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Review

The Role of the Energy Use in Buildings in Front of Climate Change: Reviewing a System's Challenging Future

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Abstract: Energy keeps the global economy alive, while also being extensively exposed to various climate change impacts. In this context, severe business competition (e.g., the building sector) and the unwise use of natural resources and ecosystem services (e.g., fossil fuel energy sources) seem to sharpen the relevant effects of climate change. Indicatively, contemporary issues at the interface of building energy performance and environmental quality levels include consequences from global warming, the increasing release of carbon dioxide to peak electrical loads, power grids, and building planning, and energy demand and supply issues. In light of such concerns, the present review paper attempts to disclose the multifaceted and multidisciplinary character of building energy use at the interface of the economy, the environment, and society against climate change. This review highlights energy efficiency concepts, production, distribution, consumption patterns, and relevant technological improvements. Interestingly, the reviewed contributions in the relevant literature reveal the need and necessity to alter the energy mix and relevant energy use issues. These include developments in climate-proof and effective systems regarding climate change impacts and shocks. Practical implications indicate that the sustainable development goals for clean energy and climate action should be followed if we wish to bring a sustainable future closer and faster to our reality.

Keywords: climate change; building energy use; energy efficiency; sustainable future

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1. Introduction

The sustainable use of resources or efficient allocation can lead to low-performance rates of natural systems (e.g., overconsumption, overexploitation). These issues correlate widely with unstructured, unplanned, and intense economic activities and human intervention (e.g., built environment, land coverage). As a result, already severe climate change conditions are sharpening. In turn, this situation reflects the availability (e.g., supply and demand perspective), sustainability (e.g., fossil fuels or renewables), and quality status of the provided ecosystem services—for instance, provisioning services, such as energy. Conventional energy is derived from scarce resources, and governments should use it conservatively and efficiently [1]. The targeted outcome supports the never-ending pursuit of optimizing resource exploitation within the limits set by natural dynamics and socio-economic forces. Supportively, ref. [2] claims that investigating the relationship between environmental indicators and macroeconomic variables is highly important to foster relevant policies like, for instance, fiscal policies on CO_2 emissions.

Energy systems emphasize the concept of green buildings offering an engineering and science base [3]. Moreover, the interdependencies of energy systems and building constraints (e.g., engineering, planning, design, carbon footprints) are crucial to achieving carbon-neutral building energy systems throughout their lifecycle [4]. Buildings are considered the most significant energy-saving space in the world, and they remain suitable fields to apply technologies for emission reduction [5]. Ref. [6] notes that the building stock relies primarily on energy generated by fossil fuels for heating and cooling purposes.

From this perspective, seeing how climate change interrelates with building energy use and efficiency would be beneficial. Both affect energy systems extensively, which in turn interrelate with environmental quality. This is a great opportunity to review and understand how the concept of 'buildings' affects the transition toward sustainable development. The present study aims to thoroughly review high-impact research efforts that discuss the impacts of climate change and building energy-related issues at the interface. The current review is led by the following research question: "What are the effects of climate change on buildings' power and energy systems concerning existing research?" To accomplish this study purpose, we process an integrative review process to meet the purpose of this study. Ref. [7] claims that integrative reviews interrelate to varied data sources, enhancing a holistic understanding of the topic in question and confronting the complexity inherent in scientific research.

Energy resource availability seems to be one of the most critical research issues, especially about building sectors' concerns. Correspondingly, the challenge lies in recognizing high-leverage interventions, such as today's decisions on future building energy trends, might create fundamental changes for improving energy systems. These significant concerns stimulated our research to explore relevant literature and gather inputs and insights across science in light of a better future. What are the effects of climate change on energy production, distribution, and consumption related to building end-use demand? What are the prospects? How might these changes affect economic growth and welfare status? Are there any established linkages and causalities? These are challenging questions in academia and business, which pursue pathways to optimize resources and processes to 'build' sustainability within the economic system. For instance, this becomes evident in high-energy demand sectors (e.g., the building sector) and relevant consumption patterns (e.g., end-use needs).

However, these considerations do not reproduce significant progress to achieve the desired balance between socioeconomic and nature dynamics, even though relevant literature has stressed the significance of energy efficiency in high-leverage industries. An integrative review of climate change impacts on building energy-related issues has yet to be processed.

The structure of the paper is the following: The Methodology section presents the theoretical background of the review process followed in this study. The next section includes the data extraction process. The following two sections concentrate on the building energy review process and the results of this study. The Recommendation section focuses on the gathered information, gaps, and future research perspectives. Finally, the last section concludes the results.

2. Methodology

By perceiving the challenge of exploiting natural resources sustainably, this study broadly reviews a series of selected published studies that discuss the climate change impacts on power and energy systems.

Whether systematic or integrative, literature reviews offer a way of summarizing individual research studies and other types of articles. Thus, these reviews integrate current topic knowledge [8]. It should be mentioned that the main difference between the systematic and the integrative review process is that the former concerns experimental study trials. The latter considers both non-experimental and experimental studies.

The present study processes an integrative review to gather and summarize previous research efforts on power and energy systems. This process allows the researcher to understand the issues of interest more deeply and thoroughly. Supportively, the integrative review approach includes a wide range of methodologies. For instance, experimental and non-experimental research, theoretical or empirical, and qualitative or quantitative studies offer great applicability for multiple research fields. Interestingly, ref. [9] asserts that such a process aims to define concepts, review theories and 'gaps,' contribute to the literature, and analyze methodologies adopted to describe research issues. In this framework, such an approach is suitable for a scope broadly related to a phenomenon or the research field of interest [7]. An integrative review process provides opportunities to incorporate findings and analysis of information into decision-making processes.

According to ref. [10], researchers adopt the integrative literature review since it exceeds merely analyzing and synthesizing research findings or primary studies [11]. They also argue that this process allows for integrating qualitative and quantitative data, opinions, discussion papers, and policy documents. This process adds sources of scientific information, creating a more comprehensive understanding of the specific phenomenon under research [12–14]. The integrative review provides a challenge to integrate existing knowledge from various communities of practice and recommend future initiatives for research [15].

Furthermore, as ref. [7] reports, little attention has been paid to efforts combining empirical and theoretical reports. The integrative review process widely considers this issue. As a review method, it also increases its potential to turn primary research methods into a more significant part of evidence-based practice initiatives. Consequently, the value of this process highlights its broadest character and enhances rigor. In this perspective, an integrative review process comprises five steps: problem identification, literature search, data evaluation, data analysis, and presentation of findings. Such an approach facilitates a researcher's review effort to integrate concepts, theories, evidence, and methodologies for the topic in question [16].

