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ORIGINAL RESEARCH

Influence of architectural space layout and building perimeter on the energy performance of buildings: A systematic literature review

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Abstract

The space layout is very essential in building design development and can significantly influence the energy performance of the built environment. Space layout design, which occurs during the early stages of scheme conception and design development, is one of the most important tasks in architectural design. This systematic literature review focused on the investigation of space layout and perimeter design variables on the energy performance of the buildings and the study of major energy performance indicators, such as lighting, ventilation, heating, and cooling load considering climatic factors. The Scopus database was used for a thorough investigation of the publications using space layout relevant keywords to study building energy performance. About 55 primary articles were assessed based on the impact of different variables concerned with space layout design mainly building perimeter variables on the energy performance of the building. From the review, we can conclude that by enhancing the perimeter design variables and spatial configuration substantial amount of energy can be saved. The orientation of the building, climate occupancy, and building form have a major role in the energy consumption investigation. According to the study, hospitals consumes more energy due to specific functional requirement than other buildings, and studies on the spatial configuration of the hospital is comparatively less where further studies can consider this issue along with the combination of multiple performance indicators. Well-configured space layout design may prevent unreasonable energy consumption and enhance the overall sustainability of the building and contribute to climate change mitigation.

Keywords Sustainable built environment · Energy efficiency · Building envelope · Cooling load · Lighting · Ventilation

Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CO_2	Carbon dioxide
DHW	Domestic hot water
ECBC	Energy conservation building code
EPB	Energy performance of the building
EPI	Energy performance indicator
HVAC	Heating ventilation and air conditioning
kWh/m^2	Kilo watt-hour/square meter
SLR	Systematic literature review
WWR	Window to wall ratio

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Introduction

Globally buildings consume 30–40% of total energy and emit 30% of CO_2 [1, 2]. Worldwide energy consumption increased by approximately 2–3%, twice the average rate of growth since 2010, owing to a strong global economy as well as increased cooling and heating energy requirements [3]. The building sector is responsible for about 55% of the global electricity use [4]. The buildings like schools, restaurants, hotels, hospitals, museums, and others with a wide variability of uses and energy requirements, i.e., lighting, heating, ventilation, air-conditioning (HVAC), domestic hot water (DHW), refrigeration, food preparation, etc. Economic and population growth raises the demand for services in the field of healthcare, education, culture, hospitality, etc. along with its energy consumption [5]. Buildings have a lot of potential for energy efficiency, but there are some special regulations and acts that must be followed to achieve this. To achieve energy efficiency, appropriate design solutions should be established related to the causes that influence the energy performance of the building (EPB). Climate, architectural form, construction materials, and enclosure are some of the elements that need to be considered, as well as overall equipment efficacy, building occupancy, and occupant behavior patterns. Modern energy efficiency technologies are largely focused on improving building envelope performance, efficient lighting systems, water conservation, renewable resource adaptation, intelligent control systems, HVAC, and so on. A combination of excellent architectural and energy system design, as well as efficient operations and maintenance post occupancy, determines the amount of energy utilized. Many countries have implemented energy-saving policies and standards, and energy conservation in architectural design is a significant factor [6]. According to the 2015 report by US Department of Energy, it is indeed important to remember that different climates will almost certainly require different designs and equipment and that the performance and value of any component technology are dependent on the system for which it is used. The rate of energy needs and the physical comfort of the users are all commonly linked. The building and its design, in combination with the surrounding environment, have a substantial effect on the energy system adopted and its related efficiency.

Influence of architectural space layout on the energy performance of the building

Architecture involves the design, construction, and conception of built space. Architects design and develop structures that are complex systems with a variety of architectural elements. From the user's perspective, many factors of environmental ability, legibility, and imageability, such as structured space and building typology, as well as the intimate interaction between inside and outside space, are required to interpret building layouts. The building design is a complicated process in which crucial decisions about the building's various systems are made at an early stage [7]. Any building's usage with a combination of architectural design, including geometry and materials, can have a significant impact on its environmental behavior [8]. Due to shifting interior and external walls, the layout boundary can also be one of the design variables of the space layout design with a non-fixed boundary. Changing space layout variables proved a reduction in the annual final energy consumption [9]. It has also been demonstrated that most of the existing unneeded space in buildings results from oversized public access and waiting rooms, as well as incorrect hallway design, unnecessary passages, oversized spaces, and increased service areas such as washrooms, offices, service areas, and others. Unacceptable height, place, and shape values for a building can lead to ineffective space use, resulting in wastage of space and added energy and material consumption [10]. The energy-efficient spatial configurations include effective volumetric variation in spaces along with strategic positioning of windows, and the use of elements such as window shades, and shaded courtyards to reduce direct solar radiation as well as reduce mechanical energy consumption. Well-thought-out layout design may avoid unnecessary energy consumption to enhance the overall sustainability of the building and contribute to climate change mitigation [11]. Gracia et al. [12] concluded appropriate infrastructure planning turns out to be a key element in meeting energy efficiency requirements where they investigated that an optimal building layout or efficient building design reduces energy consumption due to heating and air conditioning systems. Zhang et al. [13] tested by modifying many passive design characteristics of the buildings to maximize the daylight, energy, and thermal performance of three classic types of classrooms in the north of China. There are a less number of research conducted that focuses on space planning and the ways space layout influences energy performance. Musau et al. [14, 15] found the possible influences of typical mixed, closed, and open layouts and their space utilization on the energy performance of the laboratories and office buildings. The study was conducted at all occupancy levels to conclude the best combination of different layout configurations that helps to achieve a reduction in the floor area as well as its energy consumption. Bano et al. [16] investigated the placement of service rooms with minimal openings as thermal buffering on the west side and decreasing the surface-area-to-volume ratio as a design strategy to regulate the heat gain and, as a result, reduce the cooling load in six office buildings located in India's composite climate. They also determined that locating the service core all along the exterior provides for natural ventilation and sunlight. Du et al. [17] experimented with the effect of spatial layout on energy performance by creating 11 office layout variants and evaluating them for three different climatic zones to determine the day illumination effect through the design and execution of shading devices. The study used dynamic simulation and suggested future investigation of the influence of neighboring structures on natural ventilation systems related to air pressure, air velocity, and air direction. Effective space arrangement designs also resulted in a 65% reduction in lighting and a 10% reduction in heating and cooling demand. Shahzad et al. [18] analyzed energy use by comparing standard cellular plans to open office plans and discovered that the cellular plans had higher energy consumption. Gärtner et al. [19] by using three distinct HVAC systems with four different control zoning schemes, investigated the influence of a flexible workspace layout design on thermal comfort and energy demand in a contemporary open-plan office space using dynamic thermal simulation. Zhang et al. [20] investigated the different spatial configurations such as a single-sided covered corridor type, a single-sided open corridor type, and a double-sided corridor type school. The study found that the double-sided enclosed corridor type was the best option due to its high energy performance and that the one-side covered corridor type concluding was the least suitable due to its relatively decreased visual comfort quality for the cold climate. Short et al. [21] recommended a feasible overall design approach as well as more detailed configurations for specific space types to empower clients and architects to execute low-energy ventilation and cooling strategies. Aldawoud [22] studied that atrium shape is a significant component to consider from a design and energy efficiency standpoint, primarily affecting the building's heating and cooling loads. The overall space layout is always associated with space characteristics such as measurements, space form, internal partitions and openings, function allocation, boundary characteristics such as building form and orientation, enclosure design space properties such as functional requirements such as heating, cooling, ventilation, and lighting, and these are all integrated based on EPB. It is necessary to use integrated design approaches that go beyond functional requirements to enhance the passive potential of different areas for a variety of environmental requirements across varied activities [14]. We can observe the multiple variables related to the space layout effect from the research of Delgarm et al. [23] where they evaluated with the help of simulation-based multi-objective optimization, the influences of specific architectural elements of a standard room on the energy consumption of buildings in four different climatic regions in Iran and it was discovered that using optimized spatial configuration for each climatic condition can save a significant amount of energy. The study looked at the impact of various building spatial design aspects such as building orientation, details of overhang, shading, window size, glazing, and wall material qualities on building energy usage in four different Iranian climates. Lavy et al. [24] found an incremental examination of simplified core building forms, daylighting controls, and 9 layout variants based on the shape (length and breadth ratio), the number of floors, window to wall ratio (WWR) of 40% along with external overhangs and their impact on the building exterior, as well as building orientation using simulation method of US military hospitals.

The research on the influence of architectural space layout on EPB is very less compared to the research on energy-efficient design considering various approaches with related variables or parameters of architectural space layout like geometry/form, envelope, façade, windows, and shading devices. Along with these variables, geographic locations and climate for different building typologies also investigated energy performance through various methodologies and for different occupancy rates. From past analysis, much research has been conducted exclusively on other design objectives like safety, wayfinding, logistics, connectivity, functional performance, etc. than energy performance. Because of the solar gain and solar exposure of the areas, the spatial arrangement determines the thermal and daylighting properties of a building. As a result, tools aimed at early design should consider the spatial configuration of the building as a component of energy-related aspects [7]. The novelty of this systematic literature review (SLR) highlights the influence of building design variables on the energy performance of various building typologies. The various energy indicators of buildings mainly cooling, and heating load, lighting, and ventilation are comprehensively investigated.

The main objective of this SLR is to identify the most significant space layout-related variables on the EPB along with effective methodology as well as gap identification in this field to direct further research. Because an SLR is a synthesis of previous research to answer specific questions, it aids researchers in synthesizing a large amount of evidence by explaining differences between studies and providing direction for future research or directing researchers to use a scientific approach in their studies. The questions that are subjected to framework and scientific investigation in SLRs can pave the way for more research by looking into the consistency and generalizations of data in building EPB in connection to space layout, particularly in hospitals. It is indeed useful for generating hypotheses that may be empirically tested [25].

The research questions are as below

1. What are the main aspects that are considered in the study on the EPB in association with architectural space layout and building perimeter parameters?
2. What are the different space layouts and perimeter variables influencing the EPB?
3. What are the different methodologies that are used to investigate the energy performance in association with architectural space layout along with building perimeter aspect?

Methodology

This SLR aims to identify crucial areas where more scientific research is needed, with an emphasis on the EPB. The concerns investigated in SLR through meticulous and scientific analysis may open the path for additional research by examining the consistency and generality of data in the field of EPB, particularly in hospitals. It is also useful for generating hypotheses that may be tested empirically. A literature review was undertaken to determine the impact of variables of spatial configurations on EPB, as well as different approaches and performance metrics, along with interconnection between the various objectives. We used the terms influence of "Space layout on EPB", "Simulation-based EPB", and "influence of space layout variable on EPB" in our search. A literature review was undertaken to determine the impact of space layout variables on EPB, as well as different approaches and performance metrics, as well as the interconnection between the various objectives. The Scopus database was used to find papers published during the period 2006–2021 and approximately 4300 records were retrieved in the beginning using the defined keywords and the number of publications kept increasing year wise as shown in Fig. 1.

The number of works of literature was decreased to 579 articles after excluding grey literature, extended abstracts, presentations, book chapters, keynotes, non-English language papers, and inaccessible publications. Only 186 articles remained for the main body reading from the selected abstracts. 140 of them were evaluated for EPB concerning space layout and its perimeter variables, and these articles were downloaded for additional screening. There are 128 articles considered for quality assessment. In the end, 55 papers met all the inclusion criteria considered in this SLR from selected journals that are having a greater number of articles in the context of the subject area (Fig. 2).

The review papers concentrated on typologies other than residential buildings in the final exclusion step in the interest of improving global comparisons [27]. The structure of the paper includes the beginning introduction, where the description of the space layout and EPBs are elaborated. The next four parts of the paper discussed determining factors for space layout on the EPB, space layout and its related variables on EPB, performance indicators, methodologies involved in the investigation of space layout variables, and sample design details during the investigation of the EPB. Then, the entire study analysis and conclusion with potential areas for future investigation are formulated in this review paper.

Inclusion criteria for articles

Articles on investigating the EPB of buildings of various typologies in connection to various space layout variables and energy performance indicators, as well as the various approaches used in the research, were included. For this systematic literature evaluation, only research publications with an impact factor of greater than 2.0 from the Scopus database were chosen. Impact factor calculation of journal as shown in the equation below.

$$ISx = \frac{\text{Citations} - x + \text{Citations} - y}{\text{Publications} - x + \text{Publications} - y}$$

IS = On average, the articles of the Journal. x = Year of calculation, y = Previous year.

Exclusion criteria for articles

The articles concentrating exclusively on thermal comfort, construction related, the impact of environmental factors, and Net-zero building theory, and older than 2006 articles are excluded in this review article. The conference papers, book chapters, thesis reports along with review articles are excluded. The articles from the journal had an impact factor of less than 2.0 and articles from other than Scopus databases are not considered for this paper.

Quality assessment

The selection of reliable and quality papers related to the identification of topics is a very big challenge in the SLR. Even though there is no standard methodology or process to select high-quality papers, journals with clear context and methodologies and value addition to the body of knowledge on the energy performance of buildings are considered for the review along with an impact factor of more than 2.0 (Fig. 3).

