefore be removed while the rest will meet the following inclusion and exclusion criteria (Santos et al. 2017). Inclusion criteria may include that the studies are related to such topics as energy efficiency in residential buildings, traditional insulation materials, simulation-integrated design for the best result; empirical and theoretical nature of the studies, publication in scholarly, peer-reviewed journals, or reputable conference proceedings. By exclusion criteria we means the articles published in languages other than English, gray literature: reports and policy briefs, articles not related to the topic of the present research, articles published within the time period which is not included in the study period (Paez, 2017).

3.3 Data Extraction and Coding

After the identification of all the publications, the metadata and bibliographic details of the articles to be submitted will be extracted and coded systematically. Such information may include publication year, authorship, details of journal or conference proceeding, keywords, abstracts and citations (Tkaczyk, 2017). Furthermore, a method of content analysis could be used in order to pinpoint such matters as the leading topics and issues covered in the selected publications, theoretical constructs and models, methods and approaches, as well as the outcomes and results observed in the course of the research. The process of data extraction and coding will be consistent to maintain the validity of the results and multiple numbers of the researcher will carry out the process to avoid interference of the researcher (Kazdin, 2021).

3.4 3.4 Bibliometric Analysis

The obtained information will be analyzed quantitatively via bibliometric approach to explore diverse characteristics of the academic works within the field of microfinance and economic development (Akter et al. 2021). Additional quantitative data, including temporal distribution of publications, citation profiles, and author cooperation networks will be produced to reveal the characteristics of the field. Co-citation analysis and bibliographic coupling may be used to spot key authors, pioneering literature and thought community in the literature. In addition, thematic analysis and keyword cooccurrence analysis will be done in order to identify key themes, theories and trends in the field (González-Valiente et al. 2021).

4. Results and Discussion

4.1 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.

4.2 Network Visualization

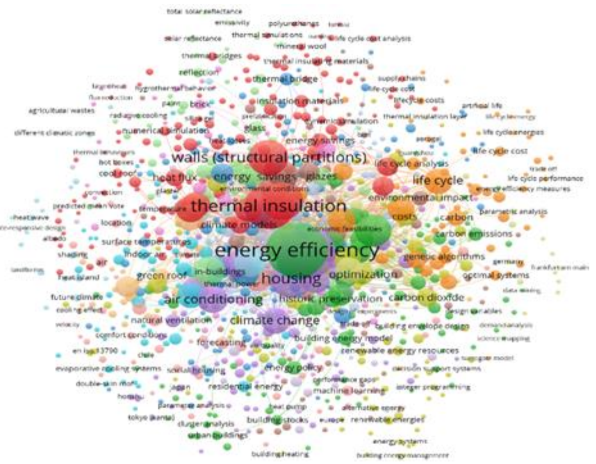

Fig. 1 Network Visualization

The figure 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's a breakdown of the major thematic clusters as they appear in the network:

1) 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.

2) 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.

3) 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.

4) 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.

5) 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.

6) 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.

4.3 Overlay Visualization

This second figure is a bibliometric visualization with a temporal overlay, which shows the chronological development of research topics in the field of energy efficiency and building insulation. Each node (topic) represents a research theme, with its color indicating the time period when the topic was most prominently discussed in the literature. The color gradient from blue (2018) to yellow (2023) indicates the temporal progression of terms within the literature. Based on the color legend at the bottom of the image, which spans from 2018 to 2023, we can identify several research trends:

1) 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.

2) 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.

3) 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.

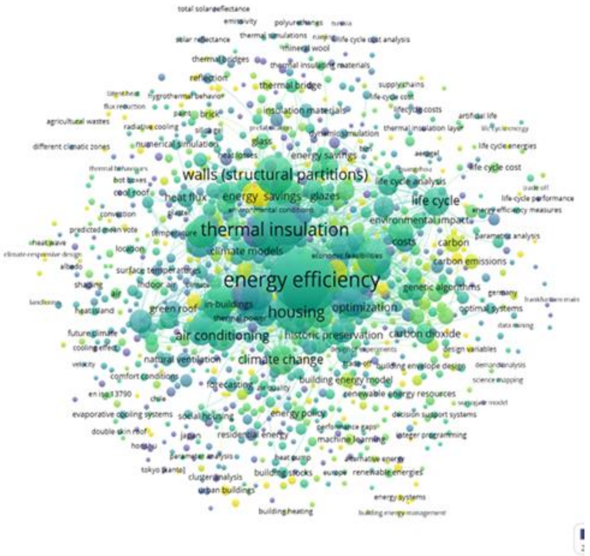

Fig 2 Overlay Visualization

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.

