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Review

The State of the Art of Residential Building Energy Retrofits in Libya and Neighbouring Mediterranean Countries: A Comprehensive Review

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Abstract: With the increasing concern about global warming and future climate change, attention has been drawn to the need to reduce building energy use through improving buildings' energy efficiency. Existing residential buildings constitute the largest percentage of energy demand and carbon dioxide emissions, and hence, offer significant potential for energy savings and reductions in greenhouse gas emissions. This review aimed to provide an in-depth analysis of current research on improving the energy efficiency of existing residential buildings in Libya and neighbouring Mediterranean countries, with a focus on research methods and tools utilised in this domain. This helped to identify potential areas of intervention to improve the energy efficiency of existing residential stock in Libya. Under identified themes, this study systematically analysed 44 publications of high relevance to the subject area found in Scopus, ScienceDirect, and Google Scholar. The results reveal that while energy retrofitting is a research area of interest in the region considered, studies in the Libyan context are limited. There is also limited attention to achieving net zero energy and embodied carbon reductions, specifically in the Libyan context. Moreover, some weaknesses were identified for most of the studies reviewed, including those in the Libyan context, related to the credibility and reliability of the energy models used in the various literature.

Keywords: existing residential buildings; building energy retrofit; building energy modelling (BEM); building model calibration; building energy simulation; model optimisation; net zero energy buildings (NZEBs)

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1. Introduction

Over 35% of global energy consumption and 40% of energy-related CO_2 emissions are attributed to the building and construction industries [1,2] (Figure 1). Moreover, energy use in residential buildings is found to constitute the largest percentages of energy demand and carbon dioxide emissions [3]. In Libya, residential buildings contribute 36% of the total electricity consumption [4]. Therefore, if the energy consumed by residential buildings could be reduced by retrofit measures, this would potentially have a considerable impact on CO_2 emissions. This paper systematically reviews the relevant literature, focusing on energy retrofitting in residential buildings in Mediterranean countries, with a particular focus on the Libyan context.

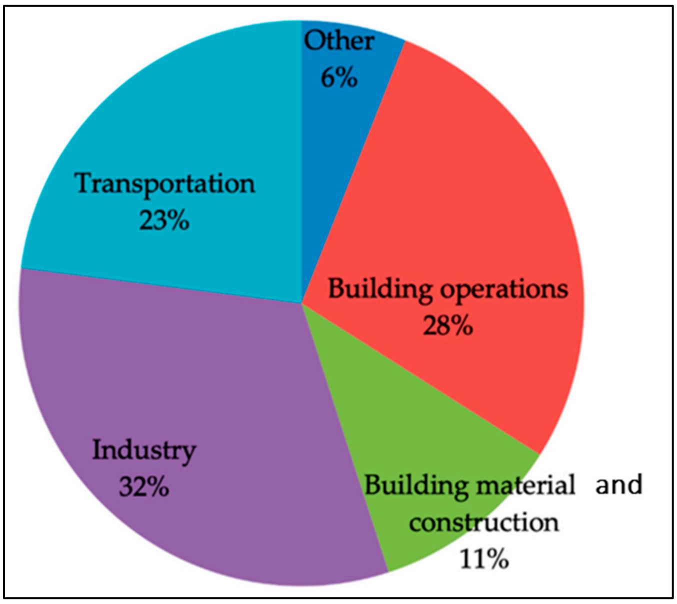

Figure 1. Global CO_2 emissions by sector [2].

This review aimed to identify the most widely addressed energy efficiency measures for retrofitting existing residential buildings in Libya and neighbouring Mediterranean countries, and to identify the research methods and tools adopted in this process. Understanding the current state of energy efficiency in existing residential buildings in Mediterranean countries will help identify potential areas of intervention to improve the energy efficiency of existing residential stock in Libya. Figure 2 shows the locations of Libya and neighbouring Mediterranean countries included in this review.

Figure 2. The locations of Libya and neighbouring Mediterranean countries included in this review [5].

2. Materials and Methods

To explore energy retrofitting measures in residential buildings and to determine the corresponding research methods and tools adopted, the authors decided to undertake a systematic review. This method of reviewing the literature was appropriate to provide a critical overview of the previous studies and assess their quality, as well as to identify gaps in the existing knowledge. This review therefore accomplished its aims by following the search strategy and flow diagram for the Preferred Reporting Items for Systematic Reviews or Meta-analyses (PRISMA), developed by the Centre for Reviews and Dissemination to help authors improve the reporting of systematic reviews [6]. However, this review did not fully follow the PRISMA method but rather certain aspects of PRISMA.

2.1. Inclusion and Exclusion Criteria

To obtain a preliminary data set, a protocol comprising the inclusion criteria and analysis method were developed. Major research engines, namely, Scopus, ScienceDirect, and Google Scholar, were employed to search for published articles on energy efficiency in residential buildings in Mediterranean countries including Libya.

Inclusion and exclusion criteria were used to remove irrelevant articles and to include articles with a primary focus on residential building retrofits that have been published in the most recent years. This review included English-only manuscripts; research work on Libya and the surrounding Mediterranean countries; and work presented in conferences and academic journal publications, including journals focusing on empirical work and building performance simulation.

For the literature search, specific search terms were employed to search the titles, abstracts, and keywords of published papers. The search terms chosen were as follows: TITLE-ABS-KEY ((residential) AND (building*) AND (energy efficiency) AND (Libya)); TITLE-ABS-KEY ((residential) AND (building*) AND (retrofit* OR renovation) AND (Libya)); TITLE-ABS-KEY ((residential) AND (building*) AND (retrofit* OR renovation) AND (Mediterranean)); (Zero) AND (energy) AND (residential) AND (building*) AND (retrofit OR renovation) AND (Libya)) TITLE-ABS-KEY ((Zero) AND (energy) AND (residential) AND (building*) AND (retrofit OR renovation) AND (Mediterranean)).

The search results were exported and the abstracts screened to exclude irrelevant articles. Those articles whose focus was not within the subject area, or which did not meet the inclusion criteria were also excluded. In the next step, the full text of all remaining articles found in all databases were assessed. The articles that met the eligibility criteria were selected for this review. Lastly, the authors carefully reviewed all the included papers to extract specific themes to analyse the papers. This review identified 44 publications of high relevance to the subject area. The results of this review were grouped into two sections: the first section presents a description of the four research themes identified from the reviewed studies, and the second section is devoted to content analysis based on these themes. Finally, the systematic review concludes with a discussion of the content analysis and ends by identifying knowledge gaps.

2.2. Parameters for the Analysis of the Literature

This review analysed each study based on four research themes identified in this review: (a) types of energy retrofit measures, (b) building energy modelling for building retrofits, (c) energy model calibration for building energy retrofits, and (d) optimisation methods.