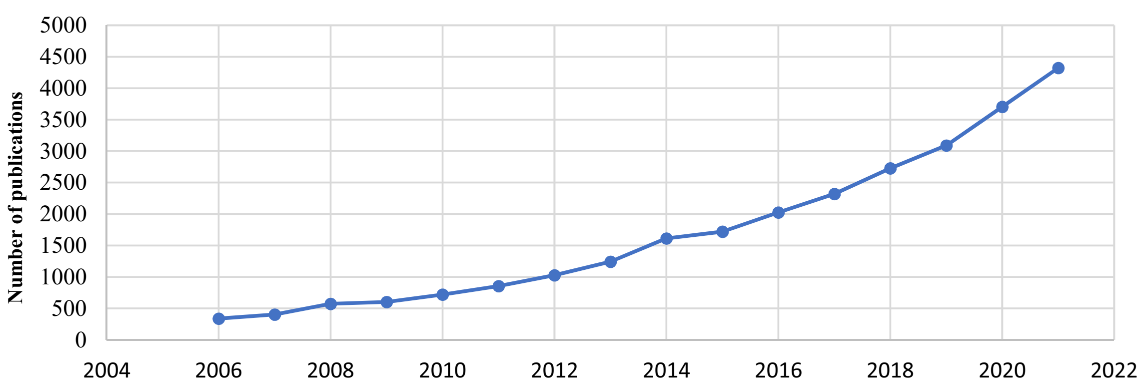


Fig. 1 Publication trend from 2006 to 2021 on EPB based on search criteria. *Source*: Scopus database

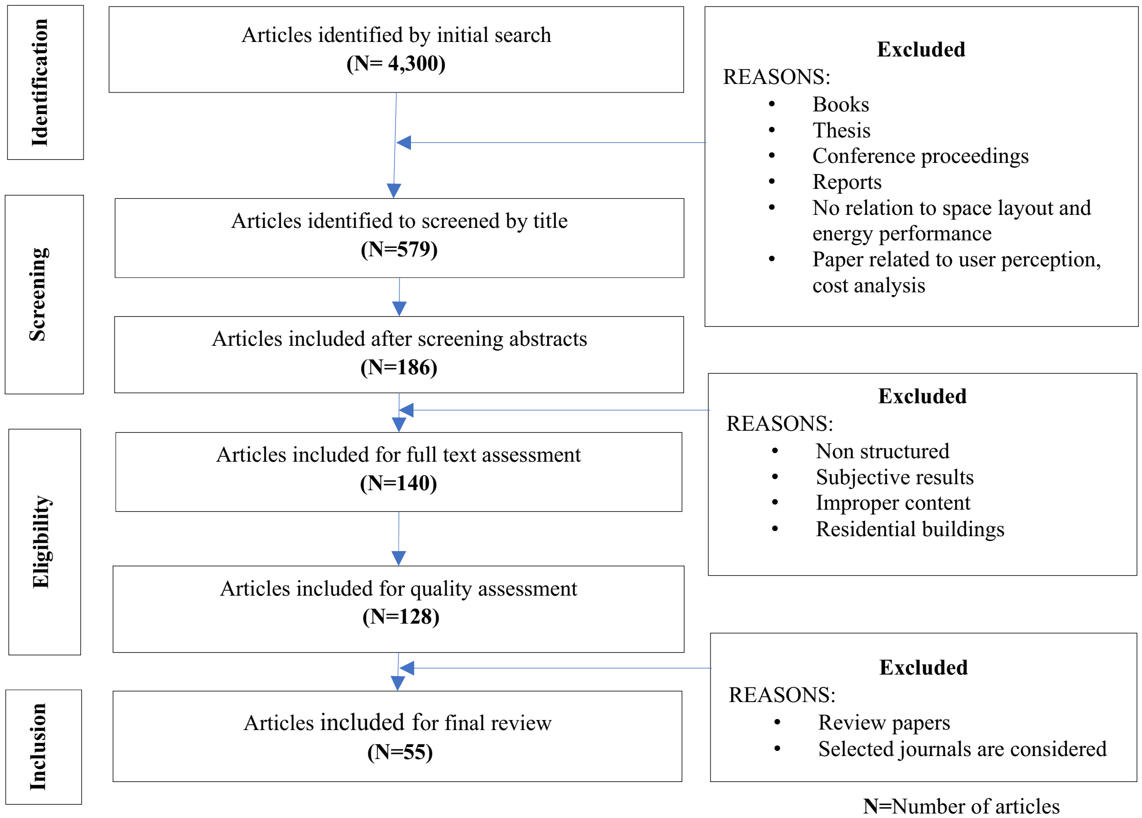
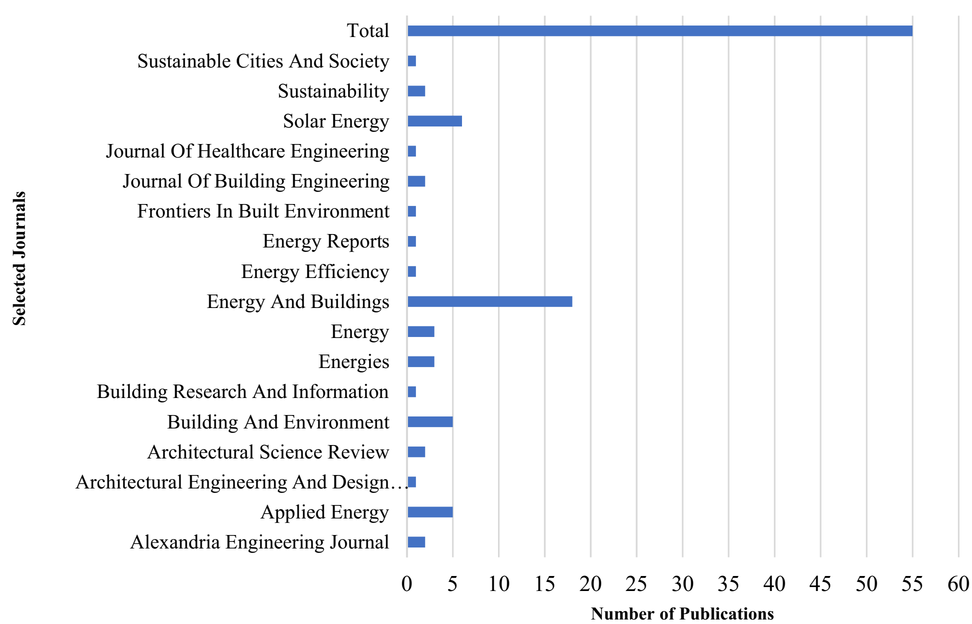


Fig. 2 Flow diagram of the systematic review process [26]

Fig. 3 The selected journal list and publication numbers of review articles. *Source*: Scopus database



Data extraction

- Determining factors for space layout influencing EPB.
- Space layout and perimeter-related variables on energy performance.
- EPB indicators like total building energy performance, natural ventilation, heating, and cooling load, etc.
- Methodologies on an investigation of energy performance along with simulation software.

The typical format for reviewing each article included the following parts: Authors, year of publication, journal with impact factor, geographic location, and climate zone of the study, building typology, keywords, focus area, methodology, variables, software used, performance indicator, sample design, a summary of the study as mentioned in Tables 1 and 2.

General characteristics of reviewed literatures

A. The keywords, “space layout”, “Energy”,” Buildings”,” Simulation”, and” Efficiency” are repeated in most of the reviewed papers. Thermal comfort, optimization, office, cooling, ventilation, and daylight also occurred repeatedly by many authors along with performance, consumption, etc.
B. Building typology- The search result shows many researchers focused on office buildings that had very basic functional parameters, and researchers discovered an ideal model to experiment and analyze the impact of space layout configurations and space boundary parameters and then the emphasis on hospital buildings (Fig. 4).
C. From the identified review papers, we can analyze that a major part of publications from Europe followed by Asia. The major Number of publications country-wise are from China.

Determining factors for space layout to influence the energy performance of the building

Before moving on to the full review, it’s critical to understand how the space layout parameters of the building can influence the EPB. There are several determining factors to decide the influence of space layout variables on the performance of energy. Orientation of the building and windows, layout configurations, shading details, window-to-wall ratio, glazing details along with climate and occupancy are the more prominent variables from the reviewed works of literature which significantly affect the total energy demand including heating, cooling, lighting, and ventilation along with thermal comfort and visual comfort.

Occupancy

Many studies ignored the effects of user activity on EPB by employing constant or inevitable occupancy inputs, which frequently result in differences between simulated and actual building performance, as well as the simulated setting becomes less realistic to real-world conditions. Because inhabitants, not buildings, are the principal users of energy, correct integration of technology and human elements may influence the design and functioning of low-energy structures [73]. Space layout, usage patterns, and system control approach defined during the design stage will differ once the buildings start functioning and result in energy ineffectiveness [15]. Space layouts also influence occupant behavior, such as whether they attend an activity or change the environment where the activity takes place. Varied occupancy levels have variable internal gains as well as different comfort requirements, such as the overall quantity of ventilation. Furthermore, diverse functions have varying levels of comfort requirements. Different comfort requirements among functions have an impact on overall energy usage [7]. The annual energy utilization of the building are all can be predicted by occupancy. Interior space design and control for diverse occupancy patterns must be carefully studied, as their effects on energy consumption may have a considerable impact on the use of office ventilation in a building. Buildings often have multiple zones, including heat transfer and balancing between them. Loads in one zone may escalate due to the varying thermal conditions of neighboring zones induced by occupant diversity [50]. These buildings may house a variety of activities with different operating hours, functional requirements, and occupancy patterns, all of which might affect their efficiency [73]. García Sanz-Calcedo et al. [35] predicted the direct proportionate correlation between the number of users in a Medical Clinic, its floor space, and the yearly energy usage of the building. Musau et al. [15] proposed an integrated planning strategy that goes beyond functional requirements to maximize the passive potential of varied spaces and activities for a variety of environmental needs. The strategy also showed users, systems organization, and activities are the determinant factors of energy performance by demonstrating the wide differences in per capita loads with space utilization intensity across activity spaces as well as layout options. Rajagopalan and Elkadi [44] studied the energy performance of three medium-sized hospitals in Victoria, Australia that is only operational during the day to find variances in energy use between different functional sections within the

Table 1 General details of the reviewed articles

Sl. No	Author	Year	Journal	Impact factor	Publisher	Place	Climate	Building type
1	Aksoy et al. [28]	2006	Building and Environment	7.176	Elsevier BV	Europe/Turkey	Cold	NS
2	Musau et al. [14]	2007	Architectural Science Review	3	Taylor and Francis Ltd	Europe/UK	NS	Laboratory Buildings
3	Tzempelikos et al. [29]	2007	Solar Energy	5.742	Elsevier Ltd	Europe/Sweeden	NS	Office
4	Yang et al. [30]	2008	Applied Energy	10.81	Elsevier BV	China–Harbin, Beijing, Shanghai, Kunming, and Hong Kong	Warm temperate	Office
5	Musau and Steemers [15]	2008	Architectural Science Review	3	Taylor and Francis Ltd		NS	Office
6	Aldawoud et al. [31]	2008	Energy and Buildings	6.675	Elsevier BV	USA/Arizona, Florida, Chicago, Minneapolis	Hot/dry, hot/humid, temperate, cold	Office
7	Poirazis et al. [32]	2008	Energy and Buildings	6.675	Elsevier BV	Europe/Sweeden	NS	Office
8	Short et al. [21]	2009	Building Research and Information	6.11	Taylor and Francis Ltd	Europe/UK	NS	Hospital/Healthcare Facilities
9	Sozer [33]	2010	Building and Environment	7.176	Elsevier BV	Europe/Izmir, Turkey	hot Mediterranean climate	Hotels
10	Nielsen et al. [34]	2011	Solar Energy	5.742	Elsevier Ltd	Europe/Denmark	cold north-European climate,	Office
11	Justo García Sanz-Calcedo et al. [35]	2011	Energy and Buildings	6.675	Elsevier BV	Europe–Spain/Extremadura	NS	Hospital/Healthcare Facilities
12	Pisello et al. [36]	2012	Energies	3.454	MDPI	USA/New York	NS	Institute Building
13	Adamu et al. [37]	2012	Building and Environment	7.176	Elsevier BV	Europe/UK	NS	Hospital/Healthcare Facilities
14	Ascione et al. [38]	2013	Energy and Buildings	6.675	Elsevier BV	Europe/Italy, Naples	Mediterranean climates	Hospital/Healthcare Facilities
15	Schulze and Eicker [39]	2013	Energy and Buildings	6.675	Elsevier BV	Europe/Germany, Italy and Turkey	Moderate	Office
16	Zhou and Zhao [40]	2013	Energy and Buildings	6.675	Elsevier BV	Asia/China (Shanghai, Beijing, Shenyang, Harbin)	Hot summer with hot and warm winter, cold, severe cold, temperate	Office
17	Tulsyan et al. [41]	2013	Energy and Buildings	6.675	Elsevier BV	Asia/India, Jaipur	Hot and dry	Hotels, Hospitals, Institutes, Retail, Government Offices, Private Offices
18	Aldawoud [22]	2013	Energy and Buildings	6.675	Elsevier BV	USA/Phoenix, Arizona, Miami, Florida, Chicago, Illinois, Minneapolis, Minnesota	Hot-dry, hot-humid, temperate, cold	Office
19	Susorova et al. [42]	2013	Energy and Buildings	6.675	Elsevier BV	USA	Hot, warm, mixed cool cold, very cold	Office

Table 1 (continued)