Integrative literature reviews are suitable to address mature research fields and topics or new, developing, emerging scientific issues as a research topic matures and the interest in the literature increases. Consequently, the relevant knowledge base is expanding and growing for this particular topic [17].

When processed in a detailed, well-organized, and thoughtful manner, many benefits derive from an integrative review process. For instance, strength evaluation of the reviewed studies' evidence, gap identification, research opportunities for further research efforts, integration (bridging) of relevant areas in a scientific domain, identification of core issues in science, generation of a research question, identification of conceptual and theoretical frameworks, and exploration of all successful methods used from researchers to reach results [18]. Consequently, in practical terms, it is an inclusive way to summarize various types of evidence justified by many methodologies, whereas it delivers a wider scientific view of the topic [11].

Receiving background knowledge from a sizable body of reviewed studies can lead current research efforts to define the scope and extent of a research topic [19]. Multiple types of data sources permit synthesizing the findings and identifying the main topic under review, enabling authors to develop a new understanding of the topic [20]. Figure 1 presents the steps to obtain the final number of reviewed publications (flowchart).

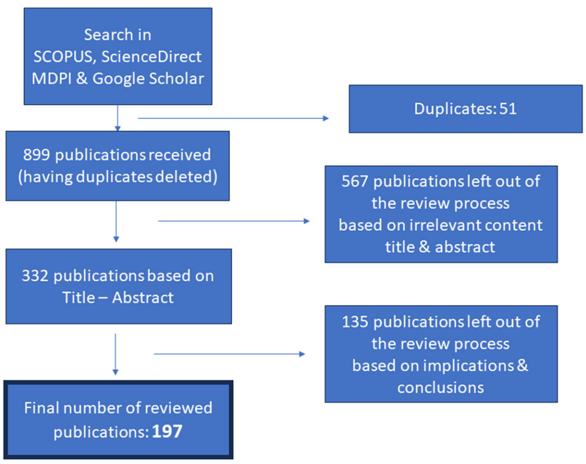

Figure 1. Steps to process this study's integrative review.

3. Data

This study's integrative review process was structured based on reliable and accredited publications within the scientific community. Search terms included energy systems, energy consumption, energy production, energy distribution, energy efficiency, energy growth nexus, power systems, electrical power, climate change impacts, climate adaptation, climate mitigation, renewable energy, and energy mix. Three of the most popular, acknowledged, and dependable databases were used to retrieve published studies relevant to the purpose of the present work: Scopus, Science Direct, and MDPI. The literature review was extended by searching the Google search engine and relevant Google Scholar data to find peer-reviewed articles published in journals indexed in the abovementioned databases. After receiving results, papers were screened for duplicates or slight relevance with the subject of interest. Essentially, publications were excluded if the study's primary purpose was not aligned with the impacts of climate change on buildings' power and energy systems. Then, studies were evaluated based on the Abstract and eligibility criteria. Criteria for keeping the studies for further review were the explicit purpose of the study, conclusions, and specific theoretical and practical implications based on test results or contributions. Another criterion was the novelty of methodologies used to support their scientific argument. Each study was thoroughly read and then listed based on the classification needs of this integrative review process. Particularly, the inclusion criteria for proceeding further with the review process were: a well-defined and visibly justified contribution to the relevant literature (e.g., research gap); the paper should have undertaken a blind peer-review process before getting published; the year of publication (e.g., studies published after the year 2000); robustness and reliability of methodology adopted; and language restrictions (e.g., written in the English language). Our data extraction purpose was to focus on and carefully analyze studies that have made acknowledged contributions to the relevant literature. Additionally, studies should have meticulously progressed relevant research efforts concerning climate change and its impacts on power and energy systems.

The review process included a variety of methods, materials, and tools used in scientific approaches from different viewpoints. These methods should highlight the multifaceted and interdisciplinary nature of the research subject. Diversity in methodology and variations in research results were identified during the process. A comprehensive analysis of the studies was made to classify points of relevance to the present effort. Then, comparisons with similar papers on the same research field took place. Next, determination of trends and tendencies in the literature was implemented. Last, the integration and summation of the significant findings related to the thematic field of the present review process was completed.

This followed data extraction process of the present study remains very constructive in retrieving each study's desired vital points and research results. To increase the reliability of this work, the data extraction process was carefully made and double-checked by both authors to overcome mistakes due to data entry errors and potential misinterpretations of concepts and methodologies of reviewed published studies.

The data extraction process allowed us to receive 197 publications. These selected publications were divided into seven categories based on their thematic field. Table 1 presents the number of retrieved studies based on the thematic area. Table 2 shows the number of reviewed studies based on the year of publication. Figure 2 illustrates a spider chart for data from Table 1, whereas Figure 3 concerns an additional spider chart from Table 2. Figure 4 shows the total number of reviewed studies. Furthermore, a trend analysis has been added (Figure 5) considering the number of publications per reference year to have a complete picture of the received results.

Table 1. Thematic fields and reviewed studies.

Building Materials	Data Analysis (e.g., Econometric Analysis)	Methods and Technology (e.g., Benchmarking Methods, Smart Technology	Model Optimization (e.g., Building Energy Systems)	Occupants (e.g., Behavior)	Policy (e.g., Policy Plans, Frameworks)	Simulations and Scenarios (e.g., Heating, Cooling, Energy Use)
11	40	35	35	27	11	38

Table 2. Reviewed studies based on year of publication.

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	2	4	0	4	0	1	4	5	2
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
5	6	19	8	10	12	9	9	9	8
2020	**2021**	**2022**	**2023**						
14	8	24	33						

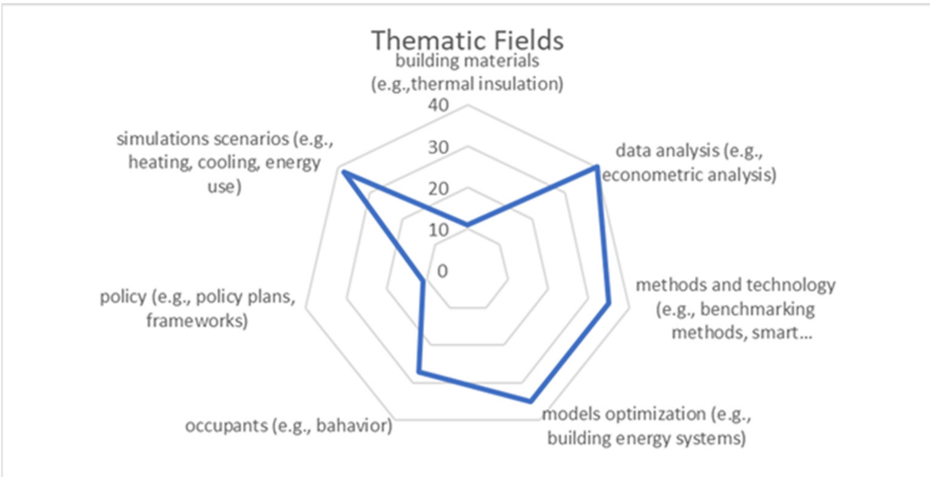

Figure 2. Spider chart for thematic fields and reviewed studies.

