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Courtyard building configuration and performance across climate zones: A systematic review of thermal comfort, energy, and daylight with implications for Chinese courtyard architecture

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Abstract

Buildings account for a substantial share of global energy consumption, much of which is associated with heating, ventilation, and air conditioning systems for indoor climate control. Passive strategies rooted in historical architectural typologies, such as courtyard buildings, offer potential to enhance energy efficiency and indoor comfort. This Preferred Reporting Items for Systematic Reviews and Meta-Analyses-guided systematic review analyzed 83 peer-reviewed studies published between January 2014 and September 2025. Using thematic content analysis, we synthesized evidence on how key configuration parameters (orientation, aspect ratio, height-to-depth ratio, window-to-wall ratio, and length-to-width ratio) affect three performance domains—thermal comfort, energy efficiency, and daylight performance—across major climate zones (tropical, hot-arid, temperate, and continental). The literature is concentrated in hot-arid and temperate climates, whereas tropical and continental zones remain comparatively underexplored. Orientation and aspect ratio were the most frequently investigated parameters, and simulation-based methods predominated. The review also identifies critical gaps in theoretical grounding, methodological standardization, and empirical diversity. Most of the studies show limited interdisciplinary integration, minimal consideration of occupant/population differences, and restricted real-world applicability, particularly for public and institutional buildings. By consolidating global evidence, this review further proposes a performance-oriented framework to interpret and advance Chinese courtyard architecture, including *siheyuan*, *sanheyuan*, and *tulou*, across diverse climatic and urban–rural contexts. These findings highlight priorities for China-focused research, including multi-objective performance assessment, empirical validation, and climate-sensitive design strategies. Overall, the review provides actionable insights for architects, urban designers, and policymakers seeking to advance climate-adaptive and context-responsive architectural practice.

Keywords: Systematic review; Passive design; Microclimate modeling; Thermal comfort; Energy efficiency; Daylight performance; Courtyard configuration

1. Introduction

The intensifying effects of climate change adversely affect ecological systems and human health. The Intergovernmental Panel on Climate Change (IPCC) projects that global warming is likely to reach 1.5°C in the coming decades (IPCC, 2021). It is widely recognized that buildings use more than 30 percent of the world's energy and are a major contributor to global greenhouse gas emissions (Berardi, 2015). Although 70 percent of a building's energy use goes to air conditioning for indoor temperature control, it is essential to prioritize energy efficiency in construction. One way to achieve this is by exploring passive design strategies inspired by traditional architecture. These strategies can reduce energy use while maintaining comfortable indoor temperatures (Mahaya *et al.*, 2022; Tabadkani *et al.*, 2022). Courtyard buildings (CBs) are a notable example of climate-responsive architecture, which, as noted by Fathy (1986), may warrant deeper investigation and creative reconfiguration in modern architectural methodologies, especially in areas defined by severe environmental circumstances (Tabadkani *et al.*, 2022; Taleghani *et al.*, 2014).

Chinese CBs, including *siheyuan* (四合院) and *sanheyuan* (三合院), as well as courtyard dwellings in Yanshen historical town (Z. Xu *et al.*, 2025), exemplify enduring instances of climate-responsive architecture tailored to varied environmental and socio-spatial contexts. Although these typologies incorporate effective passive strategies for temperature control, daylighting, and ventilation, their environmental performance has rarely been analyzed through systematic, quantitative approaches. This review synthesizes global evidence on courtyard performance to inform the evaluation, conservation, and contemporary adaptation of Chinese courtyard design.

Prior investigations have highlighted the importance of courtyards as a passive architectural strategy for improving indoor thermal comfort (Muhaisen & Gadi, 2006; Toe & Kubota, 2015). These investigations indicate that thermal comfort in courtyards is primarily influenced by solar radiation and air speed. These factors depend on the courtyard's geometric characteristics, dimensions, proportions, and orientation (Al-Masri & Abu-Hijleh, 2012; Almhafdy *et al.*, 2013; Meir, 2000). Furthermore, through this systematic review, we have identified three reviews that meticulously investigate the climatic and microclimatic characteristics of courtyard environments. The first review examined the historical and cultural evolution of transitional environments, such as courtyards, patios, and atriums, in different climates (Taleghani *et al.*, 2012). Moreover, the study examined the ecological characteristics of low-rise residential courtyards across varying climatic conditions. The second review focused on assessing thermal comfort in residential courtyards situated within Middle Eastern architectural contexts (Oktay, 2002). The third review examined courtyard thermal and microclimatic performance, emphasizing indoor–outdoor interactions (Zamani *et al.*, 2018). Although earlier evaluations addressed specific dimensions of courtyards' climatic and microclimate roles, the discourse surrounding energy efficiency, daylighting, and building functionality remains insufficiently explored.

Limited evidence on energy efficiency and daylight performance in CBs has hindered the development of effective design methodologies. First, it has limited the integration of passive design principles to optimize energy utilization while ensuring thermal comfort. Although they are historically acknowledged for their climate-responsive characteristics, CBs often fail to perform optimally when contemporary designs disregard elements of energy efficiency. This oversight may result in increased energy demands for heating, cooling, and artificial lighting, which undermines the sustainable benefits that these designs could offer.

Hence, we aim to propose a novel, simplified classification for CBs based on their functional attributes, while also acknowledging that the potential influence of climatic zones and the configuration of courtyards within buildings on performance remains an inadequately appreciated and insufficiently explored area of research. Within this framework, the current study focuses on investigating CBs related to thermal comfort, energy efficiency, and daylight performance. Preliminary scoping suggested that these three performance indicators represent the most frequently evaluated performance domains in CBs. Furthermore, the most appropriate courtyard parameters were identified based on patterns established through the study and significant findings from all relevant literature. Consequently, a systematic review was conducted to facilitate the creation of a thorough document and articulate subsequent research questions:

(i) What are the dominant research trajectories shaping the assessment of thermal, energy, and daylight performance in CBs?
(ii) Which methodologies and metrics are most frequently employed, and how do they interact with CBs' morphological configurations?
(iii) What critical research gaps persist, particularly regarding climate zone variability and empirical model validation?

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was applied to conduct the systematic literature review (SLR) on thermal, energy, and daylight performance in residential and tertiary CBs. PRISMA has been widely applied in systematic reviews on thermal comfort and energy efficiency (Han *et al*., 2022; Maier, 2021; Ouahchi *et al*., 2025; Y. Zhao & Taib, 2022), heritage (Maldonado-Erazo *et al*., 2022; Saleh *et al*., 2022; Wahed *et al*., 2021), building construction (Freitag *et al*., 2017; Maier, 2022; Mesa *et al*., 2021), and the urban sector (Chuc & Riveroll, 2022; Dona *et al*., 2021; Omrany *et al*.; Saleh *et al*., 2022; Zabelskyte *et al*., 2022). This study aims to provide insights that inform design practice and future research, identifying knowledge gaps and promoting multi-objective optimization, comparative climate analyses, and experimental validation with advanced digital modeling. This study is structured into Section 2, outlining the methodology, including database selection and screening and analysis criteria; Section 3, presenting results from the review in the context of building function, courtyard configuration and climate zones; and Section 4 (Discussion), discussing the development of a novel framework for an accurate assessment of deficiencies in existing literature, offering a clear view of current challenges in the field. Section 5 concludes with reflections on research limitations and recommendations for future work in this area.