Sl. No	Author	Year	Journal	Impact factor	Publisher	Place	Climate	Building type
20	García-Sanz-Calcedo [43]	2014	Energy and Buildings	6.675	Elsevier BV	Europe/Extremadura (Spain)	NS	Hospital/Healthcare Facilities
21	Rajagopalan and Elkadi [44]	2014	Journal of Healthcare Engineering	3.06	Hindawi Limited	Australia/Victoria	Temperate	Hospital/Healthcare Facilities
22	Lavy et al. [24]	2015	Architectural Engineering and Design Management	2.19	Taylor and Francis Ltd	USA/Fairbanks, Alaska, San Antonio, Texas	NS	Hospital/Healthcare Facilities
23	Wang and Greenberg [45]	2015	Energy and Buildings	6.675	Elsevier BV	USA–Chicago, Houston and San Francisco	Humid, Mediterranean mild climate	Commercial
24	Chedwal [46]	2015	Energy and Buildings	6.675	Elsevier BV	Asia/India, Jaipur	Hot and dry	Hotel
25	Echenagucia et al. [47]	2015	Applied Energy	10.81	Elsevier BV	USA/Palermo, Torino, Frankfurt, and Oslo	Climates of Palermo, Torino, Frankfurt, and Oslo	Office
26	Zahiri and Altan [48]	2016	Frontiers in Built Environment	2.11	Frontiers Media S.A	Asia/Iran, Tehran	Hot and Dry Climate	School Building
27	Taleb [49]	2016	Journal of Building Engineering	5.318	Elsevier BV	Asia/UAE Abu Dhabi	Warm humid	Hospital/Healthcare Facilities
28	Yang et al. [50]	2016	Energy	7.477	Elsevier Ltd	USA/Los Angeles, California	NS	Office
29	Amaral et al. [51]	2016	Sustainable Cities and Society	8.53	Elsevier BV	Europe/Coimbra, Portugal	Summer Mediterranean climate	NS
30	Delgarm et al. [23]	2016	Applied Energy	10.81	Elsevier BV	Asia/Iran	NS	NS
31	Goia et al. [52]	2016	Solar Energy	5.742	Elsevier Ltd	Europe/Oslo, Frankfurt, Rome and Athens	Cold, temperate	Office
32	Harmathy et al. [53]	2016	Energy	7.477	Elsevier BV	Europe/Serbia	Temperate climate	Office
33	Morgenstern et al. [54]	2016	Energy and Buildings	6.675	Elsevier BV	Europe/England	NS	Hospital/Healthcare Facilities
34	Lu et al. [55]	2016	Energy and Buildings	6.675	Elsevier BV	Asia/China (West of Inner Mongolia Autonomous Region)	Severe cold area	Office
35	Zhang et al. [20]	2017	Energy and Buildings	6.675	Elsevier BV	Asia/China	Cold	School Buildings
36	Shahzad et al. [56]	2017	Applied Energy	10.81	Elsevier BV	Europe/Norway/British	NS	Office
37	Ma et al. [57]	2017	Energy and Buildings	6.675	Elsevier BV	Asia/Northern China	NS	Public Building
38	Alhuwayil et al. [58]	2019	Energy	7.447	Elsevier BV	Dhahran/Saudi Arabia	Warm humid	Hotel
39	Wagdy et al. [59]	2017	Solar Energy	5.742	Elsevier Ltd	Africa/Egypt, Cairo	Desert	Hospital/Healthcare Facilities
40	Bayoumi [60]	2017	Building and Environment	7.176	Elsevier BV	Asia/Jeddah and Riyadh	Hot humid and hot arid	Office

Table 1 (continued)

Sl. No	Author	Year	Journal	Impact factor	Publisher	Place	Climate	Building type
41	Bano and Sehgal [16]	2018	Solar Energy	5.742	Elsevier Ltd	Asia/India (Delhi, Gurgaon, and Hyderabad)	Composite climate	Office
42	Prieto et al. [61]	2018	Energy and Buildings	6.675	Elsevier BV	Asia/Hongkong	Warm climate	Commercial
43	González et al. [62]	2018	Sustainable Cities and Society	8.53	Elsevier BV	Europe/Spain	NS	Hospital/Healthcare Facilities
44	Omar et al. [63]	2018	Alexandria Engineering Journal	3.732	Alexandria University	Asia/Beirut	Mediterranean climate	Educational Building
45	Bawaneh et al. [64]	2019	Energies	3.454	MDPI Multidisciplinary Digital Publishing Institute	USA	NS	Hospital/Healthcare Facilities
46	Guo and Bart [65]	2020	Sustainability	3.25	MDPI AG	Asia/China (Changchun, Beijing, Shanghai, Haikou, Kunming)	Cold, hot summer and cold winter, hot summer, and warm winter	Office
47	William et al. [66]	2020	Alexandria Engineering Journal	3.732	Alexandria University	Africa/Egypt, Alexandria	Hot-humid	Hospital/Healthcare Facilities
48	Cesari et al. [67]	2020	Energies	3.454	MDPI Multidisciplinary Digital Publishing Institute	Europe–Italy (Milan, Bologna, Rome, and Naples)	NS	Hospital/Healthcare Facilities
49	Fang et al. [68]	2019	Solar Energy	5.74	Elsevier BV	Miami, Atlanta, and Chicago	Hot, mixed, and cold climates	Office
50	Kyritsi et al. [69]	2020	Building and Environment	4.971	Elsevier BV	Europe/Urban Center of Nicosia, Cyprus	Mediterranean	Office
51	Gärtner et al. [19]	2020	Energy and Buildings	6.675	Elsevier BV	Europe/Stuttgart, Germany	Performance of different HVAC systems	Commercial Building
52	Pilechiha et al. [70]	2020	Applied Energy	10.81	Elsevier BV	Asia/Iran, Tehran	Hot, semi-arid climate	Office
53	Aunión-Villa et al. [71]	2021	Energy Efficiency	2.57	Springer Nature B.V	Europe/Madrid (Spain)	NS	Hospital/Healthcare Facilities
54	Du et al. [17]	2021	Journal of Building Engineering	5.318	Elsevier BV	Europe/Amsterdam, Netherlands, Harbin, Asia–China, Singapore	Temperate, cold, tropical	Office
55	Zou et al. [72]	2021	Energy Reports	6.87	Elsevier BV	Asia/China	Hot and humid area	School Building

NS = Not specified

Table 2 Study focus and findings along with the methodology and sample design from reviewed articles

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Aksoy et al. [28]	The impact of passive design parameters along with building shape and orientation position-on heating demand in Turkey has been studied theoretically	Mathematical analysis	NA	Orientation, shape, insulation material	Heating load	The intermediate floor of a multistory building-3 shape having the length to breadth ratio-1:1, 1:2, 2:1	Buildings with a square shape have greater advantages in heating design. The best orientation angles are 0° and 80° for buildings with a length-to-depth ratio of 2/1 and 1/2, respectively
Musau et al. [14]	In the United Kingdom, the TAS, Lightscape, and Excel software programs were used to investigate the possible implications of conventional open, mixed, and closed design and their space utilization densities/intensities of energy use in laboratory buildings	Building energy simulation	Thermal analysis software (TAS), Lightscape and excel software	Open, closed, and mixed layouts, orientation	Energy performance	3 Types of layouts -open, closed, and mixed layouts	The various ways in which users, activities, and systems can be structured in response to space-to-space environmental diversity are important factors of laboratory energy performance
Tzempelikos et al. [29]	A linked lighting and thermal simulation in Sweden was used to calculate the simultaneous influence of glass area, shading device attributes, and shading control on building cooling and lighting demand of an office	Building energy simulation	Energy Plus/TRNSYS	WWR	Lighting load	A typical private perimeter office space of 4 m × 4 m × 3 m size in Montreal	An integrated approach for automatic control of motorized shading in conjunction with programmable electric lighting systems could result in a large reduction in energy consumption for cooling and lighting in peripheral spaces, depending on climatic conditions and orientation

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Yang et al. [30]	The energy performance of office building envelope designs in the five key climate zones of china was evaluated	Mixed method-case study/statistical analysis	NA	Ratio and shading parameters, orientation, wall, window, roof, skylights, WWR	Energy performance, cooling demand	113 offices -Harbin-9 + Beijing-55 + shanghai-18 + Kunming-12 + Hong kong-19	Wall, roofs, windows, and skylights have higher heat gain/loss than those specified by local design/energy rules, prompting recommendations to increase the energy efficiency of existing buildings in china in the different climatic zone
Musau et al. [15]	In the United Kingdom, the TAS, Lightscape, and Excel software packages were used to examine the impact of space planning and usage on the energy performance of office spaces	Building energy simulation	Thermal analysis software (TAS), Lightscape, and excel software	5-space layout variants, occupancy, space area	Energy performance	5 Different types of office layout-hive, den, club, cell, and combi	Space planning and utilization have a significant impact on energy consumption and are crucial in assessing energy performance. Differences in combined thermal and lighting loads are 19% and 51% throughout the UK peak winter and summer seasons, respectively, with an average occupancy of 50%, whereas variations in per capita load are 80% and 16% during the inquiry

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Aldawoud et al. [31]	The energy performance of a central atrium is evaluated and compared to that of a courtyard with the same Geometric proportions	Building energy simulation	DOE2.1E	Glazing types and glazing area ratios, climate, number of floors	Energy performance	An open central courtyard surrounded by four adjacent spaces, a space in each direction	The open courtyard structure performs better in terms of energy efficiency than the shorter buildings. However, as the building height grows, the enclosed atrium demonstrates higher energy performance
Poirazis et al. [32]	To investigate the effect of glass on energy consumption during the occupation stage of building options with 30%, 60% and 100% window to exterior wall area in Sweden	Building energy simulation/Sensitivity analysis	IDA ICE 3.0	Orientation, open and cell type plan, the control set points, type and size of windows, type and position of shading devices	Thermal comfort, energy consumption	Six-story high building having a total height of 21 m and the floor area of 6177 m^2 with two long and facades are identical The room height was 2.7 m and the distance between floors was 3.5 m	Highly glazed single-skin structures consume more energy during the occupation stage, which can be reduced by lowering the thermal transmittance and the total solar transmittance of glass
Short et al. [21]	Evaluation of ventilation and energy performance of 200 bed hospitals at UK	Building energy simulation	NS	Floor area	Ventilation, energy performance, cost	More than 1000 room types including clinical and non-clinical spaces of 200-bed, medium sized acute hospitals under NHS Public Sector Comparator (PSC) level of United Kingdom	70% of the net floor space of small-to-medium-sized acute hospitals might be naturally ventilated whereas a hybrid ventilation technique could serve an additional 10% of the net floor area
Sozer [33]	An investigation into the building envelop design on heating and cooling loads, as well as the scope of energy efficiency in a hotel building in Turkey	Building energy simulation	e-QUEST	Walls and roof insulation, Window sizes, window glazing	Heating and cooling loads	A hypothetical model of 21 story light weight structured hotel building which was based on an existing hotel which was constructed in 1992 in Izmir	Precise building envelope design ie glazing, insulations and shading reduced 86% of heating load, 60% decrease in cooling and 40% of total site energy load reduction

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Nielsen et al. [34]	Investigation on the façade treatment without solar shading, with fixed and dynamic solar shading for the evaluation of the building's overall energy demand, heating, cooling, and lighting energy demand, as well as its daylight factors in Denmark	Building energy simulation	iDbuild	Solar shading, window heights and orientations	Total energy demand, energy demand for heating, cooling and lighting, daylight factors	Facades without solar shading, with fixed solar shading, and with dynamic solar shading	Compared to fixed solar shading, the use of dynamic solar shading significantly increased the quantity of daylight available
Justo García Sanz-Calcedo et al. [35]	Assess the impact of the number of users on the energy and environmental characteristics of a health center in Extremadura, Spain	Sensitivity/Statistical analysis based on simple/Multiple correlations	NS	Floor area, Number of users	Energy consumption	69 Health Centers of Extremadura, Spain	Annual energy usage was shown to be lower in facilities with a high associated management factor. It should also be mentioned that energy management can be implemented more effectively in smaller facilities
Pisello et al. [36]	Post-Occupancy Evaluation through In-Situ Analysis on Energy Savings in a New York Institutional Building Using a Dynamic Simulation Model	Numerical analysis, In-field monitoring, Occupants' survey, Dynamic building energy simulation	EnergyPlus	Indoor environmental parameters, Occupancy, thermal zoning	Thermal and Indoor Air Quality	A multipurpose building of having 14 floors + three basements with the total area of 73,019 m^2 and 72 m height located in the campus of The Baruch College, Manhattan, New York	Post-occupancy evaluation is an useful method for reducing energy waste in buildings, particularly in complicated and high-efficiency structures that are not operating as well as expected during the concept-design-commissioning stage

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Shahzad et al. [56]	In both summer and winter in Norway, the traditional cellular plan workplace consumed significantly more energy than the open plan office	Statistical analysis (Empirical regression analysis/ANOVA)	NA	Layout, environmental factors, window positioning	Thermal comfort, visual comfort, ventilation-energy consumption, CO_2 and light level	Two office buildings -Norwegian office built in 2000 and British office built in 2011	Thermal control is secondary in the British approach and the primary system in the Norwegian approach. The energy consumption in Norwegian case studies is significantly higher than in British case studies
Ma et al. [57]	The investigation revealed that the traditional cellular layout workplace consumed much more energy than the open plan office in both summer and winter in Norway	Statistical analysis	eQUEST	Building envelope, heat transfer coefficient/WWR, shading coefficient of external window, lighting/equipment power density		119 public buildings- 99 office buildings + 11 hospital buildings + 9 school buildings	According to the orthogonal test, the key elements impacting energy consumption are the air conditioning system, lighting density, and building envelop. The average total energy consumption per unit area of China's public, school, office, and commercial buildings is 147.20 kWh/(m^2), while the average power consumption is 47.96 kWh/(m^2 a)
Alhuwayil et al. [58]	the study was explored the energy saving potential and economics of incorporating external shading devices with self-shading envelope for a multi-story hotel building in hot-humid climate of Saudi Arabia	Building energy simulation	EnergyPlus/design builder	Shading devices	Energy consumption, heating and cooling load, cost analysis	10-story hotel building	By providing additional space and balcony for hotel rooms along with shadings and self shading devices, 20.5% of annual energy consumption reduced with reference to baseline hotel building