Figure 3. Spider chart for reviewed studies based on year of publication.

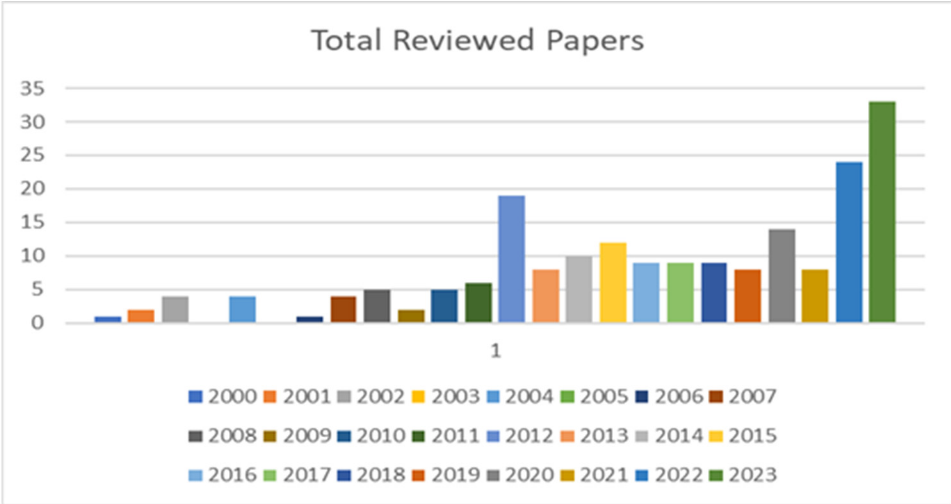

Figure 4. Chart for the total number of reviewed papers.

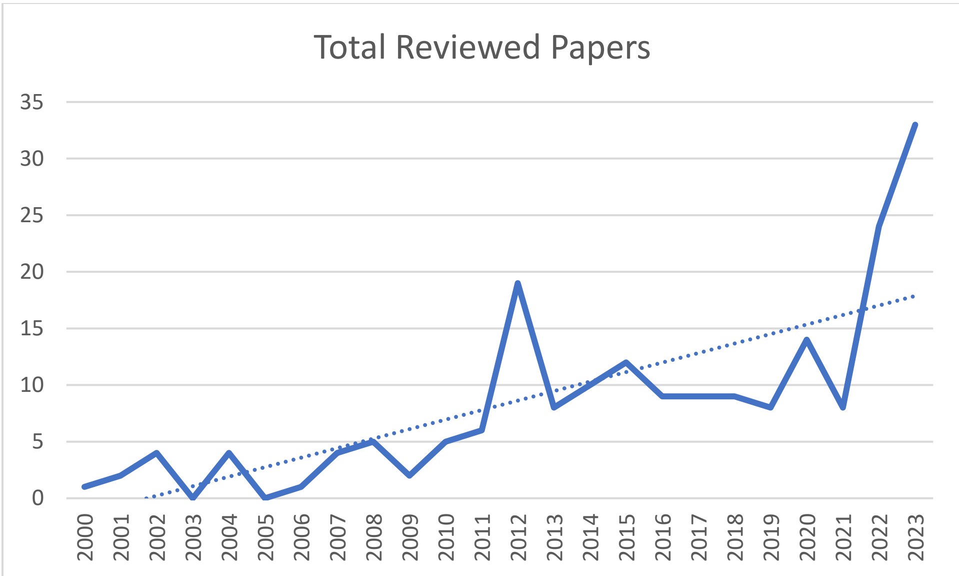

Figure 5. Trend analysis for the number of publications and reference year. The left axis indicates the number of reviewed publications. The horizontal axis indicates reference years.

4. Buildings and Energy

There is a growing interest in energy use and consumption and its environmental implications. This is mainly due to fossil fuel use, over time, rapidly and gradually, as the core energy source and the related greenhouse gas emissions (GHGs) and carbon dioxide ("CO_2") releases. This situation results in raising the global temperature to a great extent. Buildings contribute largely to energy-related emissions [21]. Therefore, the role of buildings (e.g., residential, non-residential) and their lifespan in this process (e.g., energy demand, energy-related emissions, emissions footprint) are considered fundamental. Ref. [22] mentions that the energy supply side should be able to cover future energy demands. In turn, energy demand varies based on various factors. As indicated in ref. [23], the critical determinants behind the building energy service demand vary according to different trends in the socio-economic system, technological factors, behavioral aspects, climate issues [24–27], and numerous electrification pathways. One key issue for limiting energy consumption regarding demand reduction concerns improving building stocks [28]. Buildings concretely represent the energy used in various processes (e.g., mining, processing, manufacturing, and transporting building materials) and the energy consumed in constructing and decommissioning the buildings [21]. Given the long lifetime of buildings, estimated at 50 years, it is significant to review their response to climate change throughout the years. The future perspectives on energy consumption (e.g., heating and cooling) should be considered. Not surprisingly, the issue of energy use in buildings can be incorporated into well-structured and organized mitigation and adaptation measures against climate change. Interestingly, this seems to be a high-impact issue related to weather conditions, climate zones, and energy efficiency. Energy efficiency concerns technological advancements and smart energy systems that use less energy to produce the same or better outcomes and tasks. It was calculated that in 2002, buildings globally accounted for about 33% of the world's GHGs [29]. Recent estimations indicate that buildings still cause 36% of the European Union's energy-related GHGs [30]. This issue in the building sector is currently at the top of the agenda signifying its importance in reaching the European Union's energy and climate objectives for 2030 and 2050. Specifically, ref. [31] clearly states that from 2028 new public sector buildings will be zero-emission. Additionally, from 2030 all new buildings will be zero-emission buildings. The agreement launched a new energy category for buildings, "A0", concerning energy performance certificates indicating zero-emission buildings. The final target is to activate renovations, move forward to a gradual phase-out of the worst-performing buildings, and improve profoundly regarding the national building stock. This means better and more energy-efficient buildings will result in a decarbonized building stock by 2050. Furthermore, these targets are expressed thoroughly in ref. [32] for improving the well-being of people and a net-zero age. Interestingly, ref. [33] conducted a study concerning the Building Renovation Passport (BRP) concept in terms of definitions and content (structure) to offer useful building-related documentation.