(a) Type of energy retrofit measure

Energy use in residential buildings can be significantly reduced through the implementation of energy-efficiency measures or ERMs [7]. These measures are broadly classified into the following three main categories: energy conservation, energy generation, and energy management [8] (Figure 3). Retrofit measures for energy conservation include optimising the building envelope through passive measures, such as adding insulation materials and using an efficient window glazing system, as well as using energy efficient systems as active measures. Retrofit measures for energy generation include the use of renewable energy, such as solar photovoltaic (PV) systems. Retrofit measures for energy management involves the consideration of residents' behaviours regarding the use of lighting and equipment and adjusting set point temperatures, in addition to using smart energy systems. Energy-efficiency measures can be implemented individually (single measures), or can be employed in combination (combined measures) for more energy-saving potential [9].

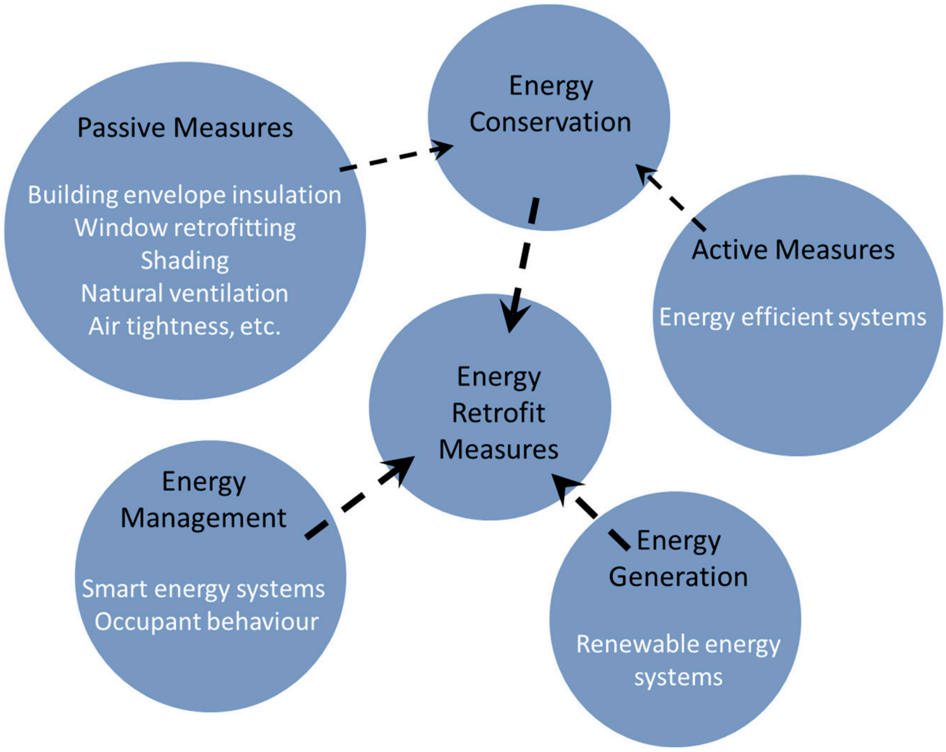

Figure 3. Main categories of building retrofit measures adopted from [8].

(b) Building energy modelling for building retrofit

Building energy modelling is an interdisciplinary field that incorporates concepts and research from electrical and electronics engineering, civil engineering, mechanical engineering, and architecture [10]. It can also be utilised to identify the possible sources and uses of energy in existing buildings and to determine the best options for energy conservation measures [11]. Energy modelling and simulations, which reveal the energy-saving potentials of any energy-saving strategy, are valuable tools in retrofit design [12].

There are many building simulation software packages available currently for whole-building energy performance simulation, with different levels of complexity and response to different variables. These packages include BLAST, DOE 2, eQUEST, TRNSYS, EnergyPlus, Energy Express, EFEN, ESP-r, IDA ICE, IES, and Revit [10,13]. Building energy modelling uses three approaches, including standalone energy simulation tools, such as EnergyPlus; the integration of energy modelling software with 3D modelling software, such as Revit; and all-in-one software, such as DesignBuilder. However, in many studies, EnergyPlus was considered the most complete simulation software tool [14–17]. Muslim [14] conducted a review on simulation tools for building energy. The review revealed that EnergyPlus was the preferred choice for building energy simulation because of its powerful capabilities, multi-platform integration, and extensive validation of its simulation algorithm. Nguyen et al. [18] argued that EnergyPlus demonstrates a high level of reliability in predicting building energy performance.

(c) Energy model calibration for building energy retrofits

Building energy modelling is proposed as an efficient approach to predict the thermal performance of buildings, and as a procedure that assists building designers in evaluating the energy performance of a building, and as a response, making necessary design changes [10–12]. Nonetheless, there is growing concern about the reliability of energy simulation models [19]. Li et al. [20] argued that there is empirical evidence of noticeable discrepancies between actual and simulated building energy performance. The mismatch between the actual and simulated (predicted) building energy performance is referred to as the "performance gap". This can be attributed to the assumptions made during the planning phase of energy retrofitting in existing buildings due to the limited access to data, affecting the validity and dependability of energy models using these assumptions [8]. Chong et al. [19] argued that the performance gap between measured and simulated building energy models has become increasingly evident with the adoption of smart energy meters and the Internet of Things (IoT). Consequently, to narrow the performance gap and to ensure the reliability of the simulation results, building model calibration is useful. Model calibration has become an essential step in building simulation to ensure agreement between the actual and simulated building energy performance, to achieve reliable results, and to allow simulation estimates to more closely match the actual building performance [21–24]. This can be achieved by matching simulation outputs with field investigation measurements using energy meters and monitoring sensors. For model calibration, both the real energy consumption and zone temperature are monitored in different studies for comparison with simulation results to ensure the simulated building models closely match the actual building and to enhance the accuracy of the building's simulation and optimisation results [25–27]. As part of a research project (rp-1051) initiated by ASHRAE in 2005, Reddy et al. [28] categorised building energy simulation calibration methodologies from the existing literature into four groups as follows:

- Calibration based on manual iteration: a technique that involves the adjustment of inputs based on the user's experience until the program output matches the expected data.
- Calibration based on graphical techniques: in this calibration process, certain graphical representations and comparative displays of the results are used to orient the calibration.
- Calibration based on specific tests and analytical procedures: this method is based on measurement tests, such as blower door tests or wall thermal transmittance (U-value). This calibration process is carried out without the use of statistical or mathematical methods.
- Automated methods of calibration that are based on analytical and mathematical approaches: this method is not user driven and relies on an automated process.