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Wagdy et al. [59]	Determine the range of sun-breaker cut-off angles and their related tilt angles that resulted in sufficient daylighting performance for the two patient room types at varying WWR and with the wall for Cairo hospitals	Building energy simulation	EnergyPlus/ Grasshopper, Rhinoceros	Sun-breaker cut off-angle, WWR, tilt angles	Energy demand, indoor thermal quality	Two patient room layout designs -the outboard bathroom patient room design and the inboard bathroom patient room design	When determining the success of a sun breaker, the cut-off angle is more crucial than the tilt angle in delivering acceptable daylighting performance
Bayoumi [60]	Investigation on the relationship between the grade of a window opening and energy savings in a one-sided window opening in two hot settings of an office building in Asia with one humid and one desert climate	Building energy simulation	IDA-ICE	Window opening grade, facade integrated photovoltaics	Cooling load, air changes per hour (ACH)	A typical north–south-oriented office building	The Window opening grade (WOG) and window fraction (WF) in the façade wall is crucial in defining the cooling load of the space and thus its energy demand and these parameters also considered in the daylight optimization
Bano and Sehgal [16]	The efficiency of various design solutions for reducing the HVAC and lighting loads of six office buildings in India was investigated	Case study	NA	Building form, envelope configuration, service core position, WWR percentage of air conditioned space	HVAC load, lighting load, equipment load	Six energy-efficient office buildings in Delhi, Gurgaon, and Hyderabad of India have composite climates	Determined the most cost-effective building envelope design options. Building plan arrangement, mixed-mode ventilation system, and WWR in decreasing HVAC and lighting energy consumption in composite climatic energy-efficient mid- and high-rise office buildings

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Prieto et al. [61]	Investigates the efficiency of selected passive cooling solutions in commercial buildings in Hong Kong's warm environment	Statistical analysis	Energy Plus/Design-Builder	Orientation, climate, shading, glazing size, and type, ventilation	Cooling energy load		The use of passive methods alone will not result in significant savings. Their effectiveness was influenced by the hardness of a certain climate as well as varied building factors
Adamu et al. [37]	The performance of buoyancy-driven airflows was studied in four different natural ventilation approaches suitable for single-bed hospital wards in the United Kingdom	Building energy simulation	PHOENICS, IES	Window opening, inlet/stack/ceiling based natural ventilation (CBNV)	Airflow capacity, thermal comfort, summer overheating, and heating energy consumption in winter	A single occupant of 3.78 m × 6.23 m × 3.5 m with a floor area of 23.55 m^2 and a volume of 82.42m3 of the Great Ormond Street Hospital (GOSH)	A 25 percent trickling ventilation opening fraction is necessary to produce required airflow rates and adequate thermal comfort in winter, and other solutions, except for window-based design, minimize summer overheating to varying degrees
Ascione et al. [38]	Explores a significant application in the realm of energy demand for air-conditioning and thermal–physical properties of the building envelope with reference to a medium-sized hospital in a Mediterranean climate	Case study	Energy Plus/Design-Builder	External wall, basement, and flat roof, building envelope, windows	heating, ventilating, and air conditioning systems, indoor comfort conditions	The National Institute for the Cancer Treatment "G. Pascale" is located on the hill area of Naples having basement + ground + 5 floors	The refurbishment of the building envelope implies an improvement in internal thermal conditions for all HVAC systems under consideration

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Zhou and Zhao [40]	Building envelopes energy-saving technology (BEEST) optimization to improve the energy performance of office buildings in Shanghai, Beijing, Shenyang, and Harbin, China	Mixed method-Building energy simulation/Optimization	TRNSYS	Exterior walls, roof, and exterior windows		11-story typical office building with an area of 26,400 m^2 having a story height of 4 m and its aspect ratio is 2.67–5 climatic regions	In cold climates, the building envelops energy-saving technology with Expanded Polystyrene (EPS) insulation system that has significant energy-saving potential
Schulze and Eicker [39]	Coupled airflow network and dynamic building simulations were carried out to determine the annual thermal comfort and energy savings of office buildings located in Germany, Italy, and Turkey	Building energy simulation	EnergyPlus	Window openings	Thermal comfort, energy consumption	3-story small administration building with a floor area of 1146 m^2 and a surface-to-volume ratio (A/V) of 0.48 m^{-1} with a flat roof, no basement, and the offices east or west orientated	Natural ventilation systems that are well-designed save between 13 and 44 kWh/m^2 of cooling net energy per year for the three locations Stuttgart, Turin, and Istanbul. The electrical energy savings from fan ventilation are around 4 kWh/m^2. per year
Tulsyan et al. [41]	Investigation of the energy-saving potential with ECBC for different typologies of the buildings in India	Mixed method -Case study, Building energy simulation	eQUEST software	Envelope parameters, building typology, HVAC, building occupancy/activity	Energy consumption, HVAC load	6 case study buildings -hotels, hospital, institute, retail, government office, and private office	The specific energy usage ranges from 137 $kWh/m^2/y$ for a government facility to 386 $kWh/m^2/y$ for a private office. The percentage of energy saved with ECBC compliance ranges from 17% for institutions to 42% for hospitals

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Aldawoud [22]	The purpose of the study is to determine the impact of the atrium form on the total energy consumption of the building and to find the best energy-efficient atrium design in USA/ Phoenix, Arizona, Florida Miami, Chicago, Illinois Minneapolis, Minnesota, and office buildings	Building energy simulation	DOE-2.1E	Geometry, glazing type, glazing ratio, climate	Thermal and energy performance	Hypothetical model—four variants	The energy performance of the courtyard building type showed more energy efficiency compared to the atrium building for low-rise structures while the atrium building performed better with high-rise structures
Susorova et al. [42]	Evaluated the impact of geometry parameters on building energy performance in a commercial office building in the United States, such as window orientation, window to wall ratio, and room width to depth ratio	Building energy simulation	Energy Plus/Design-Builder	6 climate zones, 8 window orientations, 7 windows to wall ratios, and 4 widths to depth ratios	Lighting, heating, cooling, auxiliary hot water, and total energy consumption/year/square meter	An office room located on a middle floor and midway along a building's width—6 climate zones + 8 window orientations + 7 window to wall ratios + 4 widths to depth ratios	Geometry influences energy usage greatly in hot and cold climates, but very marginally in temperate regions. Energy savings ranged from 3 to 6% on average, with a maximum of 10–14% in hot climates and 1% in temperate and cold climates
García-Sanz-Calcedo [43]	An investigation of the direct relationship between the number of health center users, floor space, annual energy usage, and architectural design element of an Extremadura hospital (Spain)	Statistical analysis (single and multiple correlations)	NA	Building size, three different climates	Final annual energy consumption per unit floor area	70 Health centers in Extremadura (Spain)	The energy consumption of the health center might increase up to 15% if the building size is not optimized

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Rajagopalan and Elkadi [44]	Investigates the energy performance of three medium-sized healthcare buildings in Victoria, Australia	Case study	NA	Building fabric, type of functional spaces, climatic conditions, HVAC systems	Electricity, gas, and water consumption	Three medium-sized healthcare facilities in the public healthcare sector in Victoria, Australia	Energy transmission across the building envelope, such as walls, windows, and roofs, as well as heat generation from users and equipment, are the primary sources of HVAC load. The case study of small hospitals found that 45% of the heating load is from the envelope, with 20% and 13.5% from the windows and walls, respectively, while 16 percent is from the envelope and 37% is from the equipment
Lavy et al. [24]	Investigate the influence that elements such as EBD-supported design interventions, ASHRAE recommendations, and energy code compliance on the hospital building envelope in cities across the United States	Mixed method-Case study/Building energy simulation	eQUEST	Orientation, daylighting controls, window/wall percentage, and exterior shading devices	Energy performance	2 Hospitals—base model + 10 variants	HVAC systems are a significant part of the overall energy efficiency of a building

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Wang and Greenberg [45]	The impacts of window operation on building performance for different types of ventilation systems-natural, mixed-mode, and standard variable air volume systems, were evaluated in a medium-sized reference office. In the United States	Building energy simulation	Energy plus	Open windows, natural ventilation, HVAC equipment, and system sizing	Temperature, energy demand profiles, heating, and cooling electric demand	5 Zone floor of 3 stories of commercial building	Identified HVAC energy savings of 17–47% with mixed-mode ventilation during summer for various climates
Chedwal [46]	Potential application of the ECBC code to existing hotel structures in India in order to improve energy efficiency and reduce energy consumption in Indian hotels	Building energy simulation	eQUEST software	Wall, roof, glass, HVAC system properties, lighting, and other types of equipment	Energy consumption, HVAC load, lighting load	3 Hotels out of 79 hotels	Implementation of ECBC to hotels Category-1, Category-2and Category-3 demonstrates energy savings of 37.2%, 18.42% and 25.82%, respectively with a payback period of 2.39–6.41 years whereas application of advance
Echenagucia et al. [47]	Changing the number, position, shape, and kind of windows, as well as the thickness of the masonry walls, to reduce the energy used for heating, cooling, and lighting in an office building at USA	Multi-objective optimization	EnergyPlus	Number, position, shape, and type of windows and the thickness of the masonry walls, WWR	Heating, cooling, and lighting load	An open space office located on the first floor of a five-story masonry building with internal dimensions of 20 m × 14 m × 4 m	The Pareto front solutions were defined by extremely low WWR values, particularly on the east, west, and north-facing façades of the study building, while the area of the south-facing windows was larger, with a greater spread, than the other orientations

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Zahiri and Altan [48]	Investigation of optimal design options for secondary school buildings using passive design principles to improve the indoor thermal conditions in Tehran	Building energy simulation	Energy Plus/DesignBuilder	Orientation, solar shading devices, thermal mass, natural ventilation, external wall, and roof insulation	Indoor air temperatures	A female secondary school building in the city of Tehran	The passive design solutions had a significant impact on the indoor air temperature and can keep it within an acceptable range based on the thermal requirements of the female students
Taleb [49]	An examination of the renovation of a hospital building in Abu Dhabi, United Arab Emirates, with a focus on building envelope renovation	Mixed method-case study/Building energy simulation	IES	Sunshade, exterior wall, a cool roof, glazing, and green roofs	External conduction gain	Five wards are located on various floors with a capacity of 300 beds and the ground floor with public services and casualty area of Al Cornich Hospital—a maternity and neonatal hospital	The green roof performed the best in terms of heat gain reduction among the five skin characteristics tested—a sunshade, exterior wall design, cool roof, green roof, and glazing. It also gave useful analysis on how to meet the recommended comfort standards for hospital structures
Yang et al. [50]	Quantitative evaluation of the energy implications of occupancy diversity at the building level for an office in California	Building energy simulation	NS	Space layout and form	Heating/cooling load	A 3 -story north-facing office building having an area of 3735 m^2 with 89 mechanically ventilated rooms of varying sizes and functions on the USC (University of Southern California) campus in Los Angeles, California	Introduces a framework for quantitatively evaluating the energy implications of occupancy diversity at the building level, using building information modelling to provide building geometries, HVAC system layouts, and spatial information as inputs for computing potential energy implications if occupancy diversity is eliminated

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Amaral et al. [51]	Proposal of a methodology for the parametric evaluation of a window ideal dimension based on the thermal performance of a reference room in the climate region of Coimbra, Portugal	Building energy simulation	EnergyPlus	Opening type, orientation, and size, overhangs, glazing	Thermal performance and energy efficiency	A reference room -the opening orientation in a two-degree step around the 360°, starting at 0° (north) and then turning east	For the specific research region, triple glazing outperforms single and double glazing, particularly in the north direction. The worst opening orientations, regardless of window type, are northeast and northwest
Delgarm et al. [23]	A mono- and multi-objective particle swarm optimization (MOPSO) algorithm is combined with Energy Plus building energy simulation engine to find a set of non-dominated solutions to improve building energy performance, demonstrating a powerful and useful tool that can save time when searching for optimal solutions with competing objective functions. efficiency	Building energy simulation	EnergyPlus	Building orientation, shading details, window size, glazing, and wall properties	Annual cooling, heating, and lighting load, electricity consumption	Single room model	By contrast to the baseline model, the annual cooling electricity drops by approximately 19.8–33.3%, while the annual heating and lighting electricity increases by 1.7–4.8% and 0.5–2.6%, respectively, for four varied climatic zones of Iran. Furthermore, the optimal design reduces total yearly building electricity demand by 1.6–11.3%

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Goia et al. [52]	Investigation of the optimal WWR for each of the main orientations in four different locations, covering the mid-latitude region, from temperate to continental climates for the specific type of office building with a single corridor layout with cell office rooms equipped with cutting-edge building envelope components and installations	Mixed method-Building energy simulations, Sensitivity analysis	EnergyPlus	WWR (0.20; 0.35; 0.50;0.65; 0.80), transparency range 20–80% of façade	Energy performance	7-story office building (45.9 m × 14.4 m × 28.9 m)-Typical plan located above the entrance floor with a central corridor and 12 office cells (3.6 m × 5.4 m × 2.7 m) on both sides of the corridor. Services, staircases, and lifts are placed at the two ends of the corridor	The most ideal WWR values are in the 0.30–0.45 range—but not for south-facing façades. Furthermore, with the best façade technology, WWR has a minimal impact on energy performance
Harmathy et al. [53]	Formulation of an optimal building envelope model utilizing multi-criterion optimization methods to calculate efficient WWR and window geometry (WG) to interior illumination quality, followed by an assessment of glazing parameters' influence on annual energy demand for a Serbian office	Building energy simulation	BIM (Autodesk Revit software)/Energy Plus (Open Studio)/Radiance	WWR, window geometry, glazing, time, sky conditions, and zone orientation	Advanced spatial daylight dispersion, average indoor daylight factor	Existing reference office building	The integral methodology for improving overall energy performance through the use of multi-criterion optimization methods, highly detailed Building Information Modeling (BIM) programs, and a dynamic energy simulation engine is both flexible and adaptable for use in a variety of climatic conditions and construction types