Given such worries, more sustainable investments will become a reality (e.g., buildings with eco-friendly materials and advanced energy systems). People (e.g., entrepreneurs and individuals) will make more informed decisions regarding energy-saving and cost-saving options (e.g., heating, cooling, and running appliances and devices). According to ref. [34], it is an imperative need to improve the energy intensity per square meter concerning the building sector by 30% by 2030 to stay consistent with the Paris Agreement climate goals. From Figure 6, which demonstrates the annual "CO_2" emissions globally, we conclude that the building sector accounts for 27% of global "CO_2" emissions [35]. Figure 7 presents the heating degree days (y-axis) for the United States, European Union, and China. Figure 8 illustrates the cooling degree days in summer (y-axis) for the United States, European Union, and China.

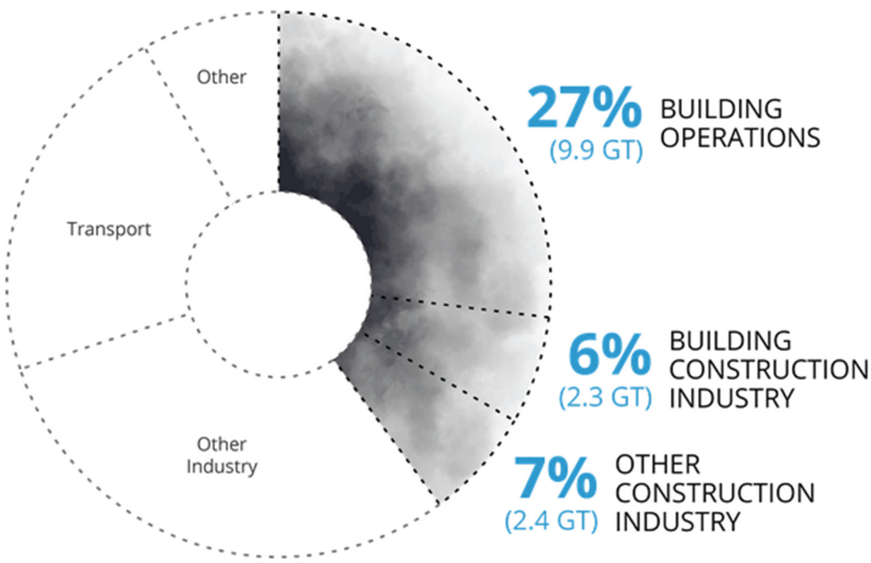

Figure 6. Global "CO_2" emissions, annually–globally [35].

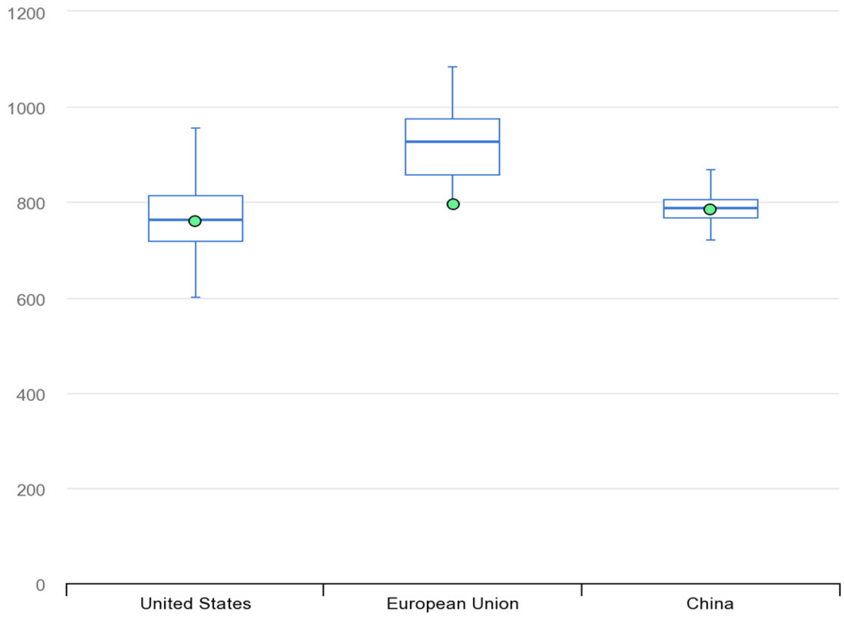

Figure 7. Heating degree days in winter months. The blue box plot indicates the period 2000–2021 on average. The green bullet indicates the year 2022 [36].

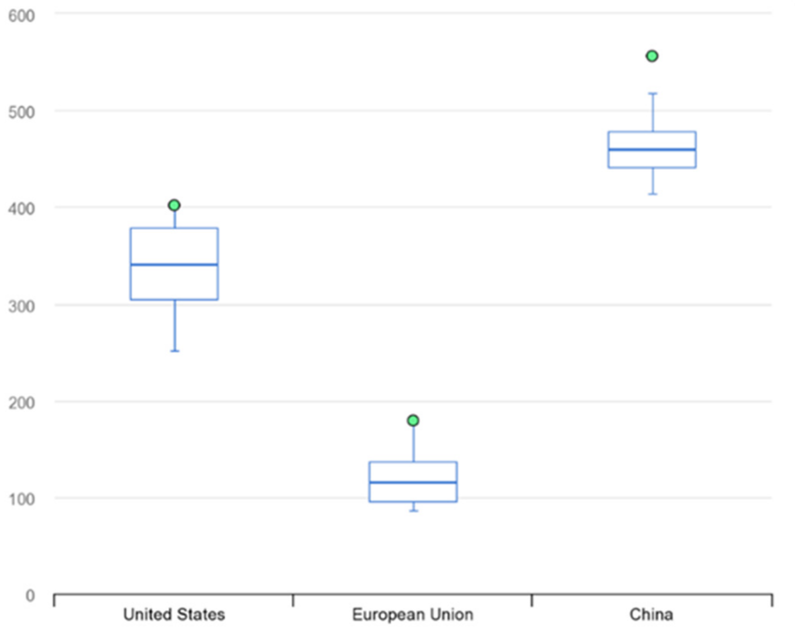

Figure 8. Cooling degree days in summer months. The blue box plot indicates the period 2000–2021 on average. The green bullet points for the year 2022 [36].