4.4 Citation analysis

Table 1. Most impactful literature reviews

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 presents a collection of the most influential papers in the field of residential building energy efficiency, with a focus on insulation materials and simulation-based design optimization. The most cited work is a comprehensive 50-year review of radiant heating and cooling systems from 2015, with 389 citations, demonstrating the enduring importance of fundamental thermal comfort research. The second most cited paper, with 291 citations, investigates building orientation's impact on energy consumption, highlighting the significance of passive design strategies in residential buildings.

Several highly-cited works focus on early-stage design decisions and envelope optimization, including a multi-objective analysis of heating, cooling, and lighting performance (263 citations) and research on optimal envelope systems in Saudi Arabia (156 citations). The presence of multiple papers from 2020 with significant citation counts, particularly those focusing on seasonal energy storage and artificial neural network applications, indicates the field's evolution toward advanced computational methods and innovative energy solutions.

The table also reveals strong research interest in green building technologies, exemplified by studies on green roof performance in different climates (211 citations) and Mediterranean settings (162 citations). The inclusion of works on structural lightweight concrete (152 citations) and optimum insulation thicknesses (152 citations) underscores the importance of material selection and thermal optimization in achieving energy efficiency goals.

This collection of highly-cited works spans both traditional approaches to building energy efficiency and newer computational methods for optimization, reflecting the field's progression from basic principles to more sophisticated, simulation-based integration strategies for optimal design.

4.5 Density Visualization

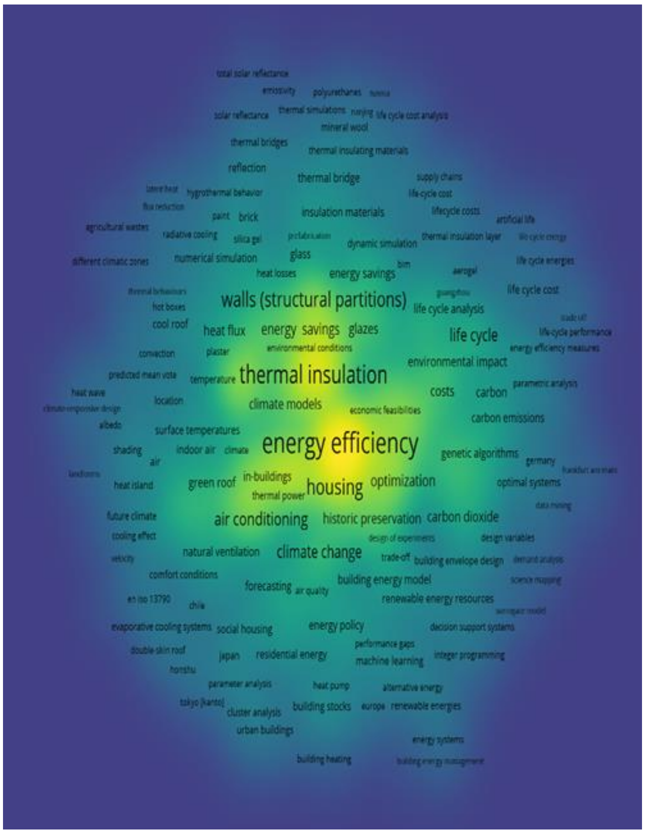

Fig 3 Density Visualization

The density visualization presents a comprehensive map of research terms and relationships in the field of building energy efficiency. At its core, the visualization employs a sophisticated heat map approach, utilizing a color gradient that transitions from an intense yellow center to green-blue intermediate areas, and finally to darker blue peripheries. This color scheme effectively represents the varying degrees of term relationships and their prominence in the literature.

At the heart of the visualization, "energy efficiency" emerges as the dominant concept, marked by the brightest yellow coloring and largest text size. This central hub is closely flanked by "housing" and "thermal insulation," forming a triangular core of fundamental concepts in the field. "Building envelopes" and "walls (structural partitions)" also maintain strong presence near this central cluster, indicating their crucial role in energy efficiency research.

Moving outward from the center, the visualization reveals a middle layer of significant terms in green-blue coloring. This intermediate zone includes important concepts such as "climate change," "air conditioning," "energy savings," and "building energy model." These terms demonstrate substantial connectivity to the core concepts while also branching out to more specialized areas. "Architectural design" and "thermal comfort" also appear in this middle range, suggesting their role as bridging concepts between technical and practical applications.