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Morgenstern et al. [54]	To investigate how relevant energy benchmarks—reflecting effective energy management and design—can be built for hospital buildings in England, a category that includes complex structures with various set-ups and wide variation between them	Case study	NA	Different departments	Electricity consumption	28 departments of 8 medium to large General Acute hospitals of England	The different hospital departments have hugely varied electricity consumption characteristics. Wards, day clinics, and some other departments have lower average consumption intensities which are reasonably well reflected by current hospital electricity benchmarks
Lu et al. [55]	Establishment of standardized linear regression models between these selected parameters and total and subentry energy consumption intensity of an office building	Statistical analysis (regression analysis), Univariate analysis of variance—(ANOVA)	NA	Climatic parameters, the air conditioning form, building envelope, heat transfer coefficient, U-value-external wall, integral window, the roof, window/window glass type	Energy consumption	27 Office buildings in China-12 buildings from Bayan Nur + 12 buildings from Ordos + 3 buildings from Wuhan city	The percentage of total equivalent power consumption consumed by electricity was a significant element influencing the total energy consumption intensity of an office building in the west of Inner Mongolia Autonomous Region
Zhang et al. [20]	Describes the use of simulation optimization methods to discover the best trade-off between lowering energy use for heating and lighting, minimizing summer discomfort time, and boosting comfort. Daylight illumination is useful in Chinese school buildings	Multi-objective optimization	Energy Plus/Rhinoceros, Grasshopper, Ladybug and Honeybee, Radiance, Octopus	Orientation, room depth and corridor depth, window-to-wall ratio, glazing materials, and shading types	Heating load, daylight illuminance, thermal comfort	Chinese schools of 2–3 story buildings	The double-sided corridor design performs best in China's cold environment, while the one-sided enclosed corridor style performs the worst

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
González et al. [62]	The correlation analysis of hospitals in Spain reveals the links between average energy usage in hospitals and the number of personnel, available beds, and building surface area	Statistical analysis (ANOVA)	NA	Location, built area, number of workers	Annual energy consumption	80 Eco-management and audit schemes from 20 hospitals were analyzed in the period 2005–2014	The average yearly energy consumption in a Spanish hospital for regular operating conditions was 0.27 MWh/m^2, 9.99 MWh/worker, and 34.61 MWh/bed, with standard deviations of 0.07 MWh/m^2, 3.96 MWh/worker, and 12.49 MWh/bed
Omar et al. [63]	In Beirut, investigate the conditions of indoor daylight and the energy performance of the library using various architectural features such as space depth, window size, external obstruction angle, and glazing apparent transmittance	Mixed-method-experimental/Building energy simulation	Ecotect, Hobo loggers, Dial DIALux	Space depth, window size, external obstruction angle, and glazing visible transmittance	Daylighting, artificial lighting, user behavior	Library of Faculty of Architectural Engineering in Beirut Arab University, Debbiah, Campus and Beirut, Le5n	The daylight designs based on hollow prismatic light function as luminaires, boosting the overall efficiency and uniformity of natural light distribution into library spaces

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Bawaneh et al. [64]	Analytical review of end-use energy data in US healthcare systems and hospitals that can be used as a standard to analyze the energy-related performance of US hospitals	Statistical analysis	NA	Floor space	Energy consumption	71 Healthcare centers in the USA	In the United States, the energy intensity of hospitals ranges from 640.7 to 738.5 kWh/m^2. This is over 2.6 times the average for commercial constructions. HVAC and lighting (non-process energy) account for around 61% of a typical hospital's energy consumption in the United States, confirming the need for technology advancements and design upgrades, particularly for HVAC systems and non-process energy consumption
Guo and Bart [65]	To accomplish the unity of energy usage and indoor thermal comfort level of an office located in different cities in China, various design criteria that meet the principle of climate adaptation are recommended	Mixed method-Mathematical analysis/Building energy simulation	EnergyPlus/Open Studio	Orientation, a layer of insulation board, U-value of exterior fenestration, SHGC, WWR, infiltration rate	Heating, cooling, and total energy consumption, thermal comfort	5 Typical benchmark geometric models were established as per local energy conservation codes	The severe cold zone and hot summer & cold winter zone appeared to have the greatest energy-saving potential, with 18–24% and 16–19%, respectively, while the cold zone and mild zone approximately equaled 15% and 12–15%, and the hot summer and warm winter zone appeared to have a relatively low (5–7%)

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
William et al. [66]	High temperatures and high humidity levels in hot and humid climate zones like Alexandria, Egypt, induce human discomfort, resulting in high HVAC energy consumption in healthcare facilities	Building energy simulation	Energy Plus/Design-Builder	Envelop-glazing, insulation, lighting	HVAC LOAD	An Alexandrian medical facility in Egypt consisting of five stories with an approximate area of 10,000 m^2	Energy savings and operational costs can be reduced by 67% through smart retrofitting and system sizing
Cesari et al. [67]	The influence of various window sizes and glazing types on heating, cooling and lighting energy demand in a hospital patient room healthcare facility in Europe cities—Italy (Milan, Bologna, Rome, and Naples)	Building energy simulation	EnergyPlus/TRN-SYS	Glazing types, Window sizes, Room orientations, Climatic conditions, and Lighting control strategies	Heating/cooling load an artificial lighting energy demand	A typical representative hospital building of healthcare building stock—experimented with 4 Italian cities, Milan, Bologna, Rome, and Naples having different climate conditions. Simulations model—two patient rooms on the third floor facing no external obstruction	Wider windows with adequate glazing and a daylight-linked dimming lighting control approach can reduce primary energy demand by up to 17%

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Fang et al. [68]	Simultaneous evaluation of the daylighting and energy performance of building with design options and also to generate the optimized design	Building simulation	EnergyPlus/Radiance	Building depth, the roof ridge location, the dimensions, placement, and orientation of the skylights, the Width of the windows on the north and south, and the length of the Louver	Daylighting and energy performance	A small single-story office building	Proposed a multi-objective method to automatically explore building design alternatives, evaluate daylighting and energy performance, and find design options with optimal performance, where the daylighting performance metric UDI is increased by 38.7%, 31.6 percent, and 28.8%, and the energy performance metric EUI is decreased by 20.2 percent, 18.5%, and 17.9% compared to average performance values
Kyritsi et al. [69]	Examining the impact of natural airflow on the passive cooling of an office unit in the Mediterranean region of Europe using quantitative field research	Case study	NA	Windows details	Thermal comfort, energy consumption	An open layout office space on the Fourth Floor of a five-story building in the urban center of Nicosia	The findings revealed that night ventilation is the most effective passive cooling approach

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Gärtner et al. [19]	Exploring the influence of a flexible space layout design on thermal comfort and energy demand in a modern open-plan office space in Stuttgart, Germany	Building energy simulation	Energy plus/TRNSYS 18, Grasshopper	Space layout, 3 types of HVAC system configurations, four different control zoning strategies	Thermal comfort	In a single-floor plan of an office building located in Stuttgart, Germany-12 different spaces layout designs	Radiant ceilings and thermally active building systems are attractive options for flexible office spaces in Stuttgart, whereas mechanical ventilation systems necessitate a more complicated control technique to provide thermal comfort
Pilechiha et al. [70]	Presents a new multi-objective strategy for analyzing and optimizing the energy processes connected with window system design in Tehran, Iran	Multi-objective optimization	EnergyPlus/Open Studio, Grasshopper-Ladybug, and Honeybee	Windows, room dimensions, orientation	Quality view, daylighting, energy consumption	The office room is located on the middle floor of a multi-story building, with an approximate area of 2300 m^2, having dimensions of 3.9 m × 8.5 m × 2.8 m with single-zone space	Consideration of window system configuration in the early stage of the design process is very important to reduce the lighting energy
Aunión-Villa et al. [71]	Investigating the energy intensity of a hospital by area and developing energy performance indicators in Madrid (Spain)	Case study	NA	Open, closed, and mixed layouts	Energy consumption	182-bed hospital—an experiment area of 25,177 m^2 (electromedicine, radiology, radiotherapy, and nuclear medicine), 3 layout variants-open, closed, and mixed layout	Operating rooms and intensive care units used more than 1000 kWh/m^2 per year, whereas catering and nuclear medicine used 500–1000 kWh/m^2 per year, radiology used 350–500 kWh/m^2, and most other units used less than 250 kWh/m^2

Table 2 (continued)

Author	Study focus	Method of research	Software	Independent variables	Dependent variables	Sample details	Key findings
Du et al. [17]	The energy performance assessment combines daylighting simulation with energy simulation for an office building in Europe and Asia	Mixed method-building energy simulation /Sensitivity analysis	Energy Plus/Radiance, Daysim, Grasshopper-Ladybug and Honeybee	Layout variants, climate, WWR, shading systems	Daylighting	An existing office building in Madrid, Spain-11 variants of space layout and 3 different climates	The plan variation has the greatest impact on lighting consumption, with the highest difference occurring in Harbin, where it is 46% without shade and 35% with shading. In Amsterdam, the highest difference in the sum of the final energy for heating, cooling, and lighting using a heat pump system is 8% for the layouts both without and with the shading system
Zou et al. [72]	Creating a complete method for optimizing the design of a standard architectural space to increase building performance in China	Mixed method-Mathematical analysis/Multistage optimization	Energy Plus/Grasshopper, Diva-for-Rhino, and SpeedSim-for DIVA	Orientation, geometry, shading devices, wall, windows	Thermal comfort, visual comfort, total energy consumption	A typical type of classroom in Guangzhou, China	On average, the 3-step optimization process improved energy performance by 24.6%, 18.7% and 14.2%, suggesting that this strategy is practicable and useful for improving building design in actual assignments

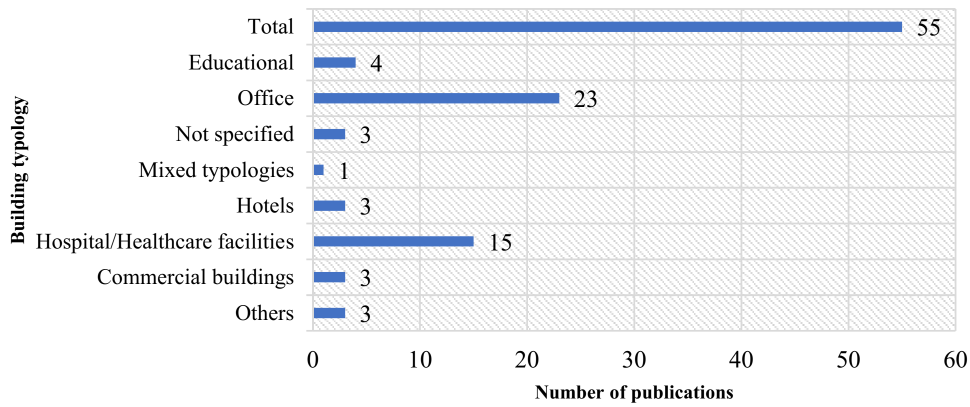


Fig. 4 Building typologies investigated in reviewed articles (*Source*: Scopus database)

studied hospitals in comparison to available benchmarks. Paula Morgenstern et al. [54] concluded that as per defined benchmarks, various departments of hospitals consume different amounts of electrical energy, with inpatient wards, day care clinics along with other departments having lower average usage intensities than high electricity usage areas of hospitals such as operating rooms, laboratories, and imaging and radiotherapy departments. Yang et al. [30] introduced a framework for quantifying the energy implications of building-level occupancy diversity, using building information modeling to stipulate building shapes, HVAC system configurations, and spatial data as inputs for computing.

Daylighting

Daylighting is a passive approach for improving energy performance and visual comfort without incurring high installation and operating costs [74]. Daylighting is seen as a key component of space identity and space quality [75]. Also, an efficient sustainable strategy to improve the EPB [76]. Lighting constitutes a significant portion of building energy consumption [77]. Insufficient natural daylight in the space and reliance on artificial lighting systems during the daytime waste more energy [63]. Building shape or geometry, along with primary design factors such as window design, shading design, roof design, façade design, building shape design, and so on, is one of the most impactful design decisions on daylighting to be considered in the early design stage [68]. An atrium, windows, and openings are potentially a major source of daylight for buildings and offer other environmental benefits in terms of solar gain, reduced energy losses, and natural ventilation [63]. According to Du et al. [17], the effect of daylighting can be explained by the different layouts including courtyards, atrium, the form of the buildings that impart different levels, and an appropriate space layout combined with the glazing design/orientation, window design and the positioning of interior partitions. Optimizing space layout design may greatly reduce energy demand, particularly lighting requirements. Furthermore, the impact of space layouts on EPB varies depending on the environment. The maximum daylight is set around the windows on the edge of the space, while it becomes minimal as we move deeper into the interior and far from the windows. As a result, approaches to enhance the depths of space with the use of daylight are required [63]. The width-to-depth ratio is a vital room geometry factor that affects the interface of isothermal interior walls and outer walls, but also the dispersion of sunshine throughout the interior space of a room. The extent of the perimeter wall of the room determines the surface exposed to heat transmission through the façade and the amount of daylight. The depth of a room defines the amount of daylight penetration inside the building. Due to the large area of its exterior wall, a wide and shallow space with proper sunlight and light dispersion has a lot of heat reception and dissipation. A narrower and deeper chamber receives less sunlight, but it also receives less heat due to the small area of its exterior wall [42]. Norbert Harmathy et al. [53] studied to enhance the indoor illumination quality, an improved building envelope model emphasizing the perimeter of the building was created utilizing a multi-criterion optimization process and identified the most efficient window-to-wall ratio (WWR), window geometry, and glazing parameters. The design and control of a shade system are heavily influenced by climatic conditions and daylight availability. The shading device's location, characteristics, and control have a big impact on the natural lighting and thermal performances of peripheral office areas. The shading features and control have a direct impact on lighting electricity usage [29]. Omar et al. [63] investigated the circumstances of interior daylight and the energy performance of the library at Beirut Arab University using various architectural factors such as space depth, window size, exterior angle of obstruction as well as glazing visible transmittance. Also proposed the daylighting designs based on hollow prismatic light guides in space design. Pilechiha et al. [70] present a method for assessing the effectiveness of view in office spaces while keeping energy efficiency and daylighting in mind, allowing for a window design optimization framework. Zhang et al. [13] investigated different spatial configurations to enhance daylight illuminance and reduce visual discomfort through an optimization process for a school building in China to prove that double-sided corridors are best compared to single-sided corridors for the study area located in the cold region.