2. Methodology

We conducted an SLR following PRISMA 2020 (Page *et al*., 2021) and the PRISMA-PICO (Population, Intervention, Comparison, Outcome) framework.

2.1. Search strategy and PRISMA flow

We searched the title, abstract, and keywords fields in Scopus, Web of Science (WOS) Core Collection, and ScienceDirect using the terms "courtyard" AND ("thermal comfort" OR "energy efficiency" OR "daylight"). Wildcards (*) and Boolean operators (AND, OR, and AND NOT) were used to refine results. The PRISMA flow diagram (Figure 1) illustrates the selection process: (i) Identification: 735 records were identified (ScienceDirect: 60%, WOS: 30%, Scopus: 10%); (ii) Screening: 255 duplicates were removed, and 480 records were screened; (iii) Eligibility: 366 records were excluded by title/abstract, and 114 full-text articles were assessed; and (iv) Inclusion: 83 studies were included in the review. Additional inclusion and exclusion criteria are summarized in Table 1.

The Boolean operator "AND NOT" was employed within the search engine to exclude particular keywords, thereby defining the exclusion criteria to constrain the results according to the subsequent criteria and information.

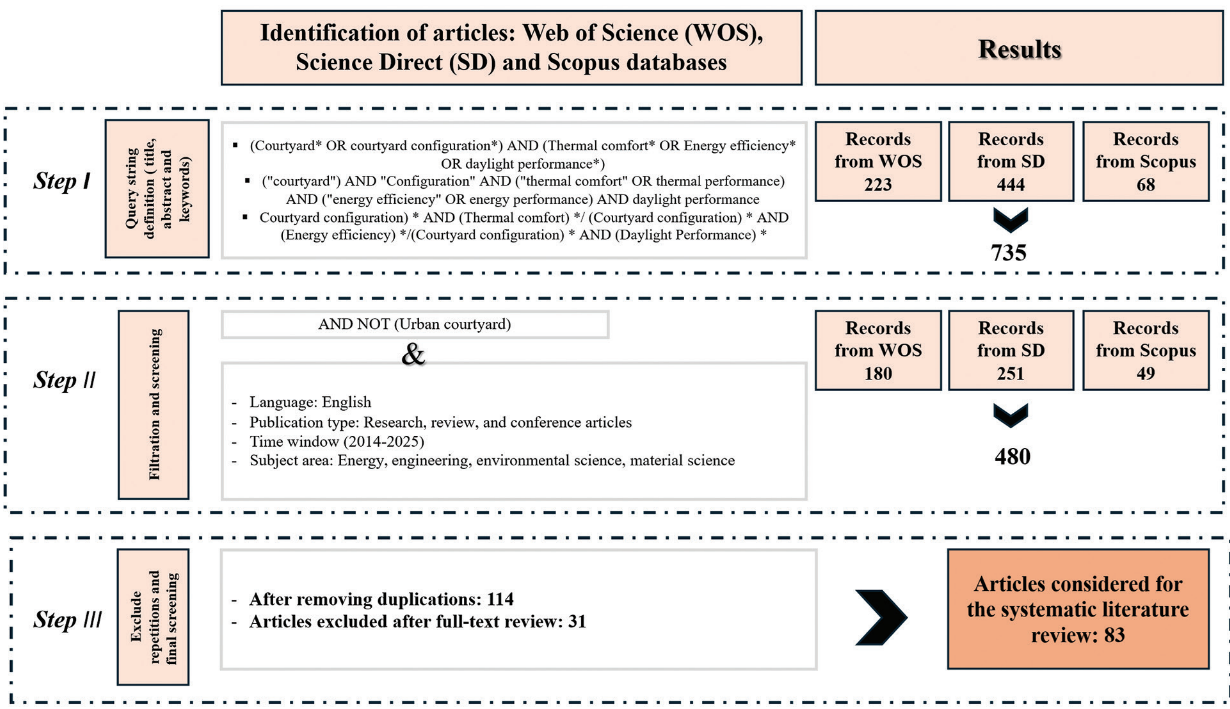

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram showing identification, screening, eligibility, and inclusion processes
Source: Image created by the authors.

Table 1. Summary of inclusion and exclusion criteria

Criteria	Content
Inclusion	• Language: Articles published in English. • Publication type: Peer-reviewed journal articles, conference articles, and systematic reviews indexed in International Scientific Indexing. • Time frame: Published between January 2014 and December 2025. • Databases: Articles must be retrieved from at least one of the following databases: Scopus, the Web of Science Core Collection, or ScienceDirect. • Study design: Simulation studies, empirical fieldwork, or case studies with quantitative or qualitative assessments.
Exclusion	• Non-peer-reviewed articles, opinion articles, and editorials. • Studies lacking relevance to courtyard building performance or failing to address climate, geometry, or orientation.

- The selected studies should address CBs and at least one of the three performance indicators
- Findings should focus on different climatic zones (e.g., hot-arid, temperate, tropical, and cold) to provide insights into how the climate interacts with courtyard design
- Research focus must be on directly investigating the impact of climate, courtyard geometry, or courtyard orientation on thermal comfort, energy efficiency, or daylight performance
- The works must include empirical studies, simulation-based research, and case studies. Theoretical or opinion pieces that did not provide data-based conclusions are excluded.

We then organized and classified the extracted data according to the criteria detailed in the next section.

2.2. Classification framework (thematic analysis)

Six procedures were followed in the thematic analysis in this SLR study to construct themes appropriate for the qualitative analysis approach, as suggested by Nowell *et al.* (2017) (Figure 2).

According to the thematic analysis, existing literature on CBs uses case studies regardless of the building's primary function. Despite the extensive discourse within the existing literature concerning CBs across a range of functional and climatic contexts, a standardized typological classification system based on their usage or programmatic purpose remains elusive. To address this gap, the present study introduces two original definitions as part of its thematic categorization framework. Courtyard housing buildings (CHBs) are defined as CBs designed primarily for residential purposes. In contrast, courtyard tertiary buildings (CTBs) are defined as CBs designed for non-residential, functional uses such as education, healthcare, and public administration. Examples of CTBs include schools, hospitals, and government offices.

This original contribution aims to bring analytical clarity to the comparative assessment of courtyard design strategies by grouping cases with similar functional demands. The distinction is particularly relevant when evaluating the performance indicators of thermal comfort, energy use, and daylight performance. These indicators are strongly influenced by a building's function and occupancy patterns.