The ASHRAE 14 Guidelines assign two statistical indices to evaluate the calibration accuracy: normalised mean bias error (NMBE) and coefficient of variation of the root-mean-squared error (CV(RMSE)) [29]. These errors should be within ±10% and ±30%, respectively, on an hourly basis or ±5% and ±15%, respectively, with monthly data. If the discrepancy between the measured and simulated results falls within the acceptable ranges as defined by the ASHRAE 14 Guidelines, the model building is considered a calibrated model [30]. Otherwise, the source of the discrepancy should be detected and altered such that the simulated building results match the measured ones. Table 1 shows the most frequently used statistical indices for the evaluation of the calibration accuracy in different published energy efficiency guidance, such as that of ASHRAE, FEMP, and IPMVP. After verifying the validity of the simulation by obtaining a simple error rate, the model is considered reliable for the simulation as a base case model.

Table 1. Calibration criteria of the Federal Energy Management Program (FEMP), ASHRAE Guideline 14, and International Performance Measurement and Verification Protocol (IPMVP) [30].

Data Type	Index	FEMP Criteria	ASHRAE Guideline 14	IPMVP
		Calibration Criteria		
Monthly criteria %	*NMBE*	±5	±5	±20
	CV (RMSE)	15	15	-
Hourly criteria %	*NMBE*	±10	±10	±5
	CV (RMSE)	30	30	20

(d) Optimisation method

The term "optimisation" refers to the process of finding the optimal solution to a problem within a set of constraints [31]. In building performance optimisation, a group of variables (x) is set according to a group of criteria, referred to as an objective function (Y), to determine the optimal solution to a problem. Single- and multi-objective optimisation are two different optimisation approaches to identifying the optimal design solution [32]. A single-objective optimisation problem is a problem that has only one objective: one single objective function of one independent variable Y = f(x). Single-objective optimisation can effectively give the "optimal" solutions for a particular objective. However, the designers are not given any information on the effects of the variables to be optimised on the different design objectives. On the other hand, multi-objective optimisation gives designers detailed information for improved decisions [33].

3. Results

3.1. Descriptive Analysis

A preliminary search in Scopus revealed 176 studies. Following screening of the abstracts, 93 irrelevant articles were discarded. The full texts of the remaining records were reviewed to exclude articles that did not meet the eligibility criteria. A total of 33 articles were then excluded, and 50 studies were assessed for eligibility. Thus, a total of 44 published works, including 36 articles in 23 journals and 8 conference papers published in conference proceedings. These studies were carefully reviewed, and important data were extracted and analysed. Figure 4 shows the literature selection criteria adopted in this study. Figure 5 reports the number of included publications by reference type, which shows that these papers had a good-quality literature basis on which to conduct this review. The final screening process, as shown in Figure 6, included 44 relevant studies. There were six studies conducted in Egypt, five studies in Jordan, four studies in Spain, four studies in Algeria, four studies in Greece, three studies in Morocco, three studies in Palestine, three studies in Italy, two studies in Turkey, two studies in France, two studies in Lebanon, two studies in Cyprus and two multi-country studies, one study in Tunisia, and one study in Libya. This illustrated that there was a scarcity of journal articles on residential building retrofitting in the Libyan context.

An analysis of the publication year shows that 68% of the studies were published during the last five years, while the remaining studies were published up to seven years earlier than this (Figure 7). This pattern suggests that energy retrofitting is currently an interesting and widely pursued research area in the region. This is due to the growing significance of energy retrofitting in residential buildings. However, there were very few studies on retrofitting the existing residential stock in Libya, as only one published paper was found in relation to this [34].

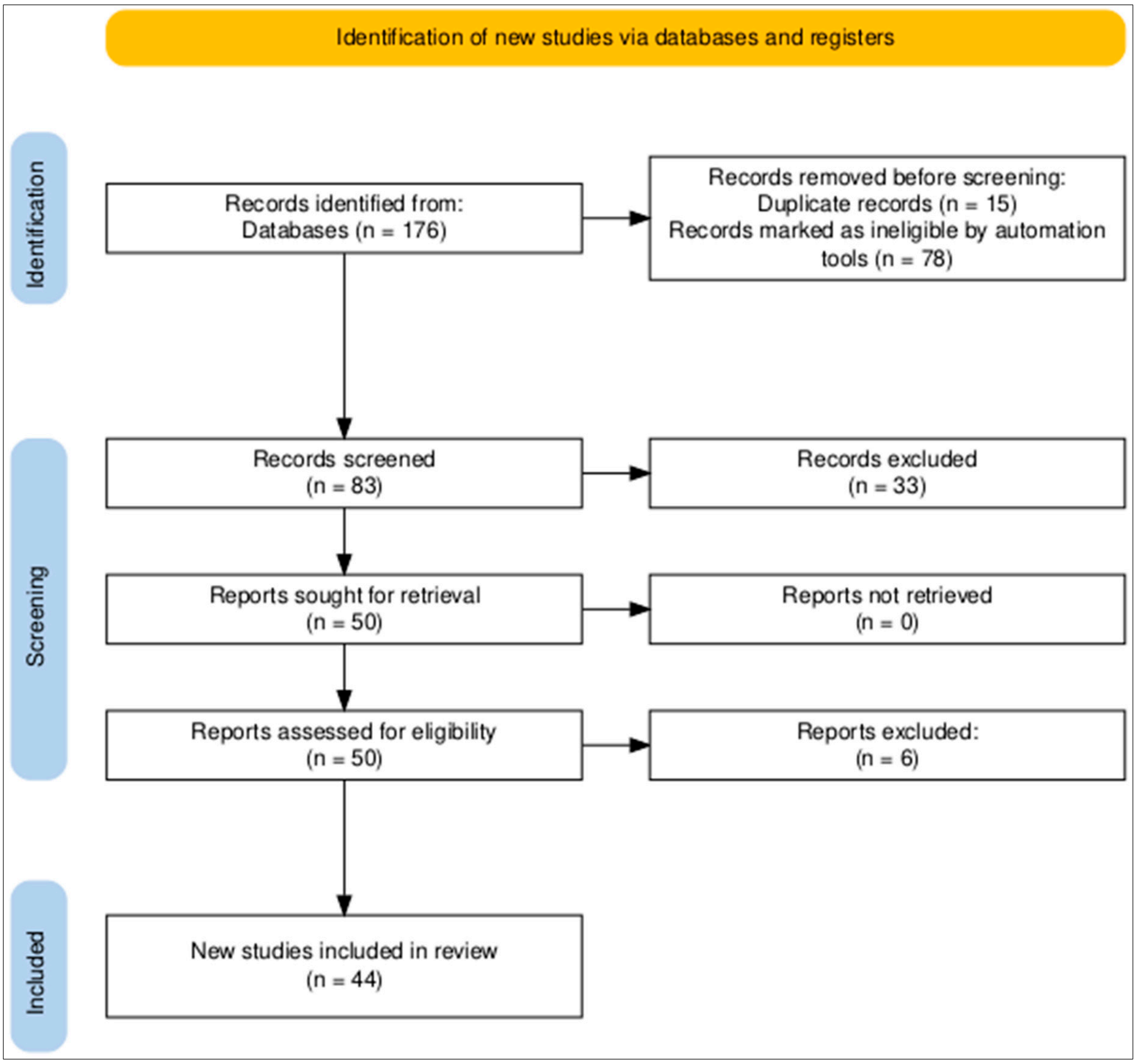

Figure 4. Flow chart for the literature selection criteria.