The outer periphery of the visualization, characterized by darker blue coloring, contains more specialized or emerging terms. These include technical elements like "evaporative cooling systems," "double-skin roof," and "mineral wool," as well as broader concepts like "total solar reflectance" and "agricultural wastes." The presence of terms like "machine learning" and "parameter analysis" in these outer regions suggests emerging technological approaches in the field. The spatial arrangement of these terms, while avoiding overlap, effectively demonstrates their relationships to more central concepts while maintaining visual clarity.

4.6 Author Collaboration Network

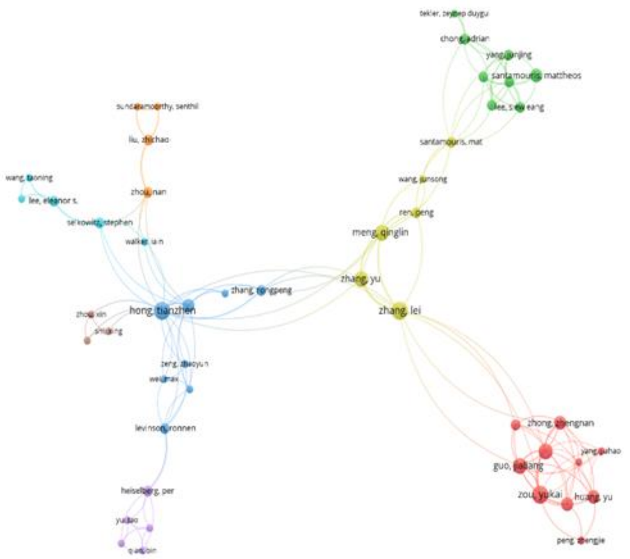

Fig 4 Author Visualization

The author collaboration map represents the spectrum of co-authorship and the community of the researchers in the field. There are distinct four groups within it – green for the first cluster, blue for the second, red for the third and yellow for the fourth; Such color marks mean that it contains four different research communities, which have, obviously, different dynamics and topics. However, in most of these clusters, several authors can be seen as central to the advances made within the field. Among the blue group hue, tianzhen has many cooperative links, and zhang, lei acts as the link between the several research groups.

Looking at the red cluster at the bottom right, zhong/zhengnan is very central; and the green cluster at the top right shows dense coupling among the researchers consisting of chong adrian, yang junjing, and santamouris.

The network resembles different types of collaboration intensities: a core formed by closely connected individuals and groups seen in the red component; and blue links, which depict a more chained cooperation; and researchers with few connections at the edges of community. All in all, even though the research communities are quite distinct, a number of links connecting the clusters suggest moderate cross-group interactions. The overall spatial configuration of network can best capture all the natural boundaries within and between a set of research disciplines while at the same time mapping the connectivity that sustains the divides. This structure indicates a field which integrates more focused research within specific groups with the targeted cross-organizational cooperation.

5. Conclusion

This work clearly makes a strong implication that increasing energy efficiency in residential building is crucial and casts a spotlight between the conventional insulation materials and the simulation method. These and traditional materials like wool, cork, and cellulose can be the environmentally friendly and inexpensive approaches providing enhanced thermal comfort and energy savings. But these materials have problems regarding strength, life span and other factors of the environment. Available synthetic insulations may outperform natural ones in terms of thermal conductivity coefficient, but their production and usage are linked to a high level of energy consumption and possible negative impacts on the environment. At the same time refined simulation instruments, such as BIM or EnergyPlus, allow accurate assessments of the material properties and the general performance of the building. However, more work has been done on the usage of traditional materials in simulation frameworks which is still found to be very limited, giving room for future research.

The analysis shows that the interest in the topics of this field has been gradually on the rise within the past several years, as the number of publications and citations has been rising. Such a growth demonstrates society's need to address energy efficiency on a more extensive scale influenced by sustainability and climate change goals. In that regard, this study is intended to be of use to researchers, architects, engineers, and policymakers in that 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.

6. Recommendations

6.1 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.

6.2 Theoretical Implications

Theoretically, there is a pressing need to foster interdisciplinary research bridging material science, computational modeling, 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.

6.3 Future Research Directions

For future work, there is a 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.

Author contributions

Mohamed Gabr: All credit of the study goes to him as he is the only author.

Conflicts of interest

The author declares no conflicts of interest.

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