Given the absence of an established function-based typology for CBs, we introduce this classification to standardize terminology and support future comparative studies. Accordingly, a thematic framework for categorization is proposed, based on four distinct criteria. This framework facilitates the analytical assessment of findings by incorporating prior categorizations of CBs, the frequency of relevant keywords, and a comprehensive evaluation of the article's content, including similarities and differences. The four criteria are: (i) The functionality of CBs (CHB and CTB); (ii) The intended purpose (thermal comfort, energy efficiency, and daylight performance); (iii) The geographical climate zone classification (the four principal categories of the Köppen–Geiger classification [A to D]); and (iv) Courtyard configuration, which includes the most prominent parameters identified in the selected review corpus and endorsed by CB academic experts, specifically orientation, height-to-width ratio, window-to-wall ratio (WWR), height-to-depth ratio (H/D), and length-to-width ratio (L/W) (Figure 3).

2.3. Screening method and data extraction

Data screening, analysis, and synthesis were conducted using an analytical framework, a structured approach to gathering and analyzing data (UNHCR, 2023). Initially designed for policy assessment and multidisciplinary health research, this approach has been implemented across multiple fields, partly due to its focus on transparency and systematic data analysis (Stewart). It has been used in several qualitative and mixed-methods studies in the field of the built environment (Bencherif, 2023; Ouahchi *et al.*, 2025).

In this SLR study, articles resulting from the PRISMA approach underwent multiple screening cycles based on

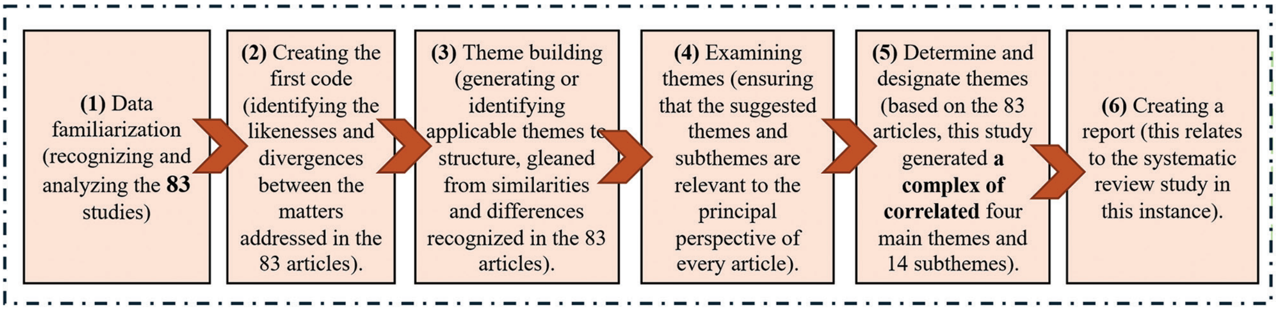

Figure 2. Procedures in the thematic analysis
Source: Image created by the authors.

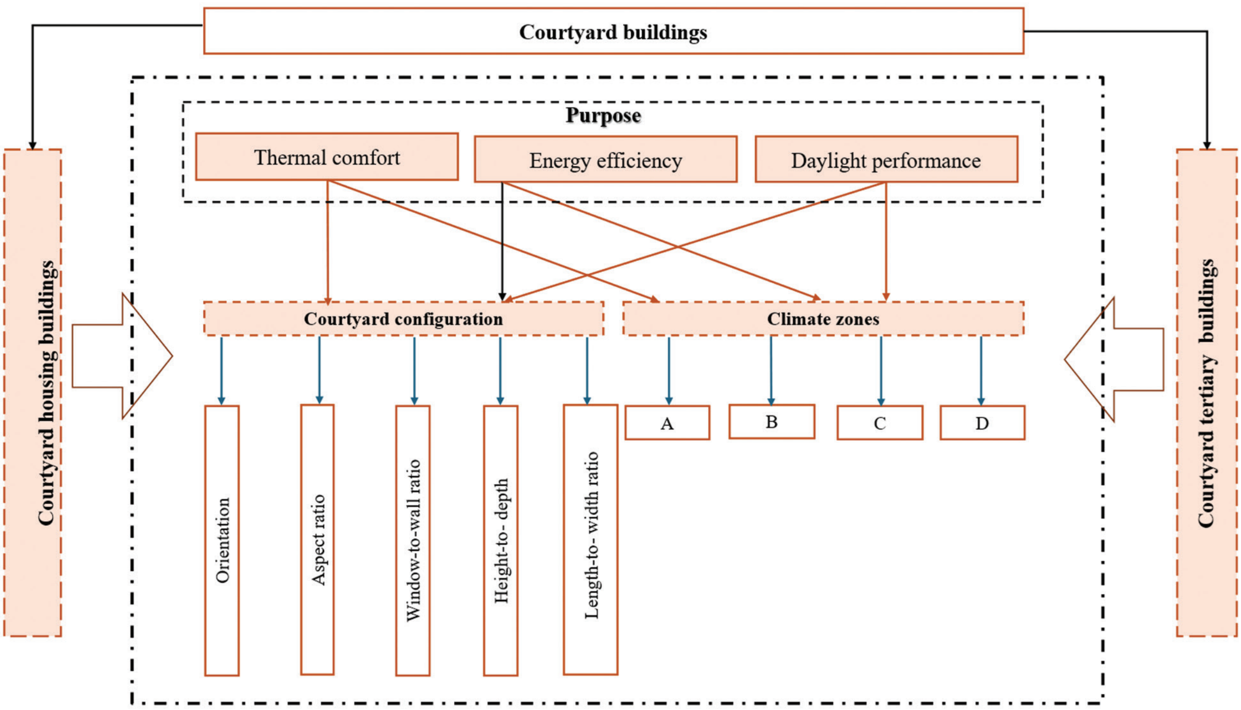

Figure 3. Classification framework in this systematic literature review
Source: Image created by the authors.

themes and sub-themes related to CB design. A matrix of data collected from the 83 articles was used in this analysis. Based on the thematic analysis (Nowell *et al.*, 2017), the themes and sub-themes were manually coded (Figures 2 and 4).

At this stage, the extracted information from each study was meticulously documented in an Excel spreadsheet, enabling comprehensive comparisons between studies and a clear understanding of the methodologies and results (e.g., author, year, country, method, indicators, and results of the effect of courtyard configuration on building performance).