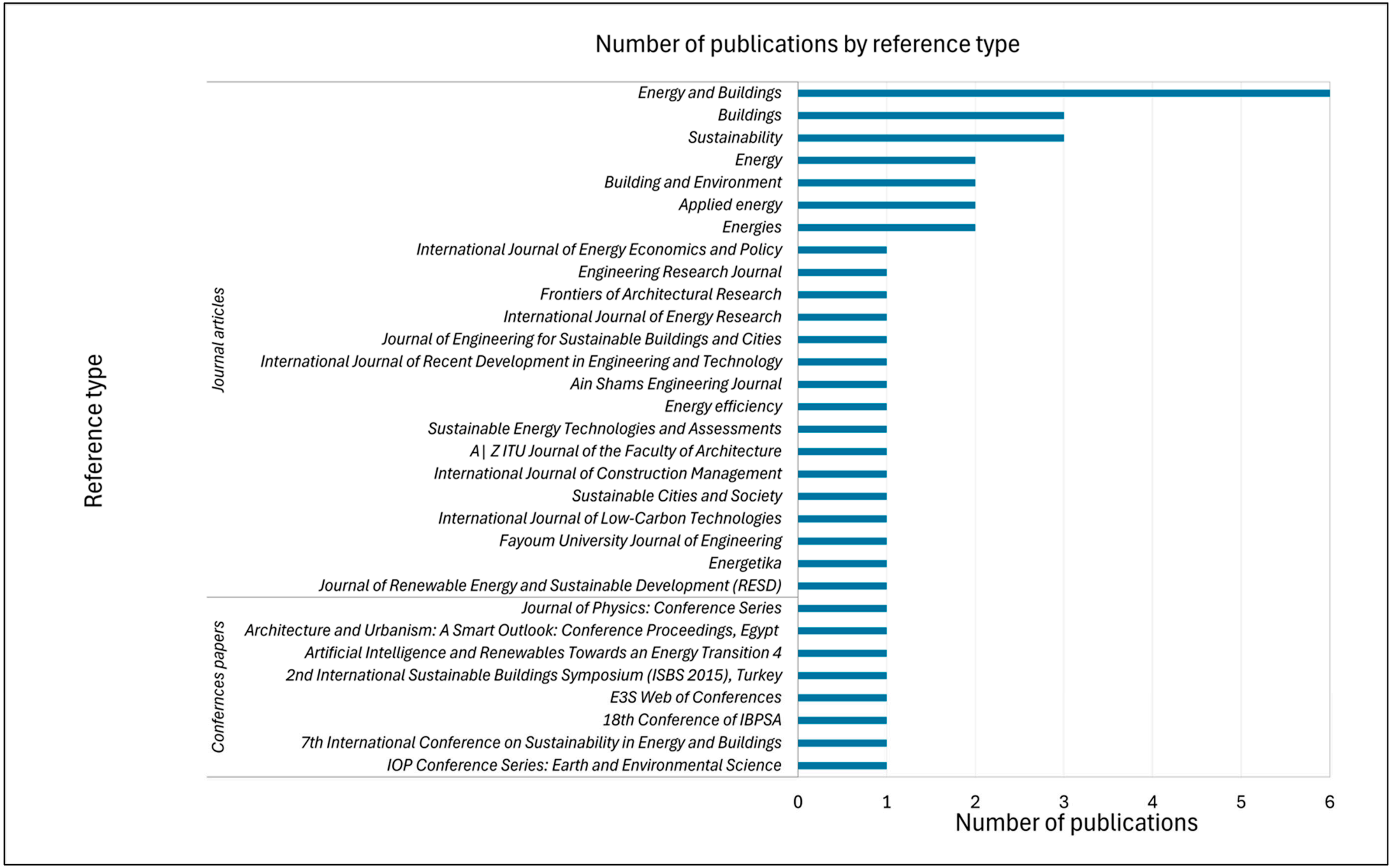

Figure 5. Number of articles per reference type.

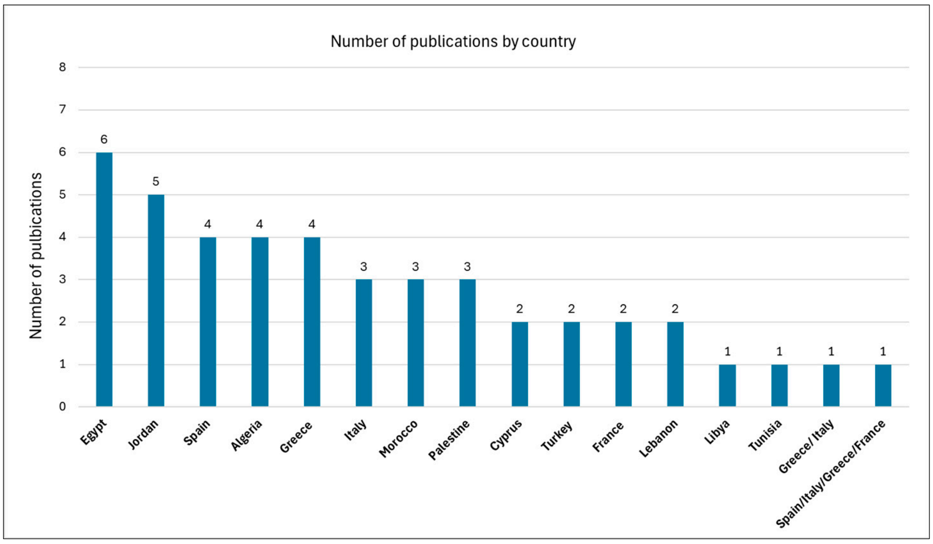

Figure 6. Number of studies by country.