According to ref. [36], emissions were increased due to fossil fuel power plants covering consumption needs for excess cooling demand during extreme summer heat. Cooling degree days in 2022 exceeded typical levels or even the maximum level seen for 2000–2021. Furthermore, for the year 2021, cooling and heating consumption needs from extreme weather increased global emissions by around 60 Mt "CO_2". Two-thirds of this are due to additional cooling needs. The remaining one-third came from heating needs. This accounted for almost one-fifth of the total worldwide rise in "CO_2" releases. Improving energy efficiency in buildings seems a promising way to reach, or at least considerably approach, the carbon neutrality target by 2050. From this perspective, ref. [26] asserts that improvements in the building stock and advancements concerning commercial equipment and household appliances can positively impact energy use and building services. This will result in limiting "CO_2" emissions. Experts should specifically set minimum levels of energy performance requirements (standards), such as appliance and equipment standards or building energy codes [25]. Furthermore, ref. [37] argues that energy efficiency efforts should be categorized into the following sections: envelope design, form, orientation and height, ventilation, carbon emission, renewable energies, and occupant behavior. The review concerned 48 studies considering the energy and carbon performance of high-rise buildings (HRB) between 2005–2020. In the literature review in ref. [38], 134 studies were systematically reviewed. The focus was on multiple topics for improving energy efficiency by limiting devastating impacts on the environment with socio-economic concerns. This research interrelates Sustainability Development Goals, namely SDG11, which considers sustainability in cities and communities, and SDG13, which concerns climate action.

Literature on climate change impacts on building energy consumption is increasing, driven by the need to process adaptation measures since they can greatly safeguard the built environment's long-term integrity and effective operation [39]. According to ref. [40], studies related to the impacts of climate change on buildings can be grouped into five categories: (i) estimation of impacts concerning energy consumption; (ii) adaptation and mitigation measures for buildings toward combating adverse effects of climate change; (iii) models for building retrofitting and renovation to handle the climate change; (iv) creation of new methods and tools for making projections for future conditions; (v) handling and estimating uncertainty concerning climate projection models and relevant impacts on building simulation results. Ref. [23] highlights the role of uncertainties when making projections and relevant estimations for energy consumption patterns and "CO_2" emissions in the case of buildings. Notably, ref. [41] presents three methodological phases to evaluate climate change impacts on buildings. The first phase includes the study context identification, which concerns the geographical context and the building typology. The second phase refers to future weather prediction. This phase considers the selection of emission scenarios, global circulation models (GSMs), downscaling techniques, weather file types, and study periods. The third phase relates to energy consumption prediction, and concerns dynamical simulation models and regression models to compare future time slices with a reference period.

The energy transition concept is widely acknowledged in the literature as a shift in the so-called 'energy paradigm', namely replacing fossil fuels with renewable energy sources to decarbonize energy systems [42]. In this effort, authors stress the importance of the 'energy triangle' approach: (i) generate electricity directly from renewables; (ii) use electricity as the core energy vector; and (iii) electrification of end-use. This 'jump' from fossil fuels to renewables constitutes an answer provider, a fundamental response against 'quick fixes' or 'easy solutions' that treat only symptoms of problems. Tackling effectively (e.g., building planning) and efficiently (e.g., using wisely resource materials) the impacts of climate change requires deep knowledge of the current situation. Forecasts for future scenarios and proactive rather than reactive behavior from all stakeholders are essential. This series of events will provide spatial planners, policy and decision-makers, and officials an advantage to prevent worse situations. The role of buildings in this process is fundamental. In this regard, ref. [43] emphasizes the energy efficiency benchmarking of buildings. It is an accurate technique to measure, track, and limit end-use energy usage of buildings by adopting comparative scenarios. This approach discloses opportunities to order energy-saving processes, such as modifications to end-use appliances or building operations. The proposed approach employs machine-learning techniques to maximize accuracy and precision compared to other benchmarking methods [44–46]. Data gathering and availability of relevant information to process simulation models and use tools and techniques to evaluate building performance is crucial. For instance, ref. [47] asserts that the precise provision of data (e.g., daily, monthly) concerning a typical meteorological year (TMY) is a requirement and important task. With this procedure, we can evaluate building energy consumption, which impacts the good use of outdoor data for building energy conservation. Consequently, in the absence of adequate data provision, the predictive power of models and the dependability of results are in question. To overcome these difficulties, ref. [48] proposes a building information modeling (BIM) and building energy modeling (BEM) process grounded on a 3D laser scanning process. Geometric information on the existing building can be implemented in the case of inadequate information to run building energy models. Moreover, ref. [49] developed a new approach that combines machine learning and a domain knowledge-based expert system. This system is helpful to increase building energy flexibility supported by a rule-based expert system and a decision tree model. Authors conceptualize energy flexibility as indicators related to cost and energy-saving margins (potential), load, and peak shaving efficiency.

Officials in ref. [6] state that by 2030, GHG emissions of buildings within the European Union must be limited by 60%, final energy consumption by at least 14%, and energy consumption for heating and cooling purposes by 18%, compared to 2015 levels. Researchers who recognize such a need constantly develop tools to evaluate energy efficiency and take corrective actions for embedding sustainability into the building sector. Ref. [50] completed one of these works. The authors highlight buildings' spatial and functional dimensions and incorporate them into urban building energy modeling (UBEM). They apply such an approach to forecasting hourly heat load profiles of residential buildings using detailed building simulation tools. This effort is vital for high-resolution results concerning spatial and temporal dimensions. The literature stresses the significance of UBEM, especially in modeling large-scale buildings. For instance, ref. [51] systematically processed a literature review considering physics-based modeling techniques. The main purpose was to assess conservation energy-related measures.

Given the multiple outstanding studies concerning sufficiency, efficiency, and renewables for attaining goals for reducing GHGs and energy demand, ref. [52] identified a gap in achieving building energy sufficiency (BES) in the building operational phase. They considered not only energy or emissions requirements but also addressed occupant demand. The definition of BES varies in the relevant literature. In the building sector, occupant demands are categorized into four categories: time and space, quality and quantity, control and adjustment, and flexibility, matching human well-being with building energy sufficiency. Energy sufficiency is defined as "a state in which the population's basic needs for energy services are met equitably and ecological limits are respected" [53]. An issue that is more than challenging, contemporary, and important to achieve sustainability. Refs. [54,55] mention that lifestyle and occupant behavior can be recognized as crucial determinants impacting buildings' final energy use.