2.4. Validation

To ensure the methodological rigor of the selected studies, the Critical Appraisal Skills Program (CASP) checklist was used to assess the quality of the research. The CASP checklist is a structured tool designed to help researchers, students, and practitioners systematically evaluate the quality, credibility, and relevance of published research. It is particularly useful in evidence-based disciplines such as medicine, health sciences, education, and increasingly, architecture and environmental studies, especially when conducting SLRs (Shaheen *et al.*, 2023). The checklist evaluated key aspects of each study, including the clarity

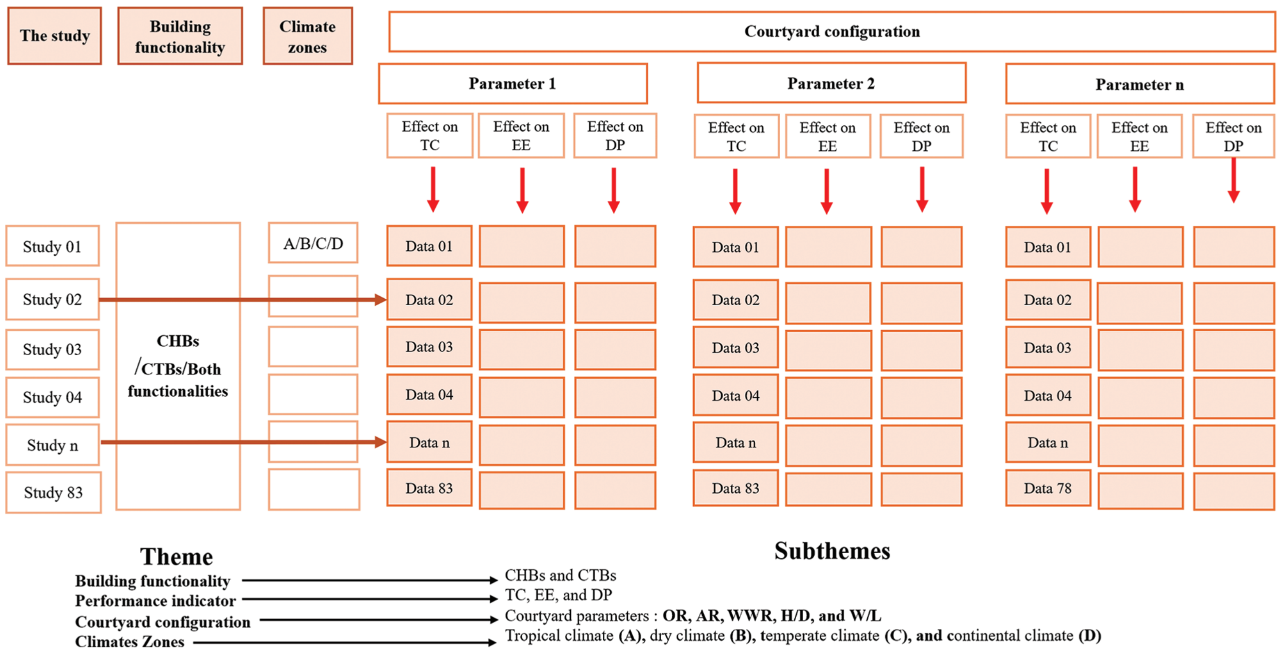

Figure 4. The processes of data screening, analysis, and synthesis. Image created by the authors.
Abbreviations: AR: Aspect ratio; CHB: Courtyard housing building; CTB: Courtyard tertiary building; DP: Daylight performance; EE: Energy efficiency; H/D: Height-to-depth ratio; L/W: Length-to-width ratio; OR: Orientation; TC: Thermal comfort; WWR: Window-to-wall ratio.

of its research aims, the appropriateness of the research design for answering the research questions, the robustness of data collection, the reliability of the data sources used, the validity of the results, and the justification of the conclusions drawn (Drici & Carpio-Pinedo, 2025; Shaheen *et al*., 2023). Studies that did not meet the required standards of methodological rigor were excluded from the final analysis. The extracted data were organized in a structured format to ensure uniformity in the analysis phase.

2.5. Methodological limitations

Although the systematic review methodology ensures rigorous and comprehensive analysis, several limitations must be acknowledged.

2.5.1. Language

Only studies published in English were included. This language restriction may have excluded relevant research published in other languages, which could bias the geographical and cultural scope of the findings.

2.5.2. Time frame

The review was limited to publications between January 2014 and September 2025. While this ensures relevance to recent developments in courtyard design and performance evaluation, earlier influential studies may be omitted.

2.5.3. Grey literature

Non-peer-reviewed sources, such as reports, theses, and design manuals, were excluded. This may have limited the inclusion of innovative or practice-based knowledge that has not yet been published in academic journals.

2.5.4. Subjective thematic coding

The categorization of studies using thematic coding—such as classifying buildings as CHBs or CTBs—was performed by the authors and may be influenced by subjective interpretation. Although efforts were made to ensure transparency and consistency, bias may persist.

Future systematic reviews should consider multilingual databases and practitioner-based sources to widen the scope.

3. Results

3.1. Overview of the search results

A word cloud visualization (Figure 5) is presented to provide a quick overview of the prominent themes emerging from the searched keywords. The size of each word reflects its frequency of occurrence (Dastoum *et al*., 2024). The word cloud highlights terms related to the predominant CB research trends and outcomes. Keywords such as "energy," "building," and "thermal" suggest a focus on optimizing building energy efficiency. In addition, terms such as

Figure 5. Word cloud of the keywords
Source: Image created by the authors.

"courtyard," "building," and "design" indicate an interest in how literature frequently examines the effect of architectural configurations (notably courtyards) on environmental performance. The presence of the keywords "climate," "environmental," "temperature," "air," "ventilation," and "simulation" points to environmental physics and simulation-based methods (e.g., computational fluid dynamics [CFD] and energy modeling) for performance evaluation. The terms "orientation," "design," "shape," "configurations," and "climatic" relate to the analysis of how courtyard parameters and climate variation affect the building performance. Finally, terms such as "houses," "dwellings," "atrium," and "occupants" suggest hypotheses about how the building functionality affects the courtyard configuration.

Overall, the word cloud underscores the main focus of this study, investigating the effects of climate and courtyard design on energy efficiency, thermal comfort, and daylight performance.

We conducted a comprehensive keyword co-occurrence analysis using VOSviewer software (version 1.6.20) to uncover significant research trends in CBs. The size of a node and the size of its label indicate the significance of a keyword, while the width of a line signifies the proximity of two keywords. In addition, distinct colors were used to delineate the various clusters in these visual network representations, enhancing interpretability and clarifying the relationships among the identified keywords (Kirby, 2023). Figure 6 illustrates how this bibliometric mapping technique visualizes the complex relationships among frequently occurring keywords in the literature.

The resulting map clearly visualizes five dominant clusters. The first cluster, shown in red, underscores the importance of "courtyard" and "thermal comfort," highlighting their significance in CB research. The blue cluster represents keywords tied to "energy efficiency," reflecting its vital role in current discussions. The green cluster centers on "building," emphasizing its relevance in the analysis. The yellow cluster indicates residential contexts tied to "houses," showcasing domestic architectural trends. Finally, the purple cluster connects "daylighting" with "courtyard building," illustrating the relationship between natural light and architectural design.