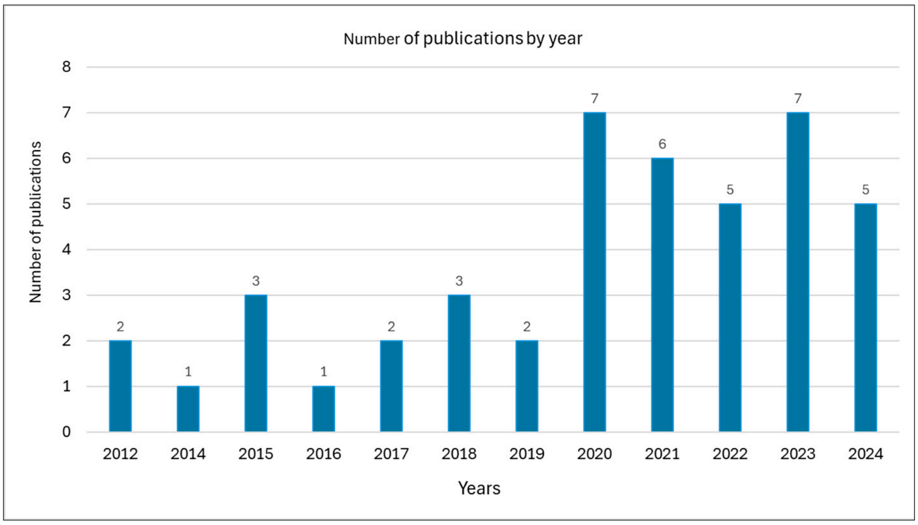

Figure 7. Number of studies by year of publication.

3.2. Results of Analysis of Review Parameters

Table 2 shows the obtained literature for this systematic review. This review analysed each article based on four research themes identified in this review. The four themes were as follows: (a) types of energy retrofit measures, (b) building energy modelling for building retrofit, (c) energy model calibration for building energy retrofits, and (d) optimisation methods.

Table 2. The obtained literature for this systematic review and the themes identified to analyse the literature.

	Reference	Energy Retrofit Measures				BEM Software		Calibration Elements					Optimisation	
			Active Measures						Monitoring					
		Passive Measures	Energy Efficient Systems	Renewable Energy	Embodied Carbon Reduction	3D Modelling Tool	Energy Analysis Software	Energy Bill	Zone Temperature	Energy Consumption	Others	Calibration Indices	Optimisation Method	Optimisation Objectives
1	[35]	x		x		DesignBuilder	EnergyPlus						SOOP	Energy saving
2	[36]	x	x			DesignBuilder	EnergyPlus				x		SOOP	Energy saving
3	[37]	x	x			DesignBuilder	EnergyPlus			x		Graphical	SOOP	Energy saving Life cycle cost
4	[38]	x	x	x		DesignBuilder	EnergyPlus						SOOP	Energy saving Cost effectiveness
5	[39]	x				DesignBuilder	EnergyPlus						SOOP	Energy saving
6	[40]	x				DesignBuilder	EnergyPlus						SOOP	Energy saving
7	[41]	x	x	x		DesignBuilder	EnergyPlus						SOOP	Energy saving
8	[42]	x			x	DesignBuilder	EnergyPlus						SOOP	Energy saving
9	[43]	x				DesignBuilder	EnergyPlus	x				Correlation coefficient	SOOP	Energy saving
10	[44]	x	x			Sketch-up	EnergyPlus						SOOP	Energy saving
11	[45]	x				DesignBuilder	EnergyPlus						MOOP	Energy saving vs. thermal comfort vs. life cycle cost (LCC)
12	[46]	x		x		DesignBuilder	EnergyPlus						SOOP	Energy saving
13	[47]	x				Sketch-up	TRNSYS						SOOP	Energy saving
14	[48]			x		Rhinoceros	Plugins Grasshopper and Ladybug						SOOP	Energy saving
15	[49]	x				Pleiade-Comfie	Comfie						SOOP	Cooling load reduction Heating load reduction
16	[34]	x	x	x		Sketch-up	EnergyPlus						SOOP	Energy saving
17	[50]	x	x			DesignBuilder	EnergyPlus						SOOP	Energy saving
18	[51]	x				DesignBuilder	EnergyPlus			x			SOOP	Energy saving
19	[52]	x				Visual Basic programming language	Ecotect program						SOOP	Energy saving
20	[53]	x				TRNSYS	TRNSYS		x			Temperature difference	SOOP	Energy saving
21	[54]	x				TRNSYS	TRNSYS/jEPlus						SOOP MOOP	Energy saving/ area-weighted mean discomfort degree-hours vs. discomfort degree-hours
22	[55]	x		x		TRNSYS	TRNSYS			x		Mean squared error (MSE) Mean absolute percentage error (MAPE)	SOOP	Energy saving

Table 2. *Cont.*

	Reference	Energy Retrofit Measures				BEM Software		Calibration Elements					Optimisation	
			Active Measures						Monitoring					
		Passive Measures	Energy Efficient Systems	Renewable Energy	Embodied Carbon Reduction	3D Modelling Tool	Energy Analysis Software	Energy Bill	Zone Temperature	Energy Consumption	Others	Calibration Indices	Optimisation Method	Optimisation Objectives
23	[56]	x					GenOpt and TRNSYS		x			Not mentioned	SOOP	Energy saving
24	[57]	x		x		DesignBuilder	Energyplus /PVsyst software						SOOP	Energy saving
25	[58]	x		x		DesignBuilder	Energyplus				x	Error rate %	SOOP	Energy saving
26	[59]	x		x		SketchUp	EnergyPlus						MOOP	Annual energy demand vs. annual energy costs
27	[60]	x	x			DesignBuilder	EnergyPlus				x	Percent deviation	MOOP	Energy saving vs. life cycle cost (LCC)
28	[61]	x				DesignBuilder	EnergyPlus				x	Percent deviation	SOOP	Energy saving
29	[62]	x		x		DesignBuilder	EnergyPlus						SOOP	Energy saving
30	[63]	x	x			DesignBuilder	EnergyPlus		x			CV(RSME)/MBE	SOOP	Energy saving
31	[64]	x				DesignBuilder	EnergyPlus Expert programme for energy generation						SOOP	Energy saving
32	[65]	x				Autodesk Revit	Green Building Studio						SOOP	Energy saving
33	[66]	x	x	x		DesignBuilder	EnergyPlus		x			CV(RMSE), NMBE	SOOP	Energy saving Thermal comfort
34	[67]	x	x			DesignBuilder	EnergyPlus		x			MBE, CV(RMSE)	SOOP	Energy saving Indoor Co2 concentration
35	[68]	x			x	DesignBuilder	EnergyPlus						SOOP	Energy saving
36	[69]	x	x			BEopt	EnergyPlus			x		Percentage difference	MOOP	Energy saving vs. life cycle cost (LCC)
37	[70]	x	x	x		DesignBuilder	EnergyPlus	x					MOOP	Energy saving vs. cost effectiveness
38	[71]	x				DesignBuilder	EnergyPlus						MOOP	Cooling load reduction vs. heating load reduc-tion
39	[72]	x		x		Revit	Revit						SOOP	Energy saving Thermal comfort
40	[73]	x					EnergyPlus						SOOP	Energy saving Thermal comfort