Natural ventilation

By integrating openings with an appropriate space arrangement, fresh air is provided to the rooms as needed. A function that needs more ventilation, such as a facility room, can be located near the windward external wall, whereas a function that demands less ventilation, such as a storage or equipment room, can be located near the leeward external wall. Slight changes in cloud cover, wind speed, and direction would have an impact on the availability of daylight and natural ventilation, which appear to be the most important aspects influenced by internal space arrangement [14, 15]. The following factors influence natural ventilation efficiency: climates, window opening schedule, building material, built area, and the number of building occupants in a building plan. Optimized window designs help to improve energy efficiency and thermal comfort in naturally ventilated structures [78]. According to Du et al. [7] changing the placement and size of buffer spaces, such as a courtyard, solar chimney, atrium, and light-well, has a significant impact on natural ventilation within buildings. The building with better space connection and integration has a higher natural ventilation velocity. The potential for natural ventilation is extreme in hot-dry and warm humid climates during all periods of the year [60]. Schulze and Eicker [39] determined that there is a need for regulating opening methods to avoid overcooling of rooms as well as provide sufficient fresh air during the heating season. Regulated natural ventilation was compared to mechanical ventilation and cooling for the assessment of cooling energy conservation. According to the simulation results, properly created natural ventilation systems save between 13 and 44 kWh/m^2 of cooling net energy per year for the 3 places Stuttgart, Turin, and Istanbul. Short et al. [21] created, cataloged, and aggregated environmental design propositions for clinical as well as non-clinical space types into a typical plan module, their energy performance along with the ventilation modeled to conclude that 70% of the gross floor area of small to medium-sized healthcare buildings could have passive ventilation and hybrid ventilation approach might serve an additional 10% of net floor area.

Control of the heating, cooling, ventilation, and lighting system

Different space layouts are suitable for different types of control for space heating, space cooling, ventilation, and lighting systems [7]. HVAC systems are required under various climatic circumstances to create a suitable indoor thermal environment for occupants, equipment, and devices [79, 80]. Room geometry, window type, and positioning may significantly affect the air-flow rate and the cooling effect [81]. Previous research has shown that proper shade design and control, combined with simultaneous control of electric lighting and HVAC mechanisms, can substantially decrease peak cooling capacity and energy usage for lighting and cooling whilst still maintaining good thermal and illuminance for interior conditions [29]. The size, number of rooms /floors, building type, and intended usage of the facility all influence the type of HVAC system employed in a structure [46]. Buildings consume energy for hot water, cooling, heating, lighting, services, and equipment, and a significant portion of this consumption can be minimized by using passive design principles [33]. According to statistical regression research by Shilei Lu et al. [55], the proportion of the air condition area that accounts for the ground floor area is significantly associated with the standardized energy utilization intensity of the HVAC system.

Influencing variables related to space layout on the energy performance of the building

We can see from a prior study that it is very difficult to isolate the influence of space layout on EPB without considering the geographic location, climate, space occupancy data, and functional/environmental requirements [7]. Most of the studies merged other design aspects with the layout of the room (Fig. 5). Other design variables that influence EPB are discovered through their interactions with space layouts, allowing the impact of space layouts to be examined. Aspect ratio, direction, usage, climate, material, and other architectural factors, for example, have varying influences on energy performance [78].

Geographic location and climate

The amount of solar radiation and mean outdoor temperature that a building is exposed to influence the climate. The climate also influences the quantity of energy required for heating and cooling, as well as the amount of energy used for lighting [82]. The unique characteristics of the natural environment, such as the amount of sun, wind, and local vegetation can have a significant impact on building design and energy efficiency. Energy fluctuation due to space planning and usage considerations is site-specific, hence its importance varies depending on the building environment. This means that, in addition to standard building design criteria, space planning solutions along with perimeter details are targeted at enhancing energy performance by responding to their contexts [14]. One of the key aspects of spatial layout design concepts to reduce building energy use is the

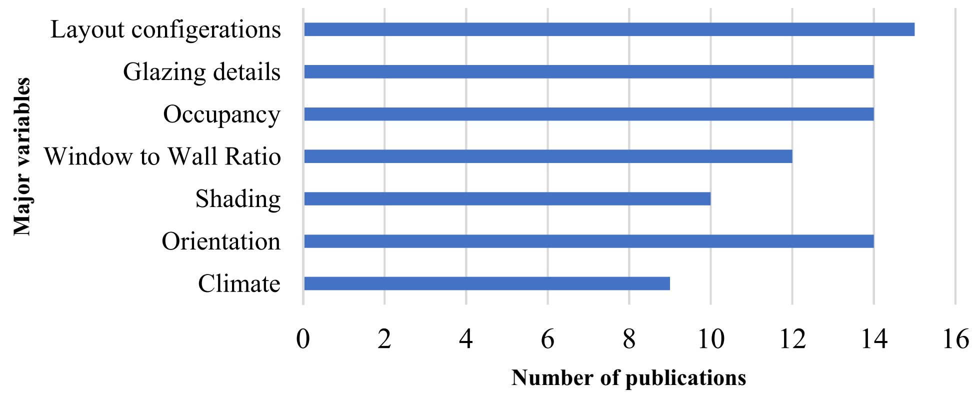


Fig. 5 The major variables considered for the investigation of EPB in reviewed articles

correlation of a local climate with both the shape and thermal efficiency of the building [48]. The environment has a significant impact on the selection of appropriate building technology, such as cooling systems and high-efficiency appliances. Also where natural ventilation is used, thermal comfort should be accomplished with low building energy usage [82]. For different kinds of buildings in different regions, there is a clear disparity in power consumption per unit at the proposed site because temperature conditions in different places fluctuate greatly [57]. Bawaneh et al. [64] found that the geographic context has a significant impact on heating energy, with varied energy usage in hospitals in different parts of the United States. Hospitals in the United States have an average annual energy concentration of 738.5 kWh/m^2, which is greater than similar reported statistics in European countries. In California, the energy consumption of healthcare complexes along with universities, schools, and accommodations through the study of monthly electric and natural gas usage invoices, as well as the total cost of energy usage data, were collected to examine the energy intensity. Guo et al. [65] proposed different design criteria that match the climate adaptation concept to attain unity in energy usage and indoor thermal comfort level. González et al. [62] concluded that the kind of management, the available bed number, the Gross Domestic Product (GDP), or the climatic circumstances, had a more direct impact on annual energy consumption than the geographic location. Several studies have also revealed that selecting an adequate WWR value is especially important in hot climates because a WWR value outside of the optimal range results in the biggest rise in energy consumption [52].

Form and orientation

The shape of a building has an impact on its energy use. Low-energy architecture necessitates careful articulation of a building's shape and forms to reduce energy use. Traditionally as a thumb rule, in passive solar building design, the form and orientation are important factors for overall energy efficiency in a building [83]. For most geometric factors, the subtropical climate has the largest difference between the ideal and worst solution, whereas the tropical climate has the least difference. Building orientation, shape, plan depth, and window-to-wall ratio have the greatest impact on EPB. The influence of plan shape on building energy consumption is largest in sub-tropical climates and lowest in temperate climates and tropical climates [84]. The ecological impact of courtyard buildings is directly influenced by their orientation. A courtyard's spatial structure can help regulate solar heat. Furthermore, a courtyard's natural ventilation system regulates convective heat transfer [85]. The ellipse was discovered to be the optimal plan form in all climates. It is the most efficient form in temperate and subtropical climates and the second most efficient shape in tropical temperatures after the octagon. Furthermore, the "Y" form is the least efficient in all climates [30]. In typical architectural practices, geometry factors are specified by a building's form, type, structural, and HVAC systems [42]. Building and fenestration geometry characteristics, when combined with other fenestration elements such as shading, room geometry, energy-efficient glazing, and adaptable building systems, will dramatically cut overall energy consumption to improve building energy performance. Aksoy [28] The influence of building form and orientation on heating demand has been thoroughly researched, and the results show that structures with a square shape have more advantages, and the ideal orientation angles for buildings with shape factors of 2/1 and 1/2, respectively, are 0° and 80°. When different geometries are employed, there will surely be differences in the form coefficient and energy utilization. Susorova et al. [42] observed through energy simulations using Energy Plus, that the impact of geometry parameters comprising room width to depth ratio, window orientation, and WWR on BEP in a commercial office structure in various temperature zones. The study found that geometrical considerations had a considerable impact on energy usage in hot and cold climate zones, but only a little impact in moderate climates in the United States. Pilechiha et al. [70] presented a novel multi-objective method to change the room shape to meet the lighting and view criteria specified according to the optimization model and building performance standards. By using virtual reference buildings. Zheng Yang et al. [50] proposed a framework that was consistent across different building geometries, different building layouts, and different diversities, and discovered that the increased complexity of building geometries, the greater the influence of diversity on HVAC system energy efficiency. Building orientation is a significant design consideration, mainly regarding solar radiation and wind. In predominantly cold regions, buildings should be oriented to maximize solar gain whereas in hot climates the orientation should encourage to reduce the heat gain inside the building.

Building envelope

Building envelopes, which distinguish the indoor and exterior environments, and especially building façades play an important role in energy conservation in buildings. The thermal barrier that separates the internal and exterior environments is largely made up of façades [86].The external and interior walls, windows, and roofs of a structure, as well as its function and location, are referred to as "building envelope" [87]. Building envelopes have been utilized for a variety of purposes over time. Control of physical environment variables (temperature, light, noise, rain, moisture, air infiltration, etc.), structural support for the structure, fire safety, security, energy conservation, and aesthetics are among these roles [88]. The design of building envelope parameters has a significant influence on building energy-saving design and hospital spatial layout [89]. The building envelope is critical in reducing heat gains and controlling the amount of energy required for space cooling. Several studies have been undertaken to assess and make recommendations on the impact of various building envelope factors on energy performance. Window details, insulation properties of the wall and roof, color, the finish of exterior surfaces, and shading details of surfaces and windows are the main building envelope features that influence cooling demand and thermal comfort along with lighting and ventilation in hospitals. The type of fenestration employed in a structure has a big impact on energy efficiency and occupant comfort in healthcare buildings and influences determining overall energy and cooling usage in the building [7]. Several studies investigated the design of an energy-efficient façade while considering the environment, building type, and physical properties of glass and framing material such as visible transmissions, solar heat gain coefficients, and thermal conductivity. In conventional architectural methods, geometry factors are often established by a building's form, type, structural, and HVAC systems. Because the form, orientation, and enclosure of a building can influence its energy consumption, it is critical to make objective energy-saving and daylighting decisions when determining its form, orientation, and enclosure [42]. Ascione et al. [38] by examining medium-sized healthcare amenities in Mediterranean climates, suggested that refurbishing the building envelope improved indoor thermal conditions in all relevant HVAC systems. Because the maximum external insulation enhances the shell's thermal capacity, the improved envelope would undoubtedly result in better internal conditions in terms of a more stable microclimate. Hanan M. Taleb [49] did a detailed examination of annual EPB for the case study and used a computer simulation to explore EPB shortfalls that define as a 'base case,' and then compared to modified building envelops that included unshaded, exterior wall retrofitting, cool roof, new glazing, and green roofs. Hatice Sozer [33] demonstrated that proper thermal insulation, glazing type, and shading components can help to limit heat transfer through the building envelope. This research reveals that precise building envelope design can considerably aid in achieving heating and cooling targets and improving the building's energy performance. Reduced cooling thermal energy consumption improved thermal comfort, and appropriate daylighting should all be goals of an efficient hospital building envelope design [90]. The building envelope determines the energy exchange between the outdoor environment and indoor spaces and hence governs the overall EPB [33]. William et al. [66] using building simulations, looked at the impact of building envelopes on HVAC and overall energy usage in commercial buildings of Egypt. Ma et al. [57] stated that the air conditioning system, lighting density, and building envelope are the main factors influencing energy consumption according to the orthogonal test. After researching the effects of shadings, window types, and so on, Poirazis et al. [32] determined that during the occupancy stage, highly glazed single-skin buildings are likely to consume more energy, and the increase was reduced to 15% while maintaining an acceptable level of thermal comfort when compared to a typical reference building with a percentage window to external wall area. Zahiri and Altan [48] implemented to have a significant improvement in indoor air temperatures, passive design strategies such as south and south-east orientation, thermal mass, thermal insulation in walls and roofs, as well as side fins and overhangs as solar shading devices, as well as all-day ventilation for a school building. Passive envelope design solutions also increase indoor environmental quality, allowing users to function better and reducing the need for mechanical systems. Wang et al. [45] investigated in a moderate-size reference office structure, the effects of window opening systems on building functioning for many types of ventilation systems, including natural ventilation, mixed-mode ventilation, and classic Variable air volume systems. The results of using the Energy Plus building performance simulation tool revealed the benefits of window opening systems on energy use and comfort, as well as HVAC, resulting in energy savings of 17–47% in varied regions throughout the summer. A computerized simulation was employed in the case study to investigate power outages. Meanwhile, the energy consumption of a new building skin was compared to that of a new building skin using ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) based parameters to limit heat gain, such as sunshade, retrofitting outside walls, cool surrounding roofs, and new windows, and green towers. Bayoumi et al. [60] investigated the relationship between the amount of window opening and energy use in two hot climate office environments particularly on certain days of the year. Rajagopalan et al. [44] assessed by dividing the envelope area by volume, and the compactness ratio to compare the energy loss against HVAC system operation. The degree of compactness determined how much heat is gained and lost via the envelope. Zahiri et al. [48] developed an optimal design solution for secondary school buildings to improve the indoor thermal conditions, which included all-day natural ventilation, the installation of side fins and overhangs, and the use of thermal mass and thermal insulation in the external walls, and roof, as well as the orientation through dynamic building thermal simulation.