Closer examination of the co-occurrence map revealed significant patterns that clarify the current focus of CB research. The central positioning of the keywords "courtyard" and "thermal comfort" underscores their pivotal role in scholarly discourse. These nodes' prominence indicates their status as core themes. Thermal comfort serves as the primary evaluative parameter for assessing courtyard design and benchmarking for various configurations across different climates.

The interdisciplinary nature of CB research was evident in the connectivity among identified clusters, showcasing contributions from environmental science, building physics, architectural design, engineering, and urban planning. This suggests that CBs are viewed as complex systems, where form, climate, and function intersect rather than as isolated architectural types. The importance of geometric parameters in evaluating courtyard performance is also underscored, as terms such as "aspect ratio" and "shape factor (L/W)" frequently appear alongside "thermal comfort" and "energy efficiency." This indicates a growing emphasis on the impact of courtyard geometry on airflow, solar access, and heat retention, which are vital for optimizing indoor quality and comfort.

Furthermore, the growing focus on daylight performance in CB studies is noteworthy. The cluster featuring "daylighting" and "WWR" was historically underexplored but now reflects a heightened interest in visual comfort and natural lighting strategies. This interest aligns with global sustainable architecture goals that aim to reduce reliance on artificial lighting.

Finally, the distinction between CHBs and CTBs is emerging as a critical research topic. The co-occurrence map shows that these categories are treated differently. While CHBs dominate publication volume, CTBs are gaining attention, particularly regarding their performance in institutional, educational, and commercial contexts. This

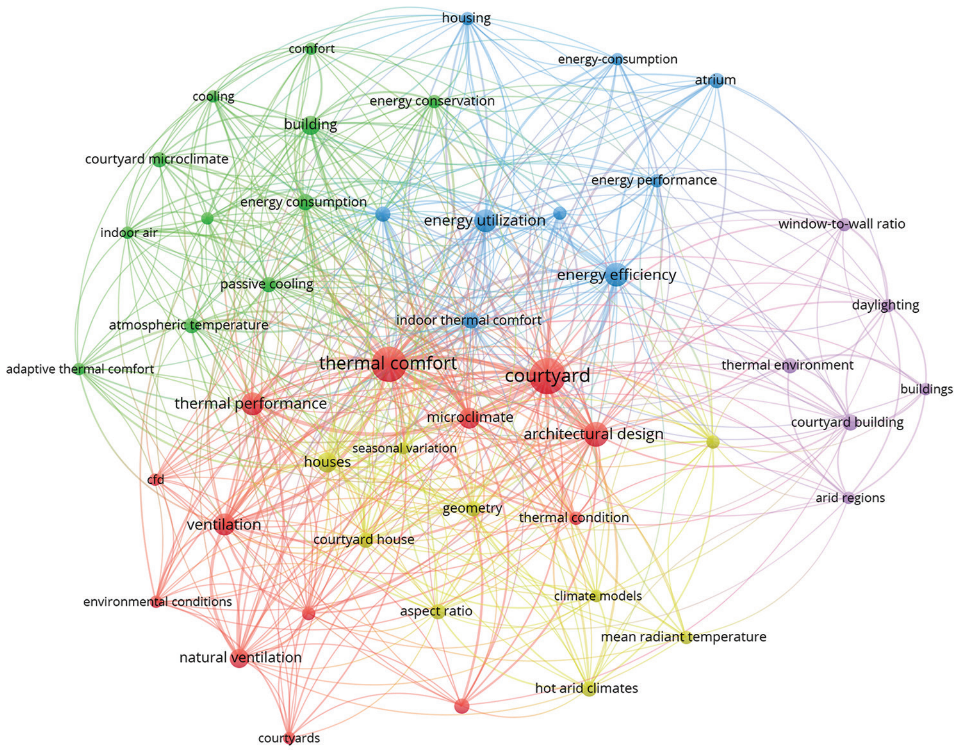

Figure 6. Keywords co-occurrence analysis map of the reviewed articles
Source: Image created by the authors.

trend suggests the expanding applicability of the courtyard model to various functions and promotes context-sensitive analyses of performance, considering different use cases and environmental conditions.

3.2. Identification and analysis of the tendencies in the courtyard building field

Collecting and synthesizing the most relevant and up-to-date information are essential to encouraging and enhancing the integration of courtyard designs in buildings. The data analyzed in this study can therefore serve as a valuable resource for developers, users, and stakeholders aiming to improve energy efficiency and the overall quality of indoor environments.

Five courtyard parameters were identified to analyze the main trends sought in CBs depending on their purpose, climate group, or courtyard configuration. Figures 7 and 8 for more information, and refer to Table 2 for a description.

To analyze the main trends sought in CBs, the five identified parameters were examined depending on the purpose and climate group (Figure 9). Over the past decade, orientation and aspect ratios have consistently emerged as the most influential courtyard parameters affecting thermal comfort (Abdallah, 2022; Abdallah *et al.*,

Table 2. General view of the courtyard buildings' parameters identified in this systematic literature review

Parameter	Definition
Orientation	The directional alignment of a courtyard relative to the sun and wind. Proper orientation optimizes solar exposure, balancing thermal comfort and reducing energy loads. It also affects daylight distribution and the efficiency of natural ventilation.
H/W ratio	This parameter represents the ratio of the courtyard's height to its width. It modulates solar exposure and airflow by shaping shading patterns and the courtyard microclimate, thereby influencing thermal comfort. It also affects daylight penetration; lower ratios provide more shade, while higher ratios enhance light access.
WWR	The WWR is the proportion of a courtyard building's total wall area that is occupied by windows. A higher WWR can enhance daylight penetration, improve natural lighting, and reduce the need for artificial lighting.
H/D	The H/D refers to the relationship between a courtyard's vertical height and horizontal depth. A higher ratio promotes air circulation and improves thermal comfort.
The shape factor (L/W)	The L/W defines the proportional relationship between the length and width of a courtyard. A higher L/W ratio often results in a longer courtyard, which enhances natural ventilation and daylight distribution.

Abbreviations: H/D: Height-to-depth ratio; H/W: Height-to-width; L/W: Length-to-width ratio; WWR: Window-to-wall ratio.