Table 2. *Cont.*

		Energy Retrofit Measures				BEM Software		Calibration Elements					Optimisation	
	Reference		Active Measures		Embodied Carbon Reduction				Monitoring					
		Passive Measures	Energy Efficient Systems	Renewable Energy		3D Modelling Tool	Energy Analysis Software	Energy Bill	Zone Temperature	Energy Consumption	Others	Calibration Indices	Optimisation Method	Optimisation Objectives
41	[74]	x				iSBEM-cy	iSBEM-cy						SOOP	Energy saving
42	[75]	x		x		iSBEM-cy	iSBEM-cy						SOOP	Energy saving/ CO2 reduction
43	[76]	x	x				DOE 2						MOOP	Energy saving vs. life cycle cost (LCC)
44	[77]	x					EnergyPlus		x				SOOP	Energy saving Thermal comfort

3.2.1. Types of Energy Retrofit Measure

Different passive and active ERMs were explored in the research articles, including adding envelope insulation; replacing window glazing; adding window shading; adjusting the WWR; improving the airtightness; boosting the night-time natural ventilation; deploying efficient HVAC systems, lighting, and appliances; and integrating renewable energy sources. However, in the reviewed articles, passive measures showed the highest impact on reducing the energy use. Moreover, adding insulation to the building envelope had the greatest impact among other passive measures. For instance, a typical two-story semi-detached house made with a reinforced concrete roof and hollow concrete block wall with no insulation located in Tripoli, Libya, was investigated using EnergyPlus simulation software with SketchUp and OpenStudio software packages [34]. To improve the building energy efficiency of the case study building, single and combined energy efficiency measures were assessed. These included upgrading the building envelope with expanded polystyrene insulation material, upgrading the lighting system, and the installation of solar water heaters and photovoltaic solar panels to cover the required energy for artificial lights. The study revealed that insulated roofs, which were responsible for the high thermal load, gave the highest energy savings, followed by the wall insulation. The study also found that insulating the roof was more effective at reducing the cooling load than insulating the walls, which showed a higher influence on reducing the heating load than the roof insulation. The study attributed this to the fact that during the summer, solar heat gain from the horizontal surface (roof) is higher than that gained by the vertical surface (walls). A similar finding was observed in the study by Stasi et al. [73]. A study was carried out to examine the application of a phase change material (PCM) with a melting temperature of 25° to the external walls and ceilings of a multi-apartment building located in Italy using an EnergyPlus tool. According to the study result, using the PCM on walls alone increased the heating savings, while a ceiling application maximized the cooling energy savings. Combined solutions provided the most balanced seasonal benefits, which led to the largest overall energy saving while maintaining optimal indoor comfort. On the other hand, window glazing and shading showed the lowest impact on the energy use reduction. For instance, in Alghoul et al.'s study [34], upgrading the single-glazed windows to double-glazed windows had the lowest impact on the energy reduction. This was attributed to the low window-to-wall ratio (WWR) of the studied building. In the case of the low window-to-wall ratio (WWR) both the U-value and SHGC of the energy-efficient glazing had slight influences on the energy consumption [78]. The application of insulation and dynamic thermal mass in the building envelope not only shows a significant impact on the energy use reduction but also reduces the indoor temperature and improves the indoor thermal conditions. For instance, research was conducted on the impact of incorporating phase change material into the building envelope of a two-story house located in the Ghardaïa region, Algeria [47]. A 3D model of the building was developed by SketchUp software and then imported into TRNSYS for the energy simulation. The results show that optimising the building envelope with PCM panels could contribute to annual energy reductions by up to 36.4% and improve the indoor thermal conditions, achieving indoor temperature reductions of between 2.36 °C and 4 °C.

Ground floor insulation was found to be not required for buildings in the Mediterranean climate. For instance, Sobhy et al. [53] studied a family terraced house with a reinforced concrete roof and clay brick walls located in the climate of Morocco using TRNSYS software. The study revealed that roof insulation allowed for reductions in the heating and cooling loads. Adding shading devices and efficient glazing had less influence on the energy reduction compared with insulating the envelope. On the other hand, slab-on-grade floor thermal insulation caused summer overheating, which led to an increase in the demand for cooling.

Based on the reviewed articles, roof and wall insulations were found to be the most influential passive measures for improving the building energy efficiency. However, 94% of the articles considered petroleum-based insulation materials, such as polystyrene fiberglass and polyurethane foam, while biobased materials were investigated in only two studies. One study considered the use of hemp fibres to insulate the building envelope, where it was found that this material achieved the same overall annual energy requirement as when using petroleum-based insulation materials [68]. Another study applied date palm midrib fibres for the envelope insulation. The study also showed that this material improved the energy efficiency effectively as an equivalent to standard insulation [42].

Figure 8 reveals the importance of passive measures in energy reduction. Upgrading the envelope with insulation materials was an approach taken by 89% of the studies, followed by replacing the window glazing, adding shading, and upgrading the airtightness in 54%, 38%, and 20% of the studies, respectively. With regard to the active retrofit measures, an efficient HVAC system showed the highest impact among the other active measures. Other active retrofit measures, such as energy-efficient lighting and appliances, showed less influence on the building energy efficiency and were deployed less in previous research compared with passive retrofit measures. However, the implementation of a PV system as an active retrofit measure for energy generation was investigated in 44% of the research and was found to have a substantial impact on meeting a building's energy needs.

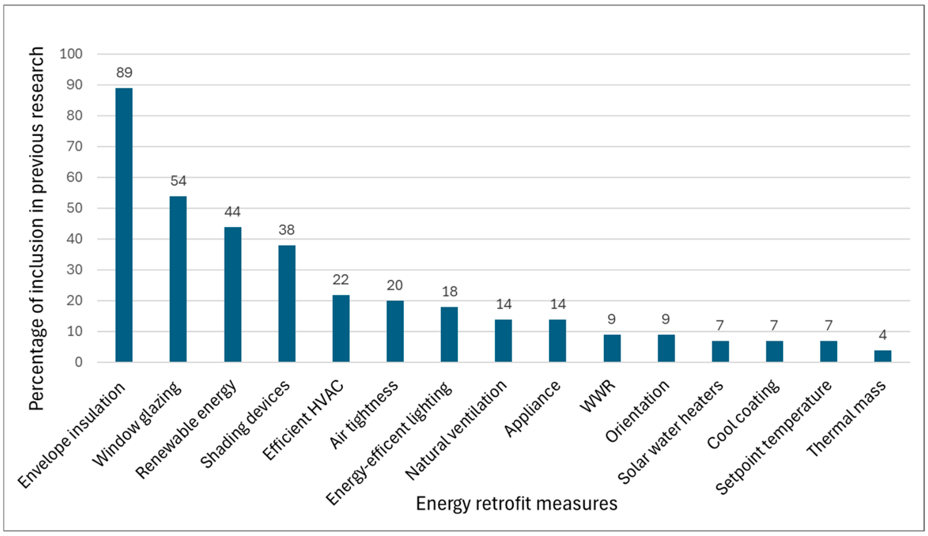

Figure 8. Use of various retrofit measures in previous research.