Technological advancements and innovations in the construction and use of buildings are important for experiencing sustainability goals. This is how smart technology enters the equation of building energy efficiency. Notably, ref. [56] states that data-driven models for occupancy prediction are appropriate (e.g., indoor environmental data-driven model) with machine learning techniques. In this context, Bluetooth Low Energy (BLE) technology promises to increase energy efficiency in buildings. Notably, such a smart technology approach identifies a set of occupancy profiles representing the varied occupancy patterns observed in the research area [57]. Interestingly, technology-oriented solutions help to reduce energy consumption with a positive impact on protecting the built environment. However, technological solutions and innovations concerning materials used are demanding and complex issues since buildings comprise dynamic systems, and the occupants demonstrate different behaviors in a complex mode [54].

Current and future researchers should motivate, inspire, and guide further innovative achievements, models, and applications to maximize space for energy efficiency and drastically limit energy use in buildings. Given the conditions in socio-economic systems worldwide, this is a multidisciplinary task with many variables in the 'equation' of sustainable development (GHGs, "CO2" emissions) and predictors of building energy consumption and efficiency.

5. Results

The review process discloses the results of selected articles. This study aimed to release contemporary issues from reviewed articles concerning climate change impacts derived from building energy use and related GHGs and "CO_2" emissions. These results can be further examined for inclusion in decision-making processes. They can also contribute to formulating energy management schemes and building planning for energy-efficient buildings. Ref. [58] concludes that using remotely sensed data when making predictions for energy efficiency levels of buildings brings opportunities for future work. This work can integrate additional data sources compared to on-site, in-field visits of certified energy auditors, which might make the whole process slow, costly, and geographically incomplete. The research concerned data from 40,000 buildings in the United Kingdom. Accordingly, technology plays a unique role in promptly getting things done efficiently, accurately, and cost-effectively. For instance, using the Internet of Things (IoT) smart ecosystems helps reach decisions that can benefit all stakeholders in the energy system [59]. Supportively, ref. [60] proposes a novel IoT-based occupancy-driven plug load management system. Energy use reduction is feasible with these systems' help, whereas their applicability promises a building-wide implementation. Review results show that these issues deeply interrelate with the concepts of 'smart' or 'intelligent' buildings. Interestingly, advanced technology helps make predictions, define occupancy profiles, and adjust heating, ventilating, and air conditioning (HVAC) operations. Then, we expand our ability in light of limiting building energy consumption [61]. This is especially the case in building lighting, a fundamental issue in the literature. Since artificial lighting accounts for 19% of energy consumption in building environments, advanced lighting control systems facilitate occupants to regulate or customize their luminance preferences (indicatively see ref. [62]).

Climate change mainly impacts building-energy demand by increasing or decreasing the demand needs for cooling and heating. Building technologies (e.g., building equipment and shell, renovations to the building stocks) contribute primarily to achieving energy-efficient buildings [25]. Ref. [22] concludes that climate change affects residential demand due to average temperature rise, weather conditions, and space heating and cooling needs. Future energy and electricity consumption demand considerations are associated with numerous factors: environmental (e.g., energy mix and renewables inclusion) and socioeconomic factors (e.g., severe market competition and energy use, production lines, and innovations). The main methods adopted to estimate the future residential demand use are parametric, energy balance, and degree-day models [22]. Another method is the building energy simulation technique [21]. Various energy simulation tools are processed to elaborate on energy and "CO_2" building performance and energy efficiency gains. All are targeted to enrich strategies and plans for decreasing the environmental impact of buildings due to climate change. Ref. [63] stated that no validated tool could precisely and explicitly simulate buildings' power demand; for instance, at the city level. Thus, space for further improvements and deployments of new models is present and comparable to existing ones.

Optimization methods and settings always play a significant role in processing scenarios. They help draw safe conclusions about how buildings will behave and evaluate their resilience and mitigation capacity [40]. Energy efficiency issues are also critical [64]. Interestingly, machine learning and a domain knowledge-based expert system ease building demand-side management while they advance the building's energy design and control systems for greater demand flexibility [49]. Review results show that energy flexibility is vital for keeping a power grid sustainable and resilient. Furthermore, it is a significant measure to decrease utility costs for building owners [65]. Moreover, we receive information for building characteristics (e.g., energy consumption) based on machine learning methods from various authors, such as [66–68], as well as for energy efficiency inputs based on deep learning-based multi-source data fusion frameworks [69].

Energy sufficiency is highly important since it comprises one of the three energy sustainability strategies, following energy efficiency and renewables [70]. The authors elaborated on 230 sufficiency-related policy measures from a systematic document analysis. They searched the European national energy and climate plans (NECPs) and long-term strategies (LTSs). They concluded that relevant regulatory frameworks comprise a valuable instrument to achieve great sufficiency rates concerning national energy management plans in European Union countries.

Mitigation and adaptation alternatives challenge the potential to handle changing conditions of climate. Mitigation measures can be applied to building envelopes and internal loads [71,72]. Dropping the lighting load density is a great energy-saving option, mainly applied in cooling-dominated buildings in warmer climates [73]. Ref. [74] found that an improved artificial light source (e.g., LED lamp technology) will support constant solar lighting and energy efficiency in indoor illumination. The role of technology always remains crucial in using less energy without losing the desired output. Climate adaptation measures should be appropriately planned when designing buildings and at the operation stages to limit significantly negative impacts [75].

The preceding results stemming from the reviewed studies focused on minimizing the devastating impacts of buildings and energy needs regarding climate change conditions. Consequently, links exist among energy demand, the building and construction industry, and climate change impacts. These interrelations question the achievement of a nation's goals toward a sustainable future—an issue that needs continuous efforts, multifaceted approaches, and cooperation. These issues need partnerships in academia and business environment, within countries, across nations, always with a long-term perspective. A crucial issue for receiving benefits from all research efforts remains the proper and ethical circulation of gained knowledge among scientists. Review studies offer this opportunity in favor of advancing the flow of research results, conceptual frameworks, and any other scientific input.

In this context, Figure 9 illustrates the technical aspect at the interface of buildings' efficiency and climate change impacts. This figure showcases how the technical relationships interact with building energy performance and behavior to reduce relevant "CO_2" emissions. Table 3 presents the more popular methods and models processed by reviewed studies to accomplish robust research and make forecasts and projections based on simulations and scenarios, for instance, reduction of energy consumption and relevant "CO_2" emissions. Practically, we wish to increase the contribution of renewables in the energy mix for residential and non-residential buildings, and reviewed studies with technical aspects concerns, including the fundamental role of building design and building envelope and materials to experience building efficiency. A wide range of technical factors should be put together to achieve the outcome of using less energy without losing quality. For instance, the thermal performance of materials, buildings' thermal insulation (e.g., walls, ceilings, roofs), and buildings' systems (e.g., HVAC control systems and occupants' energy use profiles) were the subject of research to increase efficiency, avoid diminished comfort, identify energy use patterns, gather data, and prevent energy loss. The reviewed studies stress the importance of using eco-friendly materials and replacing traditional or conventional ones. Indicatively, the authors highlight the need to use insulated concrete forms instead of traditional poured concrete in building foundations. Furthermore, the authors propose to replace spray-foam insulation with structured insulated panels in buildings' structural framing.