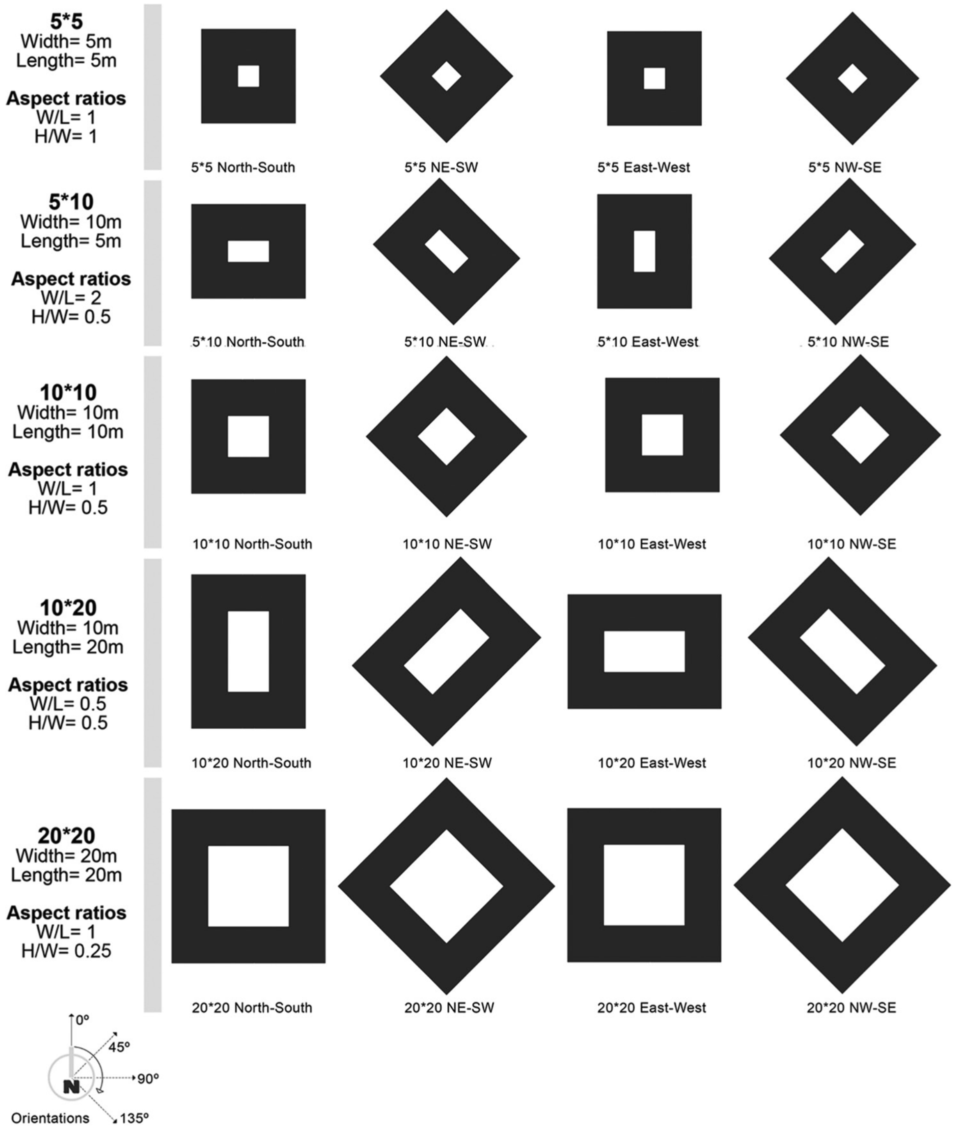

Figure 7. Courtyard buildings with different orientations, aspect ratios, and length-to-width ratios
Source: Reprinted from Toris-Guitron *et al.* (2022).

2019; H. Akbari *et al.*, 2021; Al-Hafith *et al.*, 2019, 2023; Almhafdy *et al.*, 2019; Azimi & Shafaat, 2024; Balah *et al.*, 2024; Bulus *et al.*, 2017; Dai *et al.*, 2023; Defiana *et al.*, 2018; Diz-Mellado *et al.*, 2023a, 2023b; Diz-Mellado *et al.*, 2024; Forouzandeh & Richter, 2019; Ghaffarianhoseini *et al.*, 2015; Guedouh & Zemmouri, 2017; Guedouh *et al.*, 2019; Hosham *et al.*, 2019; Khan *et al.*, 2023; Khastar & Taleghani, 2024; Lin & Gui, 2024; López-Cabeza *et al.*, 2022; Mahmoud & Ragab, 2021; Mundra & Kannamma, 2019; Nasrollahi *et al.*, 2017; Pilechiha *et al.*, 2021; Sahnoune & Benhassine, 2023; Salameh *et al.*, 2024; Soflaei *et al.*, 2017; Soflaei *et al.*, 2016; Soflaei *et al.*, 2020; Sözen & Koçlar Oral, 2019; Subhashini & Thirumaran, 2020; Sun *et al.*, 2023; Tabadkani *et al.*, 2022; Taki & Alsheglawi, 2022; Teshnehdel, Soflaei, *et al.*, 2020; Toris-Guitron *et al.*, 2022; Xu *et al.*, 2025; Zamani *et al.*, 2019), energy efficiency (Acosta *et al.*, 2018; Almhafdy *et al.*, 2019; Forouzandeh & Richter, 2019; He *et al.*, 2022; Tabadkani *et al.*, 2022; Taki & Alsheglawi, 2022; Vaisman & Horvat, 2015; Xu *et al.*, 2025; Zamani *et al.*, 2018; Zhu *et al.*, 2024), and daylight performance (Acosta *et al.*, 2018; Bin Dalmouk & Al-Sallal, 2020; Guedouh & Zemmouri, 2017; Guedouh *et al.*, 2019; Gunasagaran *et al.*, 2022; Khastar & Taleghani, 2024; Sheta *et al.*, 2024; Vaisman & Horvat, 2015). Rather than isolated findings, the literature revealed a clear pattern: orientation predominantly governs solar exposure and daylight penetration, while the height-to-width ratio (H/W) modulates shading and air movement.