Windows are one of the most important aspects of a building's design. Windows are frequently a significant component of the exterior appearance of the building, whether there are little perforated openings in the facades or a total glass curtain wall. Windows are inseparable parts of the building's envelope. They represent the source of daily light, provide visual contact with the environment and provide ventilation and natural cooling [91]. The amount of energy consumed through heating, cooling, or lighting in a building is mainly influenced by its window systems [92]. Windows can be thought of as thermal holes for a building in terms of energy use. As a result, window design and selection must include both aesthetics and serviceability [93]. Windows influence the energy needs of a building in four ways: heat conduction, solar radiation conduction, air conduction, and daily light transmission. That influence also depends on the characteristics and orientation of windows, climate conditions of the building's location, solar radiation, and the building's heating and cooling systems. Energy losses through the window can be minimized by careful and adequate design, both of a window as a whole and its elements [94]. Appropriate window orientation and careful design of a window as a whole along with its different elements also help to restrict solar radiation gains and losses, reduce the frequency with which mechanical ventilation is used, and so lower energy expenses [95]. Windows and other glazed spaces are the most vulnerable to heat gain or loss of all the elements in the building envelope. Windows in general, are the weakest parts of the building elements which act as a bridge to allow the outdoor condition to be transferred into the indoor space [96]. The room's air velocity and flow are moderated by the size, shape, and orientation of the openings; a tiny input and big outlet improve the room's airflow velocity and distribution. Glazed openings also allow natural light to enter a structure. The important components of a window that govern requirements of heat gain and loss, ventilation, and daylighting are the glazing systems and shading devices [29]. Most of the reviewed articles investigated the energy performance of the hospitals by considering window details as one of their important variables which includes window size [23, 67], WWR [17, 44], window opening grade [53], window orientation, and geometry [24, 42, 52], etc. Norbert Harmathy et al. [53], optimized the building envelope model using a multi-criterion optimization methodology to determine efficient WWR, window geometry, and glazing parameters to enhance the indoor illumination quality. Mohannad Bayoumi et al. [60] explored the relationship between the window opening grade and energy savings in a one-sided window opening in two hot environments, one humid and one arid. Cesari et al. [67] by examining four distinct orientations in four Italian cities, the energy performance of nine different glazing systems was examined concerning a typical size opening with a 25% WWR and a floor-to-ceiling window with a 77% WWR. The optimized WWR for each of the major orientations was observed in four locations, covering the mid-latitude area from temperate to continental climates by integrated thermal lighting simulations, coupled with a sensitivity analysis for an office building with a single corridor that the total energy use may increase in the range of 5–25% when the worst WWR configuration is adopted by using integrated thermal and lighting simulations. Wang et al. [45] in a medium-sized reference office building evaluated the effects of window operation on building performance for several types of ventilation systems, including natural ventilation, mixed-mode ventilation, and conventional variable air volume (VAV) systems.

The shading device's location, characteristics, and control have a big impact on the natural lighting and thermal efficiency of peripheral space. To combine daylighting requirements with the need to limit solar gains, shading must be considered an integral aspect of facade system design for every building [29]. The major goal of utilizing shading devices is to keep direct sunlight from reaching the exterior walls and windows. Overhangs, fins, blinds, and shading of neighboring buildings and far obstructions are all examples of shading [48]. Several factors must be addressed when designing glazed facades with shading devices in any building, including the building type, natural light perspective, and latitude. Shade device types are influenced by building form and orientation in particular. The type of shading device utilized influences the level of ideal daylight, thermal comfort, and visual comfort [97]. Tzempelikos et al. [29] used a connected lighting and thermal simulation module to calculate the simultaneous impact of glazing area, shading device attributes, and shading control on building cooling and lighting requirements in peripheral spaces including examination of window-to-wall ratio and shading characteristics. The simulation results show that, depending on climate patterns and orientation, when an integrated approach for the control system of mechanized shading is used in connection with easily controlled electric lighting systems, substantial reductions in energy consumption for cooling and lighting could be accomplished in perimeter spaces. Du et al. [17] simulated office building variants in three different climates with two situations, without a shading system and with an exterior screen to evaluate the final energy consumption concerning lighting, heating, and cooling load The simulation findings demonstrated that the geographical arrangement of produced variants and the huge difference in energy needs in different climates had the largest impact on lighting demand when the shading device was used as an independent variable. Nielsen et al. [34] investigated the three types of facades i.e., without solar shading, with fixed and dynamic solar shading along with various window orientations and heights. To evaluate the total energy demand for heating, cooling, lighting, and daylight factors of the building. Compared to fixed solar shading, dynamic solar shading significantly increased the quantity of daylight available, emphasizing the importance of using dynamic as well as integrated simulations early design stage to make educated decisions about the façade. Alejandro Prieto et al. [61] explored the effectiveness of passive cooling strategies considering envelope parameters like windows and shading devices in commercial buildings from warm climates through the statistical analysis and simulation process. Waleed Khalid Alhuwayil et al. [58] researched the energy usage of a multi-story hotel structure in a hot and humid environment using various external shading schemes When compared to the base scenario, the findings showed that the proposed retrofit plan with external shading and self-shading effectively eliminated a large amount of the energy demand, and the investment was cost-effective due to the short payback period.

Building energy performance indicators

Several studies focused on single and multi-performance indicators or energy efficiency with thermal comfort, lighting, ventilation, along with HVAC load in healthcare structures. There are some research focused solely on energy performance or thermal performance or daylighting or natural ventilation and many others are focused on multiple parameters including energy demand, thermal comfort, and indoor environmental quality (Fig. 6). Thermal performance and energy consumption together got investigated mainly by considering window details along with orientation, and shading devices as variables [69, 72, 80]. There are many other indicators along with main performance indicators like energy consumption, heating, and cooling, lighting load like airflow, average indoor daylight factor, daylight factor, equipment load, external conduction gain, gas consumption, indoor air quality, indoor air temperatures, and indoor environmental quality. According to the international standard ISO 50006-2014 [98], "an EPI (Energy Performance Indicator) is a value or measure that quantifies energy efficiency, energy use, and energy use performance in facilities, systems, processes, and equipment" [99]. The energy performance indicator is noted as EPI, which is stated in kWh/ m^2/year. The EPI is calculated by dividing the yearly energy expended by a building in kilowatt-hours by the gross floor area in square

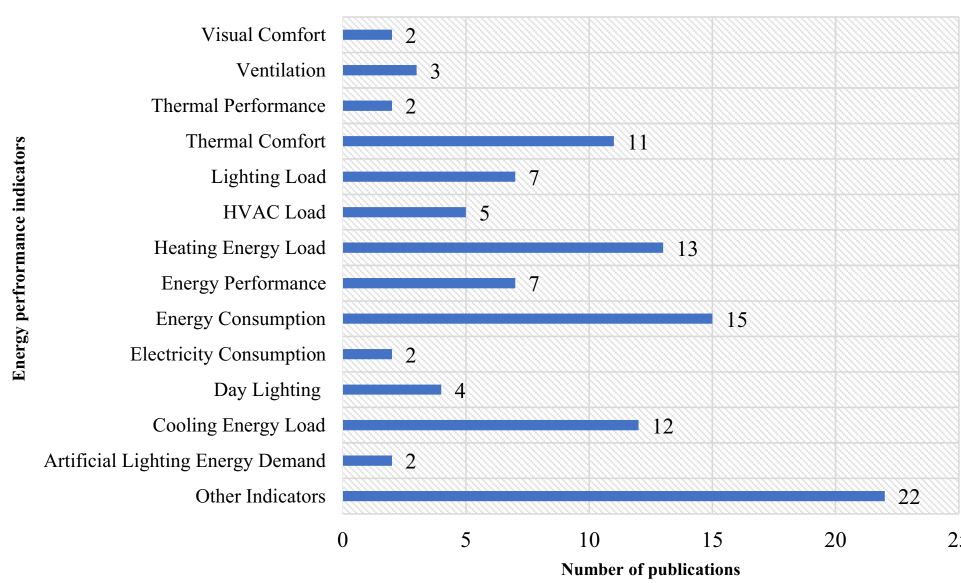


Fig. 6 Energy performance indicators investigated in review articles

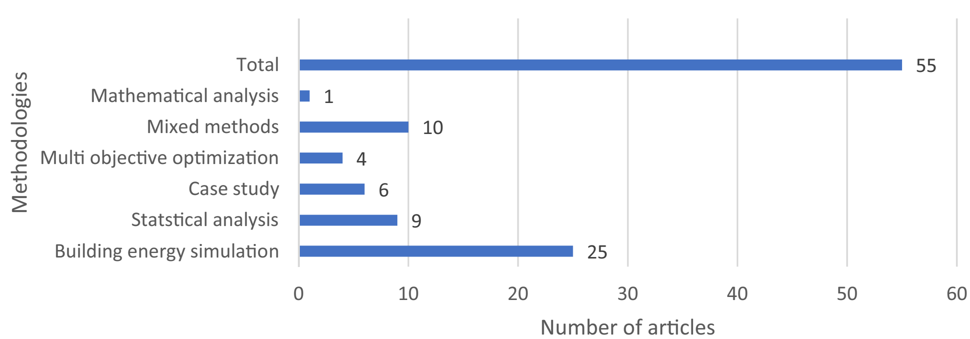
meters of the building. Numerous energy performance indicators are used to describe building performance, and they differ in terms of the boundary at which they are monitored, and the contributions used for their calculation [16]. Regarding the calculation period, most studies calculated the energy use for the whole year, for only some seasons and peak days for different building typologies located in the various climatic zone [7]. Single rooms, zone-wise, or entire buildings were investigated through case studies or through developing a simulation model to calculate the EPB. Nielsen et al. [34] calculated the total energy demand, heating load, cooling load and lighting load, and daylight factors of office buildings by investigating shading details as a variable through simulation. Also, we can find from works of literature that opening details, orientation, and climatic factors play a major role in heating, cooling, lighting, and ventilation load which directly influence thermal comfort and total energy consumption of the buildings [49, 52, 67]. The thermal performance of the building was investigated by considering window detailing in terms of size, geometry, orientation, and glazing parameters in different climatic parameters to achieve a significant result [14, 51].

Methodologies considered for investigating the EPB

There are several different methodologies are considered to study the EPB concerning different space layout variables and performance indicators of different building typologies as well as the climatic zone (Fig. 7).

Most of the research in this area was conducted using experimental or simulation techniques, sometimes combining both as needed. There 25 studies are based on building energy Simulation method [14, 15, 19, 22, 23, 29, 31, 33, 34, 37, 39, 40, 42, 45, 46, 48, 50, 51, 53, 58–60, 66, 67] and out of 10 research 7 number of literatures are combined building energy simulation method with other methodologies like statistical analysis, optimization and case study method [24, 32, 41, 49, 52, 63, 65]. The 6 studies are based on case studies [16, 38, 44, 54, 69, 71], and 9 studies [35, 36, 43, 55–57, 61, 62, 64] employed a statistical analysis of the energy performance investigation.4 number of studies are exclusively based on multi-objective optimization [20, 47, 68, 70]. A detailed analysis of annual EPB for the case buildings was performed using a computerized simulation to explore energy performance shortcomings as a base case [49]. Building geometry, space layout, the grouping of rooms in thermally homogeneous zones, building orientation, building construction, thermal properties of all building components, building usage, internal loads and schedules for lighting, occupants, and equipment, HVAC system type and operating characteristics are some of the input data required for energy simulation of buildings [100]. In recent years, thermal dynamic simulation has been widely employed in the design phase to assess the appropriateness of the intended project to thermal and energy performance objectives. This simulation assumes that the findings accurately represent the actual behavior of the buildings. A comparison of site measurements and numerical simulation results is required to demonstrate this idea [101]. Guo et al. [65] employed a mixed-method approach evaluation as well as intensive computer simulations to discover the ideal design approaches within the energy as well as thermal comfort constraints. Five separate benchmark geometric models were constructed in OpenStudio, indicative of diverse climates, while using the EnergyPlus engine to examine the coupling relationship between energy usage and thermal comfort, according to local energy conservation codes. Using the dynamic simulation method and calibrating the simulated energy consumption against the building's actual energy use. Chedwal et al. [46] concluded that there is a significant energy saving potential of up to 27.9 kWh/year in hotel buildings in India by implementing ECBC (Energy Conservation Building Code) along with other energy efficiency measures. Lu et al. [55] through statistical regression analysis, assessed that standardized energy consumption intensity of the HVAC system is significantly related to the gross floor area. Adamu et al. [37] used four natural ventilation systems intended for single-bed hospital wards to assess the viability of buoyancy-driven airflows. These tactics include single-window opening, inflow and stacking,