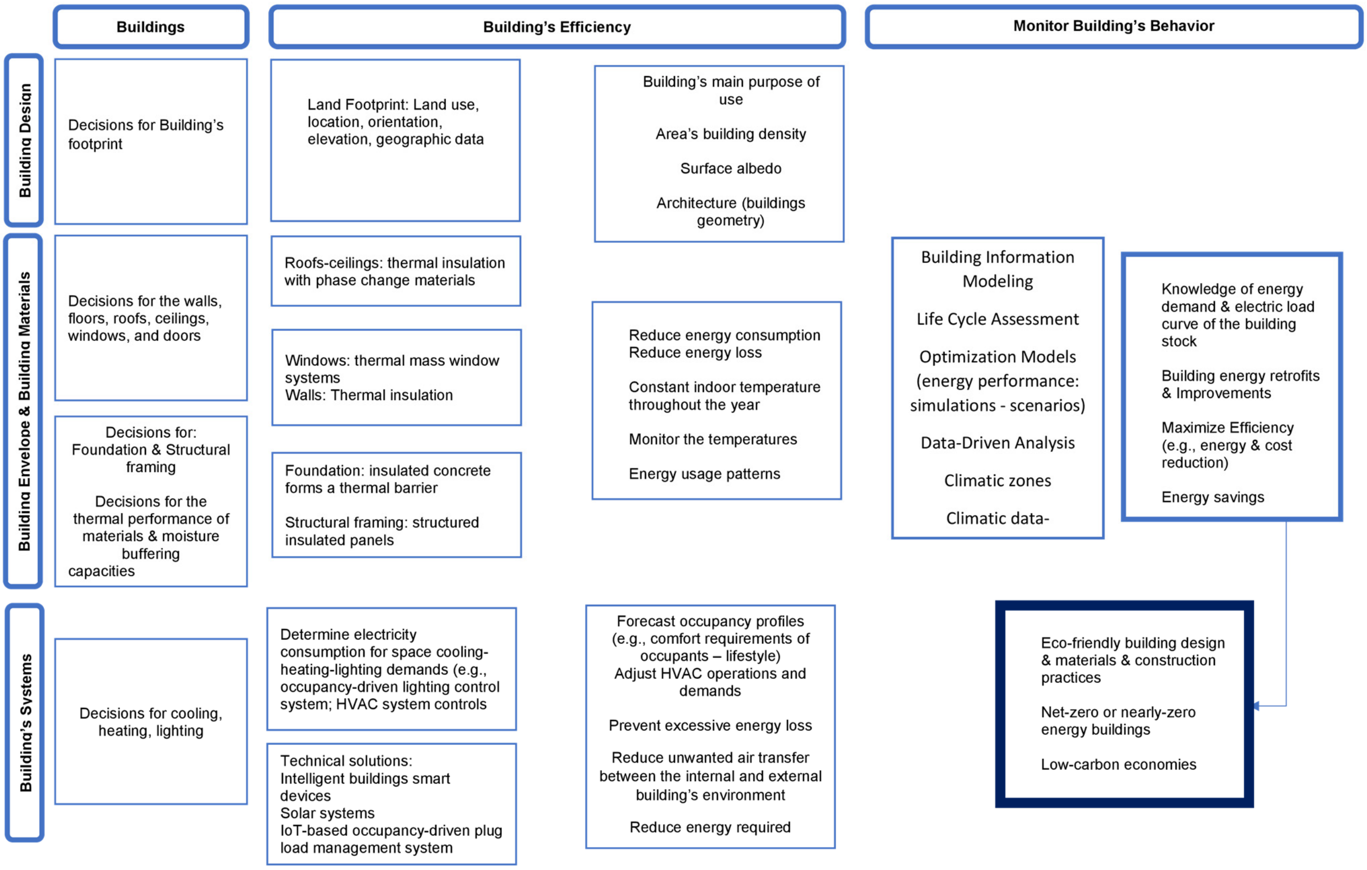

Figure 9. Technical aspects at the interface of buildings' energy efficiency and climate.

Table 3. Reviewed data-driven econometric methods and optimization models.

Data-Driven Analysis		**Optimization Methods**	
Econometric models—specifications (e.g., regression models—statistical analysis)	Qualitative and quantitative analysis	*Simulations Scenarios (e.g., energy modeling, occupancy prediction models, building stock models)*	Classifications algorithms
	Panel data analysis		Computational methods and software
	Parametric and sensitivity analysis		GIS-driven statistical models
	Social network analysis Quadratic assignment procedure		Benchmarking models
	Data mining methods and analysis		Machine learning models

Energy optimization models (e.g., scenarios and simulations) will direct the distribution and transmission endeavors to reduce linkages and power grid problems (e.g., overconsumption, overloading). This sequence of events requires alignment of the energy sector with reduction targets of carbon emissions (e.g., replacement of fossil fuel to produce energy and generate electricity). For this reason, technological advancements and innovations (e.g., intelligent buildings, smart technology, Internet of Things (IoT)-run devices) might keep buildings' energy performance, consumer behavior, and energy use patterns in the desired equilibrium with positive environmental impacts.

6. Recommendations

This study's review covered a wide range of issues and topics related to energy efficiency and the energy footprint of buildings as a function of climate change impacts. All researchers' efforts concentrate on technologies, regulatory frameworks, models, and instruments that help reduce "CO_2" emissions and energy use of buildings. Many studies focus on energy savings and the energy performance of buildings to embed sustainability in the construction phase, operation, and lifecycle of buildings. Ref. [76] underlines the necessity for highly energy-efficient and decarbonized building stock toward a decrease of 19%, at least by 2050. Supportively, it is central to advance the energy efficiency of buildings to reach the targets of a carbon emission peak by 2030 and carbon neutrality by 2060 [77,78]. Indicatively, in the case of the European Union, energy performance certificates provide a pathway to determine the energy efficiency of buildings [79]. These figures are not simply numerical values or percentages, but mirror the current reality; they mark future objectives and call for immediate action to advance the built environment.