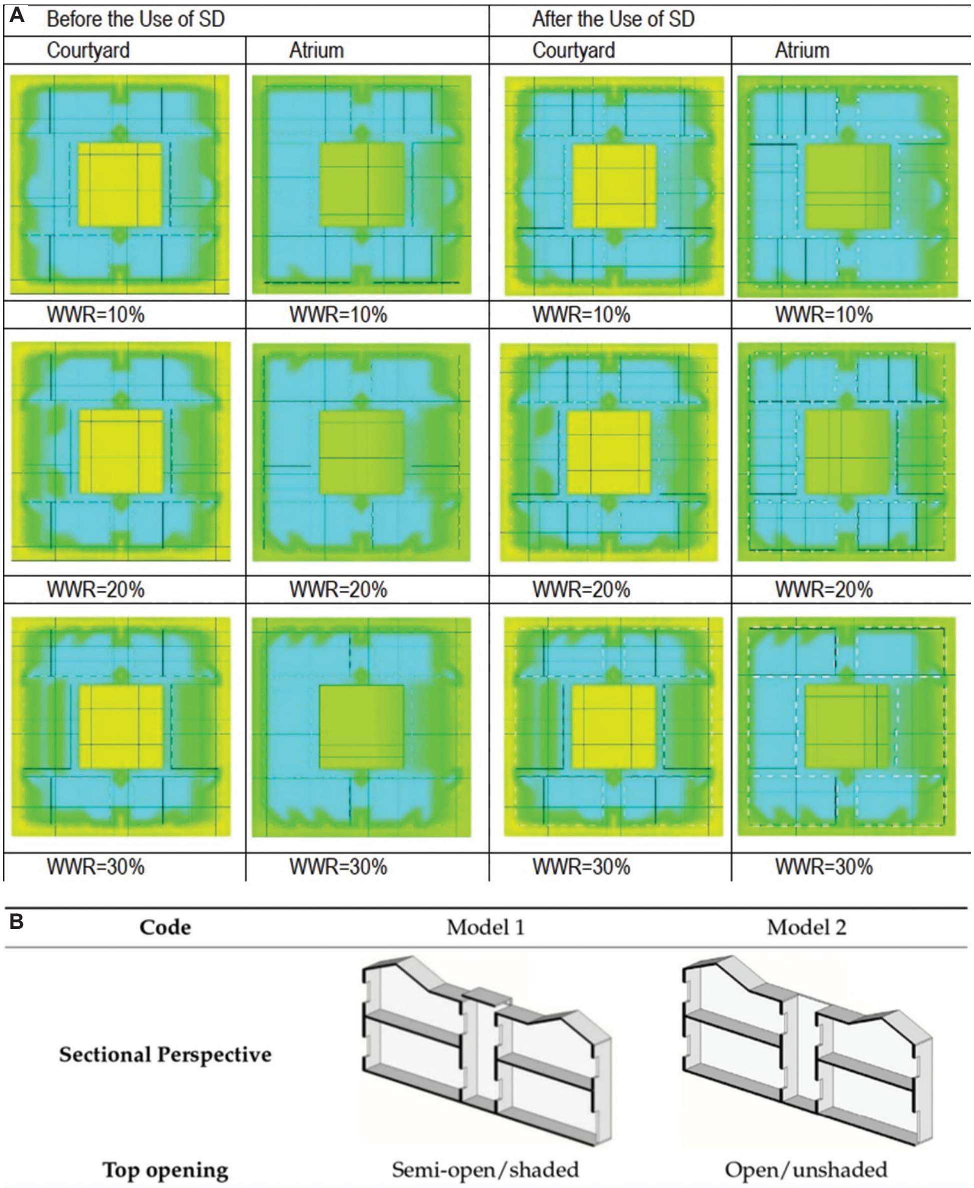

Figure 8. Two of the primary parameters in courtyard building research. (A) Window-to-wall ratio (WWR). (B) Height-to-depth ratio (H/D).
Source: Reprinted from (A) Talip *et al.* (2021) and (B) Sun *et al.* (2023).
Abbreviation: SD: Shading device.

Evidence is especially strong in arid climates (climate zone B) (Abdallah, 2022; H. Akbari *et al.*, 2021; Al-Hafith *et al.*, 2019, 2023; Balah *et al.*, 2024; Dai *et al.*, 2023; Guedouh *et al.*, 2019; Khan *et al.*, 2023; Khastar & Taleghani, 2024; Mahmoud & Ragab, 2021; Mahmoud & Abdallah, 2022; Nasrollahi *et al.*, 2017; Pilechiha *et al.*, 2021; Salameh *et al.*, 2024; Sheta *et al.*, 2024; Soflaei *et al.*, 2016; Soflaei *et al.*, 2020; Taki & Alsheglawi, 2022; Teshnehdel, Soflaei, *et al.*, 2020), where numerous studies using validated simulation tools converged on the importance of minimizing direct solar gains through optimized courtyard alignment. Similar consistency was observed in temperate climates (climate zone C) (Acosta *et al.*, 2018; Diz-Mellado *et al.*, 2023a, 2023b; Diz-Mellado *et al.*, 2024; Domínguez-Torres & Domínguez-Delgado, 2024; Forouzandeh & Richter, 2019; Guedouh & Zemmouri, 2017; He *et al.*, 2022; Lin & Gui, 2024; Tabadkani *et al.*, 2022; Zhu *et al.*, 2024), although outcomes are more sensitive to seasonal variability. By contrast, findings in tropical climates (climate zone A) (Almhafdy *et al.*, 2019; Callejas & Krüger, 2022; Defiana *et al.*, 2018; Gunasagaran *et al.*, 2022; Subhashini & Thirumaran, 2020; Sun *et al.*, 2023; Tabadkani *et al.*, 2022;

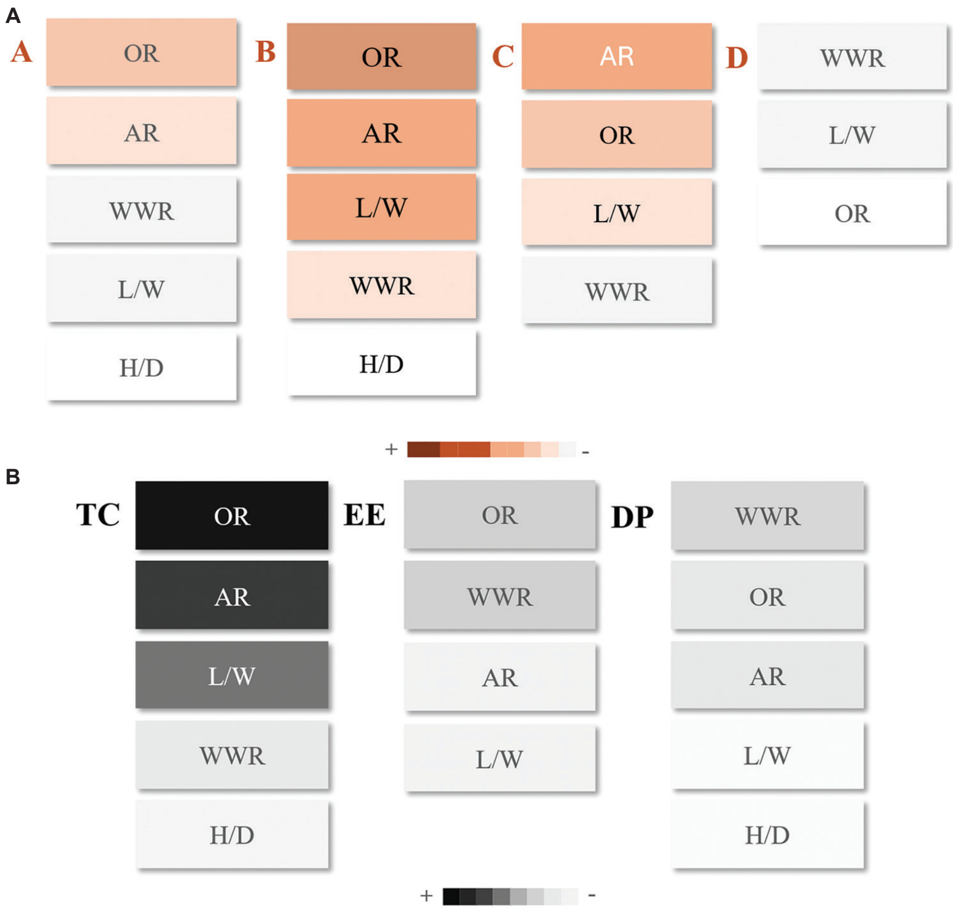

Figure 9. The distribution of the main parameters of CBs was reviewed according to their (A) climate zones and (B) purposes
Source: Image created by the authors.
Abbreviations: AR: Aspect ratio; DP: Daylight performance; EE: Energy efficiency; H/D: Height-to-depth ratio; L/W: Length-to-width ratio; OR: Orientation; TC: Thermal comfort; WWR: Window-to-wall ratio.