Energy Retrofit Approaches for Net Zero Energy Residential Buildings

Demand for energy worldwide is expected to increase due to population growth, the development of new cities, and the widespread use of HVAC systems [55]. As part of the global efforts towards reducing the energy use and environmental impacts of buildings and as an urgent necessity in the construction sector to achieve an energy transition, the concept of net zero energy buildings (NZEBs) has emerged [79]. NZEBs are defined as "buildings that generate at least as much energy as they consume on an annual basis when tracked at the building site" [80]. Adly et al. [41] argued that the aim of this concept is to design highly sustainable buildings that rely on two main principles: energy conservation and energy production using renewable resources. Building energy retrofitting and refurbishment through modifications have been suggested to enhance energy performance and reduce the demand for energy [58]. However, the most effective approach to achieving building energy efficiency is through incorporating renewable energy sources on site [81]. Consequently, energy-efficient optimisation employing passive measures and active measures, including the integration of renewable energy sources, enhance the building energy performance.

Several studies were conducted on the reduction of building energy demand to reach zero energy building targets [35,41,46,55,57–59,62,71,72]. For instance, Adly et al. [41] carried out a study to optimise a single-family detached house (villa) located in Cairo, Egypt, by integrating two strategies: energy efficiency retrofitting techniques to reduce the energy demand, and renewable energy systems to generate sufficient energy for the building to meet net zero energy buildings targets. DesignBuilder software was used to passively optimise the building through the application of insulation materials, upgrading of window glazing, and retrofitting of lighting systems. When all the retrofitting types were combined, 22.6% energy reductions were achieved. The roof area allowed for the installation of 44 PV panels angled at 30°, with an electric power of 250 W each. The energy produced by the PV system was calculated manually. The finding of 88.68% energy use reduction suggests that NZEBs could be met by applying these two strategies. Ali et al. [35] aimed to optimise a typical house type located in Irbid, Jordan, using dynamic building energy modelling (DesignBuilder) to achieve a near net zero energy building. The study utilised three optimisation stages: passive measures, active measures, and integration of a photovoltaic system. The simulation results reveal that about 37.81% energy savings could be achieved by applying both passive and active measures. The study on the photovoltaic system using PVsyst software showed that the integration of a PV system could reduce the energy demand further by up to 82.41%. A study to reduce the consumption and improve the thermal comfort for a terraced house was conducted in Nice, France [57]. The study involved the implementation of passive measures, including the addition of insulation to the walls, roofs, and floors; upgrading windows; and minimising the infiltration rate. Accordingly, the building energy demand was reduced by about 50%. To meet the remaining energy needs, integrating photovoltaic panels into the building‘s structure as an active system was studied using PVsyst software. The results reveal that the PV system covered a substantial portion of the electrical energy demand. Therefore, based on the reviewed articles, achieving targets around NZEBs is feasible for Mediterranean climates using a combination of passive and active strategies.

3.2.2. Building Energy Modelling (BEM) for Building Retrofit

The majority of the studies, at around 70%, employed EnergyPlus for building energy simulation, and mostly with DesignBuilder software, which is the most established and advanced user interface of EnergyPlus. About 30% of the total studies used other building energy simulation tools (Figure 9). This result supports previous reviews stating that EnergyPlus is considered as the most complete and reliable simulation tool [82].

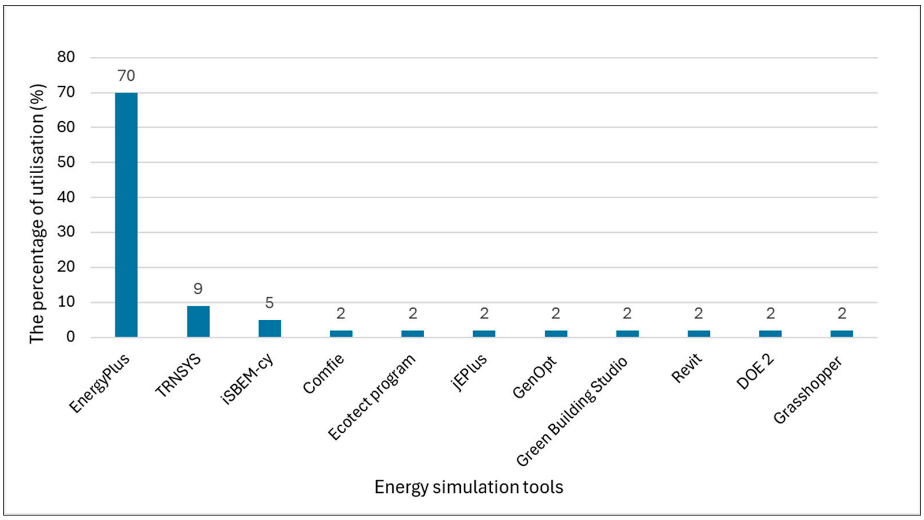

Figure 9. Energy simulation tools identified in this review.

3.2.3. Energy Model Calibration for Building Energy Retrofits

The majority of the studies reviewed did not report calibrating the building energy models to ensure that the models closely represented the actual buildings [35,38–42,44,46–50,72–76,83]. Some studies employed a simple model for conducting the simulation without clarifying how reliable these models were [39,42,84]. Therefore, these models were not fully validated as representatives of the actual buildings, and the optimisation results cannot be taken as a guide for improving the actual buildings' thermal performance. Some studies employed electricity bills for the model calibration. For example, Abdelrady et al. [43] compared the simulation results with the actual energy consumption of an apartment building using the electricity bills of a third-floor apartment to represent the average power consumption of all apartments within the building. The average error and the correlation coefficient were used as indices to calculate the discrepancy between the actual and simulated model, and both indices were found to be within the acceptable range [43]. Other studies employed data from previous studies or government reports to calibrate the case study building model. For instance, due to gaps in governmental reports on utility bills and consumer electricity bills, the space heat conditioning requirements obtained in a study was compared with data provided in previous research with a similar house [58]. Another study compared the baseline energy consumption of the building model with the total electricity consumed in the residential sector based on an annual government report [36]. Kitsopoulou et al. [60] compared the thermal loads of the model simulation results with data calculated in another study for the same building model.