At a time of increasing interest in developing 'green' consumption patterns, the relationship between energy and high-leverage market sectors (e.g., the building sector) seems to be a motivating topic for research. All efforts should focus on managing natural and technical resources to meet all environmental, economic, and social needs; for instance, from construction to building operations and occupant behavior. Perceiving these responses' direction, magnitude, linkages, and causalities allow researchers to anticipate environmental changes better and adapt as necessary. Interestingly, switching focus from short-term management plans to long-term strategies based on comprehensive and sophisticated research efforts is a promising way to bring sustainability to the building sector.

Keeping the momentum active, methodologies and econometric models (e.g., panel data or time series analysis) are significant. These methodologies investigate linkages, causalities, and long-term relationships. They decode impacts between growth variables at a macro level and energy-related variables. In turn, researchers can use variables or proxies or indicators that reflect building performance, efficiency, sufficiency, flexibility, demand, end-use, resilience, and request of the energy grid operator. This approach needs further development since it is scarce, untested, or insufficiently mentioned.

For instance, a set of variables for further elaboration could be building energy consumption rates or British thermal units (BTUs) from cooling and heating devices (air-conditioning) in different climate zones and seasons. This approach could impact environmental degradation or growth rates in the context of the Environmental Kuznets Curve (EKC) hypothesis and energy growth nexus discussion. This approach can be adopted for a group of countries (e.g., eurozone member states, OECD countries, G7 countries, G20 countries, Asian countries, and USA states. Another interesting point would be the inclusion of high-leverage and profitable market sectors (e.g., the construction sector) under the same econometric modeling. In this approach, data received from various techniques mentioned in this study could widely benefit such an approach. This perspective might have needed to be more visible to the broader community within natural and socioeconomic systems for energy-related issues.

Indicatively, ref. [80] states that the energy-growth nexus concentrates on the contribution of energy as a factor of production in the economic sector. Consequently, this approach helps to reach results concerning the sensitivity of the growth process against energy conservation measures. In particular, concerns are visible regarding the optimum equilibrium between use—users and demand—growth [81] (Ekonomou and Halkos, 2023). Hence, we obtain feedback for regulating energy consumption. For instance, for limiting greenhouse emissions and fossil fuel resource depletion in the presence of climate change. This is an unexplored area in the case of buildings, and future opportunities for thorough research are present, particularly for highly energy-dependent economies.

Another interesting point is the EKC hypothesis test. Refs. [82,83] explored the linkage between environmental quality and the economy in the EKC hypothesis context. They determined a specific point after which the growth process does not impact environmental quality levels. In this strand of literature, variables that determine building energy-related variables are absent. For instance, "CO_2" emissions from buildings could enter the EKC equation for further research. Given the importance of the building sector in the economic system, researchers should grasp the opportunity and open a new debate based on this approach. Building materials should be eco-friendly with thermal insulation characteristics to 'arm' buildings capable of becoming efficient. Indicatively, we mention replacing poured concrete with insulated concrete and using structured insulated panels instead of spray foam insulation in buildings' structural framing (see [84,85]).

Many researchers utilize building model simulations, use databases, and establish scientific arguments based on forecasts and projections with environmental concerns. One additional research field that can be matched with these research findings would be their impacts on welfare status concerning the Index of Sustainable Economic Welfare (ISEW). These results can interrelate with relevant climate change impacts. Ref. [1] elaborates further on inputs and insights we gain when investigating the role of ISEW in the interaction of energy and economic growth.

Individual behavior regarding energy use and building appliances and devices is a crucial issue that deserves our scientific attention. This issue directly connects pro-environmental behavior, environmental awareness, and everyday life's eco-friendly attitude. Lifestyle trends and ways of thinking and acting (e.g., mindset, culture) affect building energy demand and use. In this perspective, one could process empirical research focusing on willingness to pay for energy quality improvements (e.g., renewables, solar panels, photovoltaics, smart technologies) in buildings (e.g., residential and non-residential buildings). For instance, this approach can be processed on a city scale or neighborhood. Moreover, the willingness to accept living and acting in conventional, traditional buildings that impact environmental quality levels can be explored. The received results can be matched with climate change impacts. These preference-stated methods can benefit climate change mitigation and adaptation plans. Furthermore, estimating the total economic value concerning the effects of climate change on building an environmental footprint is a valuable addition to scientific research. Consequently, they can guide the relevant absorption of economic resources and utilization of financial instruments. Indicatively, in the case of the European Union, an option could be the National Strategic Reference Framework (ESPA). This financial instrument can advance building environmental performance against climate change. These issues and topics remain less visible in the relevant literature.

Last but not least, we must act individually and collectively under interdisciplinary teams. The goal is to reach tangible and measurable results and yield prosperity in human life, in which a practical role is assigned to the built environment.

We should note that many authors have adopted the PRISMA flowchart (indicatively see [86]) to visualize and conduct their review process. This approach is highly referenced and recommended in the relevant literature and is dependable for conducting similar reviews.

7. Conclusions

The present integrative review study concerns the climate change impacts in the presence of energy-related issues attributed to buildings. Buildings play a fundamental role in preserving air quality (e.g., "CO_2" emissions), type of energy resource use (e.g., fossil fuels against renewables), and energy demand and end-use issues. Reviewed articles resulted from a comprehensive review process from well-acknowledged databases: SCOPUS, ScienceDirect, and MDPI. All reviewed articles contributed to relevant literature on a wide range of issues. Indicatively, studies presented in this work concern building simulation modeling, energy efficiency issues, technology and innovations, and energy sufficiency matters.

Results indicate that energy efficiency is an issue under continuous research and optimization methods to receive data and make projections and forecasts for future scenarios. This is a demanding and challenging issue. Sustainable energy use is not an issue of customization, but an integrated concept profoundly related to energy efficiency. Gathered knowledge suggests that building stocks and materials must limit devastating environmental effects in light of climate change conditions. Mitigation and adaptation strategies call for the integration of 'green' patterns in the building sector and consider maximizing the percentage of renewables in the energy mix related to building consumption. Environmental benefits from reducing energy consumption rely on improving machine learning and knowledge-based methods and techniques. Researchers constantly improve these issues by offering new understandings of building environmental performance.

Future challenges call for demonstrating a proactive character, individually and collectively, if we wish to experience a better future in the built environment. New areas for further research arise. Empirical studies can be implemented to investigate linkages of building environmental indicators with economic growth rates and environmental degradation regarding climate change impacts.

Considering all of the above, the role of buildings in preserving the natural and human environment is vital. We anticipate that the present review study will benefit current and future research to move closer, safer, and faster to sustainable building environments and combat climate change drastically.

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