Fig. 7 Various research methodologies adapted in the reviewed articles



same-side dual-opening, and ceiling-based natural ventilation, which is a revolutionary concept. As a case study, these solutions were investigated using a dynamic thermal simulation model and computational fluid dynamics on a new ward in a London hospital Pisello et al. [36] presented post-occupancy evaluation by in-situ analysis to achieve an average monthly energy savings of 20.5% for lighting, heating, cooling, lighting, additional sources, and types of equipment, of overall primary energy demands for electricity, decreasing from 385.8 to 306.7 kWh/m^2 year via calibrated and validated dynamic simulation model. Zou et al. [72] developed a comprehensive technique for enhancing building performance by improving the design of typical architectural spaces. The optimization process is divided into three stages. The first step is to build a database by generating research objects at random and stimulating their development. The second phase of multi-objective optimization is to construct artificial neural network models as an alternative to time-consuming building simulations to predict building performance quickly. Finally, perform multi-objective optimization based on the actual design limitations. Delgarm et al. [23] combined a mono- and multi-objective particle swarm optimization algorithm with EnergyPlus building energy simulation software to find a set of non-dominated solutions to improve EPB, resulting in a powerful and useful tool that can save time when searching for optimal solutions with competing for objective functions. EnergyPlus is one of the most robust, trustworthy building simulation tools that can model energy consumption for heating, cooling, ventilation, lighting, as well as plug and process loads [33]. Echenagucia et al. [47] with the help of a multi-objective search using genetic algorithms, reduced the energy required for heating, cooling, and lighting an open space office building by changing the quantity, placement, form, and type of windows and thus the thickness of masonry walls using the NSGA-II algorithm in conjunction with EnergyPlus building energy simulation tool. Norbert Harmathy et al. [53] developed an integrated approach, a multi-criterion optimization method, in conjunction with extremely detailed Building Information Modelling programs and dynamic energy simulation engines, to achieve better energy performance of offices by relating building envelope optimization and comfort of users in a wide range of climatic conditions and for varying construction types. Zhang et al. [20] presented the results of a simulated optimization study of numerous spatial configurations to determine the best trade-off between reducing energy use for heating and lighting, reducing summer discomfort time, and maximizing useable daylight luminous flux. Lighting load, HVAC load, thermal load, and ventilation methods are among the software that can be used in conjunction with various simulation engines to evaluate the EPB. The energy plus simulation engine, when combined with other simulation software, produces an upgraded building model that can be used to evaluate the energy, thermal, heating, cooling, lighting, and ventilation performance of different building types. Current computer simulation resources can largely predict energy usage by HVAC, lighting fixtures, and appliances, among other things. EnergyPlus, OpenStudio, Revit, DesignBuilder, eQUEST, and other simulation tools are used to create these energy use figures [66]. The trustworthy results encouraged many researchers to use Energy Plus in their studies. Different simulation engines are developed to investigate the energy performance of the building with advanced plug-in software. Energyplus engine coupled with different software like an OpenStudio and DesignBuilder is utilized in most of the research. Ecotect software was used to simulate daylight. Where it offers vital information about the architectural aspects that affect the current situation's sunshine. This includes elements such as windows, as well as their characteristics such as position and size, as well as their impact on the amount of daylight that enters the area and the duration of daylighting [28]. Although DesignBuilder is based on a complex simulation program, it attempts to address the architect's specific language with a visually orientated interface and inputs in different levels for developing and evaluating comfort as well as energy-efficient architecture from concept to completion [102]. Bawaneh et al. [64] proposed a mathematical formulation for efficient assessment of the optimal healthcare building floor area, which anticipates their yearly energy consumption and can be used as a source of reference for project planning and as an indication to monitor the energy management of such buildings. Liu Yang [30] examined the cooling and heating requirements of the office building envelope in five major climate zones of China using the total thermal transfer value method and the heating degree-days method to develop standard building envelopes based on information collected from building surveys, local energy codes, and the ASHRAE Standard. Musau et al. [14] used the TAS, Lightscape, and Excel computer programs to evaluate the possible implications of typical open, mixed, as well as closed configurations and their space usage densities/intensities on a base case.

Sample design to assess the energy performance of the buildings

The number of samples considered in the various methodologies for the investigation of energy performance are ranging from a single building to 119 buildings [57]. The entire building samples to single rooms like classrooms [72] and patient wards [59] were investigated to analyze the various energy performance indicators like cooling, heating, ventilation, lighting, electricity consumption, and thermal comfort in different building typologies. Adamu et al. [37] explored ventilation strategies via dynamic simulation and computational fluid dynamics, by investigating different departments of the Great Ormond street hospital located in the United Kingdom. Wang et al. [45] focused on the investigation of the impacts of window control on building performance for various types of ventilation techniques in a medium-size reference office building where the floor is divided into 5 functional zones to develop a simulation model. Many researchers considered typical floors [47] to multistorey buildings [40, 77] in their research to develop an experimental framework or to create a simulation model as well as a base case [58, 73]. Aunion-Villa et al. [95] analyzed energy consumption of HVAC, medical types of equipment in an energy-intensive department like radiology, catering, nuclear medicine, operation theatres, and intensive care units of a hospital with a 182-bed capacity and an area of 25,177 m^2. Different instruments are used to collect energy consumption data in various departments. The sample used in the simulation-based projects is either an actual case study building or reference model [17] or a hypothetical model [22]. Most of the simulation models of an actual building, reference buildings, or hypothetical models are developed using software like AutoCAD, DesignBuilder, OpenStudio, rhino grasshopper, etc. To examine the room energy consumption under different temperature circumstances, a typical hospital structure representing the Italian healthcare buildings was chosen as a case study and placed in 4 Italian cities, Milan, Bologna, Rome, and Naples Cesari et al. [67] collected the data for the investigation process of energy consumption of any building gather from field studies, technical reports, energy audits, measurements using instruments, etc. There are several articles focused on the investigation of space layout by developing space layout variants which were found to be effective in assessing the EPB. Different variants are created based on the climatic considerations [17], spatial arrangement [22], envelope parameters [42]. Rajagopalan et al. [44] created 10 variants of space layout of two buildings selected out of 30 hospitals based on age, location, and size of the building to investigate the energy consumption in medium-sized hospitals in Australia. Du et al. [17] designed 11 variants based on the existing reference space layout of the office which was simulated in 3 different climatic zones to measure the effect of spatial layout on EPB in different climates. Zhang et al. [20] selected a common form of classroom space with 30 design characteristics and was selected as a case study to demonstrate the optimization process. The optimization targets were set at energy demand, thermal performance, and daylight environment. It can be observed that some of the researchers are focused on mixed building typologies as the sample frame to investigate the energy usage in the buildings. Ma et al. [57] considered the 119 public buildings in which 99 office buildings, 11 hospital buildings, and 9 school buildings are considered as samples for the energy consumption investigation in China. García-Sanz-Calcedo et al. [12] evaluated the physical and functional elements that have the greatest impact on sizing healthcare facilities, as well as the practical correlations between energy use and emissions by considering 70 health centers in Extremadura (Spain) for research. Whereas Bawaneh et al. [64] provided an analytic overview of end-use energy consumption statistics in healthcare systems in the United States hospitals. Shahzad et al. [56] compared the building performance of the two buildings, they are an office building in Norway constructed in 2000 and a British office building constructed in 2011 against the standards and benchmarks. It included energy consumption, thermal performance, carbon dioxide, and light levels. Short et al. [21] examined more than 1000 room types of clinical and non-clinical spaces to suggest the typical environmental design strategies for hospitals to enhance the EPB. He collected electricity consumption of 28 departments of 8 medium to large critical hospitals in England through a field survey.

Results and discussions

The literature survey mainly focused on the energy performance of hospitals and their parameters along with other functional requirements of buildings. The space layout is an integrated part of architectural design, and many works of literature identified the whole architectural design effect on energy consumption patterns and suggested alternative technology, passive strategies, building form, and orientation. The geographical location and climate play an important role in energy-efficient buildings. There is more research concentrated on climates of warm humid, hot and dry, and moderate climates in various locations like the USA, UK, and Asia. The HVAC, lighting, and electricity consumption are regulated using effective strategies like design optimization, passive strategies, and alternative building methods. The most selected case study building typology is an office building with a 42% rate and healthcare buildings have been studied with a rate of 14%. The least studied building typology that complies with Fig. 3 is mixed-use buildings with a 2% rate. 5% of the whole studies are not specific to any building typologies. Table 2 demonstrates that most of the studies have been done theoretically with a 45% rate in the literature in which simulation tools are used to analyze energy performance and 10% of works of literature considered mixed methodologies [103]. Building simulation helped to evaluate the building model for energy performance very accurately within a shorter period and many alternate energy optimization solutions can be generated based on the necessity and the context. 44% of the research depended on EnergyPlus as a simulation engine and out of which 25% of studies considered DesignBuilder as software**.** EnergyPlus software is considered in much research to get more accurate results compared to other simulation engines, as it is validated by the Department of Energy, USA. From the review, it can be concluded that 27% of articles studied the effectiveness of the layout along with other perimeter parameters. The next major part of the study concentrated on occupancy, orientation, and glazing parameters with 25% each. 29% of the study highlighted the importance of shading devices and details on the energy performance of the building [55]. Also, different user activities and systems against space-to-space environmental diversity are significant determinants of the energy performance of any complex buildings [14]. 25% of the studies addressed the methodological system to investigate the energy consumption and performance of different design variables of the buildings and also resulted in significant variation in the energy load including HVAC, lighting, and electricity [23, 30, 40, 46, 48–51, 53, 63, 68, 72]. HVAC efficacy is most rewarding in structures that operate 24 hours like hotels, hospitals, etc. [41].

The review also explored the future research direction where many of the papers investigated the energy consumption and building design elements of particular buildings and suggested the same criteria or methodology for other complex buildings like hospitals, hotels, etc. [20, 23, 46]. The single-room experiments can be extended to complex buildings considering the building envelope parameters along with more environmental factors as decision variables and the building energy demands along with cost functions through multi-objective optimization [20, 23]. There is further scope to develop an optimal model-based control approach to achieve the space layout and thermal zone configuration in complex structures where there is flexible occupancy as well as space use intensities [14, 19, 36]. More research can be towards adapting effective adaptive thermal control and passive strategies along with the consideration of HVAC components' operation, type, and control for solar optimization to reduce the HVAC energy consumption in buildings giving special emphasis to individual departments of hospitals [29, 54, 71]. Energy use in hospitals is higher than compared other public buildings, so it is essential to investigate its energy consumption performance to develop a comprehensive strategy to reduce the mechanical load [104]. But there is limited research on the impact of space layout of hospital buildings on building energy performance. There is a lack of the proper energy consumption calculation methodology for multi-dimensional functions, activities, and the management systems of hospital buildings. There is a concern about the diverse functional requirements in varied departments and zones of the hospitals, as well as their investigation of energy performance along with suggestions for an effective research framework to analyze actual energy data [54]. In hospitals, combining lighting and ventilation system for energy simulation can be a great solution to calculate a wide-ranging energy performance considering the architectural design emphasizing space layout and building perimeter.

Conclusion

The systematic literature review was carried out to identify the variables, their assessment criteria, methodology for evaluation, and optimization strategies for the energy performance of the buildings from selected 55 articles. Many works of the literature identified the impact of the architectural design and space layout effect on energy consumption along with the building perimeter variables. Three are suggestions for alternative technology, passive strategies, enhancing envelope parameters improving building form and orientation, and focusing on climatic parameters. In recent years, the methodologies to investigate energy performance in buildings is mainly focused on simulation-based study with multiple objectives, which gives accurate results, and analysis can be conducted in lesser time. Exterior window WWR, door opening size, type, and location/orientation, as well as frame types and insulation, all have a significant impact on influencing the energy load. According to the study, proper sizing of the building will reduce around 17–35% of energy consumption. Choosing the correct glazing system will reduce the 35–40% energy load of the building. Enhanced Window detailing can bring a 30–60% energy consumption difference in a building. Despite much research on the design of energy-efficient windows, there is still a lack of information on the mutual impact of the orientation of windows along with size and position on energy loads. Literature review shows a lack of insight into the correlation between space layout and energy performance framework which needs to be studied further, especially in terms of multiple energy performance indicators like heating, cooling, lighting, and thermal comfort, especially in the healthcare-built environment. Compared to other buildings such as public buildings, offices, commercial and hotels, hospitals consume more energy because of their diversified functional requirement and activities. There is a lack of studies on the effect of hospital architecture design on energy consumption and related costs and it is very much necessary to conduct interventional studies, investigate the effect of using different methods on reducing energy consumption, and choose effective economical practices. There is varied energy consumption in each space or zones of a hospital since there can be a detailed analysis of each department individually to explore the energy efficiency of the hospital like outpatient department, inpatient department, offices, day-care units, operation theatres, intensive care unit, kitchen, radiology department, emergency wards, etc. along with geographical and climatic conditions**.** In India, the study on the energy performance of hospitals is inadequate, so precise analysis is required. Implementing the ECBC building code and advanced energy efficiency techniques can be used to analyze energy-saving potential in hospitals in India. The impact of climates such as composite and warm humid climates need to be explored to integrate the functional objectives in the process of investigation for the EPB with relation to space layout which is scarcely mentioned in the previous research. Future research could be directed toward the spatial configuration of the energy performance of hospital buildings with multiple parameters simultaneously. Well-thought-out layout design may prevent unreasonable energy consumption to enhance the overall sustainability of the building and contribute to climate change mitigation.

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Declarations

Conflict of interest The authors declare no conflict of interest regarding the publication of this manuscript.

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