Only five articles adopted model calibration using measured data [37,53,63,66,67]. Royapoor and Roskilly [26] argued that the prediction accuracy of building energy models can be thoroughly assessed using measured data, especially with the availability of environmental and energy monitoring equipment. Bataineh and Al Rabee [37] measured the energy consumption data for a single day and graphically compared this with simulated data. In another study, the actual air temperature of two indoor spaces, measured for a month in summer and a month in winter, were compared based on ASHRAE 14 calibration indices [66]. Caro and Sendra [67] measured the air temperature for two indoor spaces for a typical week in summer and used this for calibration based on the approach of the U.S. Department of Energy, which uses the indices of mean bias error (MBE) and the coefficient of variation of the root-mean-square error (CV(RMSE)) to ensure the accuracy of the simulated model. However, for robust model calibration, and to ensure that the model represents the actual building performance over the year, data measured over a long time and in different seasons of the year are required to avoid discrepancies.

3.2.4. Optimisation Method

With regard to the optimisation methods used, the majority of these studies adopted a single-objective optimisation problem (SOOP), which aims to optimise one variable at a time or multi-variants at a time against one objective function [35–37,39–42,52,55,56,61–63,77]. However, the multi-objective optimisation problem (MOOP), which helps in making decisions that consider trade-offs between two conflicting objectives, was adopted in only seven articles. For example, three studies investigated the trade-off between energy saving and life cycle cost (LCC) [60,69,76]. Ascione et al. [71] investigated the optimal trade-off between summer and winter energy performances. However, despite the importance of thermal comfort investigations in building retrofits, none of the reviewed studies considered the use of a simulation-based multi-objective optimisation problem to determine the trade-off between the energy usage and the thermal comfort, including in the Libyan context.

4. Research Gap

The results of this review reveal research gaps in the existing literature. Limited attention has been paid to retrofitting existing housing stock, particularly in the context of Libya. In addition, limited research reviewed here aimed to achieve a net zero energy level for the Libyan housing stock. Therefore, further study is needed to investigate the potential for meeting net zero energy building targets through the integration of a PV system for Libyan housing using the building energy modelling (BEM) tool.

Although DesignBuilder enables the modelling of solar photovoltaic power systems, none of the studies that deployed DesignBuilder for the model simulation exploited this feature to investigate the potential for meeting the building energy levels needed to achieve the NZEB target. Consequently, meeting building energy needs and achieving NZEB targets by integrating both passive and active hybrid retrofit approaches using DesignBuilder would be a novel methodological contribution to the existing literature.

A major weakness in the literature is represented by the credibility of the energy models, where most of the studies reviewed, including the one on Libya, were carried out without ensuring the reliability of the energy model and relied on assumptions for their model setup, which would affect the accuracy of the simulation results. Measured data, which are essential for the building model setup and for understanding the prediction accuracy of the building model, were adopted in several studies. However, the measurement of the environmental data and energy consumption in these articles covered only a short period, which could lead to discrepancies between the actual building's energy use and the building energy model. Consequently, for a robust model calibration, and to ensure that the model represented the actual building performance, building monitoring over the whole year is necessary.

Model calibration on a monthly and hourly basis is also needed to ensure that the building model closely represents the actual building. In addition, measuring the total energy of the building, as well as the energy used by each category across the whole year, would provide important information through which the categories responsible for the greatest energy consumption could be identified, and thus, the appropriate energy retrofit measures could be determined. Further important data that, if not specified accurately, could have an impact on the accuracy of the energy model of an existing building is the thermal transmittance of the building envelope (U-value). Information about the structure and materials of the existing building envelope may not be accurate or may be unavailable. Consequently, it would be beneficial to employ on-site measurement as a current approach for evaluating the thermal properties of the existing building envelopes of different residential building types in Libya using a heat flux sensor, which would form an addition to existing literature on building energy retrofits in Libya.

Reducing energy consumption could have an impact on indoor thermal comfort. However, the trade-off between energy consumption and thermal comfort was not comprehensively investigated in previous research, including that in the Libyan context. Consequently, the balance between energy consumption and thermal comfort needs to be explored using a multi-objective optimisation problem. While this approach is an existing feature in DesignBuilder, none of the studies reviewed that used DesignBuilder for energy simulation employed this feature. Consequently, the use of this tool would form a methodological addition to the existing knowledge of residential building retrofits in Mediterranean countries, including Libya, to find an optimal solution that achieves a trade-off between energy saving and thermal comfort.

Embodied carbon reduction in building retrofits needs to be considered. Biobased insulation materials, for example, are renewable and contribute to reducing the embodied carbon of the building. However, the majority of previous research, including that in the Libyan context, deployed petroleum-based insulation materials, and only two studies investigated biobased insulation materials. Consequently, further studies to investigate the effectiveness of different biobased insulation materials on energy reduction in Libyan housing stock would be an additional contribution to existing knowledge.

5. Conclusions

In this study, a systematic review was carried out to explore the existing research and knowledge gaps in published research focusing on energy retrofits in existing residential buildings located in Libya and neighbouring Mediterranean countries. Using search terms and keywords, which were carefully selected to focus on the purpose of this systematic review, 44 relevant studies were found. Most of these were published in the last five years, but due to the limited number of publications within the research context, published literature dating back to 2012 were also included in the systematic review. Following the initial review, the articles were reviewed and analysed based on four themes identified in this review. Finally, the systematic review concluded with a discussion on content analysis and by identifying knowledge gaps and future research directions.

This systematic review revealed a lack of research on retrofitting existing residential stock in Libya, as only one corresponding published research article was found. A simulation optimisation approach integrating both passive and active hybrid retrofit approaches to meeting NZEB requirements would be a novel contribution in the Libyan context. In addition, finding the optimal solution to achieve a trade-off between energy saving and thermal comfort for Libyan residential stock is also required. Embodied carbon reductions in building retrofits need to be considered. Biobased insulation materials, for example, are renewable, low-carbon materials and contribute to reducing the embodied carbon of the buildings in many cases. However, the majority of previous research, including that in the Libyan context, deployed petroleum-based insulation materials. Investigating the effectiveness of low-carbon materials, such as biobased insulation materials, in energy reduction in the Libyan housing stock would be an additional contribution to existing knowledge.

Most of the studies reviewed, including that in the Libyan context, lacked credibility and reliability in validating the energy models. This was due to the lack of adequate measured data required for energy model setup and calibration. Consequently, further research with robust and detailed model calibration based on measured data is needed to ensure the reliability of the simulation results.

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