Toris-Guitron *et al.*, 2022) were less uniform, potentially due to high humidity and diffuse light conditions that reduce the relative impact of orientation. A smaller body of research in continental climates (climate zone D) suggests that WWR and courtyard shape can overshadow orientation effects due to the extreme seasonal temperature swings ratio (Tabesh & Sertyesilisik, 2016; Vaisman & Horvat, 2015; Yaşa & Ok, 2014).

Although Table 3 provides only limited data across courtyard parameters and climate zones, the empirical evidence discussed remains largely consistent with previously reported findings. Notably, Soflaei *et al.* (2020) suggested that courtyard width and length exert less influence on thermal comfort than height, orientation, and wall material. This observation highlights the need to reassess how these parameters interact across different climatic contexts, particularly in relation to energy efficiency and daylight performance.

Overall, although the individual studies vary in scope and methodology, the cross-climatic evidence collectively reinforces the critical role of orientation and aspect ratios, particularly in hot, dry, and temperate regions, while highlighting the need for more rigorous, validated studies in tropical and continental zones.

Figure 10 presents the two main categories of CBs previously discussed: CHBs and CTBs. Figures 11 and 12 provide a comprehensive framework illustrating the three core objectives of recurring evaluations: thermal comfort, energy efficiency, and daylight performance. They also outline key contextual factors considered, including Köppen climate zones (A, B, C, and D) and courtyard design parameters, such as orientation, aspect ratio, WWR, H/D, and L/W. In addition, the distribution of outcomes across these parameters was analyzed separately for CHBs and CTBs.

The results depicted in Figures 10 and 11 indicate that scholars are dedicating more of their efforts to assessing

Table 3. The outcomes of empirical studies across different climate zones and courtyard parameters

Authors	Climate zone	Discussed parameter	Main viewpoint
Vaisman and Horvat (2015)	Continental climate (D)	WWR, shape factor (L/W)	The row houses with internal courtyards can increase daylight hours by 9–20%. A WWR between 20% and 42% is recommended to reduce the energy consumption while maintaining similar illuminance increments.
Abdallah *et al.* (2019)	Hot and dry climate (B)	H/W, L/W, orientation	A courtyard with an H/W of 1.2 provides better thermal comfort. North–south-oriented, elongated courtyards with an aspect ratio of 1:2 perform better in terms of thermal comfort.
Rivera-Gómez *et al.* (2019)	Temperate climate (C)	H/W, orientation	An H/W greater than three can significantly improve the thermal comfort level of the courtyard.
Soflaei *et al.* (2020)	Dry desert (arid)	H/W, L/W, orientation	The study shows that using the enhanced design for courtyard houses in the BWh climate can improve thermal comfort by 42.3%, with the majority of this enhancement attributed to geometrical properties and wall type. The maximum thermal comfort, 39.3%, was obtained for a courtyard with the maximum height (9 m), 0° orientation, L/W=1.5, wall material Type 2, and double-pane window Type 1.
H. Akbari *et al.* (2021)	Hot and dry climate (B)	H/W, orientation	Courtyards with larger H/Ws are more suitable for hot and dry climates.
Akhlaghinezhad *et al.* (2023)	Hot, dry climate of Yazd	H/W, L/W, orientation	The impact of H/W, L/W, and orientation on thermal comfort accounts for 70.9%, 25.7%, and 3.4%, respectively.
M'Saouri El Bat *et al.* (2023)	Hot and dry climate, temperate climate, cold climate	H/W, L/W	In hot and dry climates, a deep and moderately narrow design can significantly reduce cooling energy demand by about 10%; temperate climates are more suitable for courtyards with narrower widths and moderate depths, which can reduce energy consumption by about 58%; in cold climates, a square courtyard design is more advantageous.
Azimi & Shafaat (2024)	Semi-dry and cold climates	H/W, L/W	A H/W of 3:1 can significantly enhance thermal comfort, with a UTCI improvement of 19°C. Additionally, compared to a 3:1 ratio, a model with an L/W of 2:1 has a UTCI reduction of 6.7°C.

Abbreviations: H/D: Height-to-depth ratio; H/W: Height-to-width; L/W: Length-to-width ratio; UTCI: Universal thermal climate index; WWR: Window-to-wall ratio.

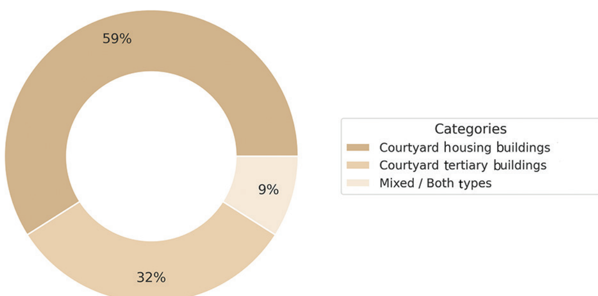

Figure 10. Breakdown of courtyard buildings
Source: Image created by the authors.

CHBs (68% of the findings) to enhance building thermal comfort (87%), energy efficiency (35%), and indoor daylight conditions (12%). It was observed that the primary objective of the research is thermal comfort. The configuration of courtyards significantly influences thermal comfort by affecting air circulation, shading, solar exposure, and heat dissipation. Parameters such as orientation and geometry are key factors in this configuration. Properly designed courtyards enhance natural ventilation, regulate indoor temperatures, and mitigate heat gain or loss, particularly in hot climates, thereby improving thermal comfort. Conversely, CTBs (41%) receive less attention (Figure 10). The research community's focus follows a similar pattern to the previous category, except for daylight performance, which increased by 9 percent. This is because the assessment of daylighting performance is often associated with CTBs due to their susceptibility to thermal overexposure issues.

Regarding the dissemination of findings across various climatic zones, the analysis indicates that tropical (A) and continental (D) climates have received the least scholarly attention. This might be due to their predictable temperature patterns and limited climatic variability. Regarding thermal comfort, the courtyard typology examined for arid (B) and temperate (C) climate zones (Figures 11 and 12) exhibits a greater prevalence of 45 percent and 29 percent, respectively, in CHBs and 38 percent and 18 percent, respectively, in CTBs. The emphasis on arid climates (B) may be due to their considerable daily and seasonal thermal fluctuations. This observed pattern corroborates

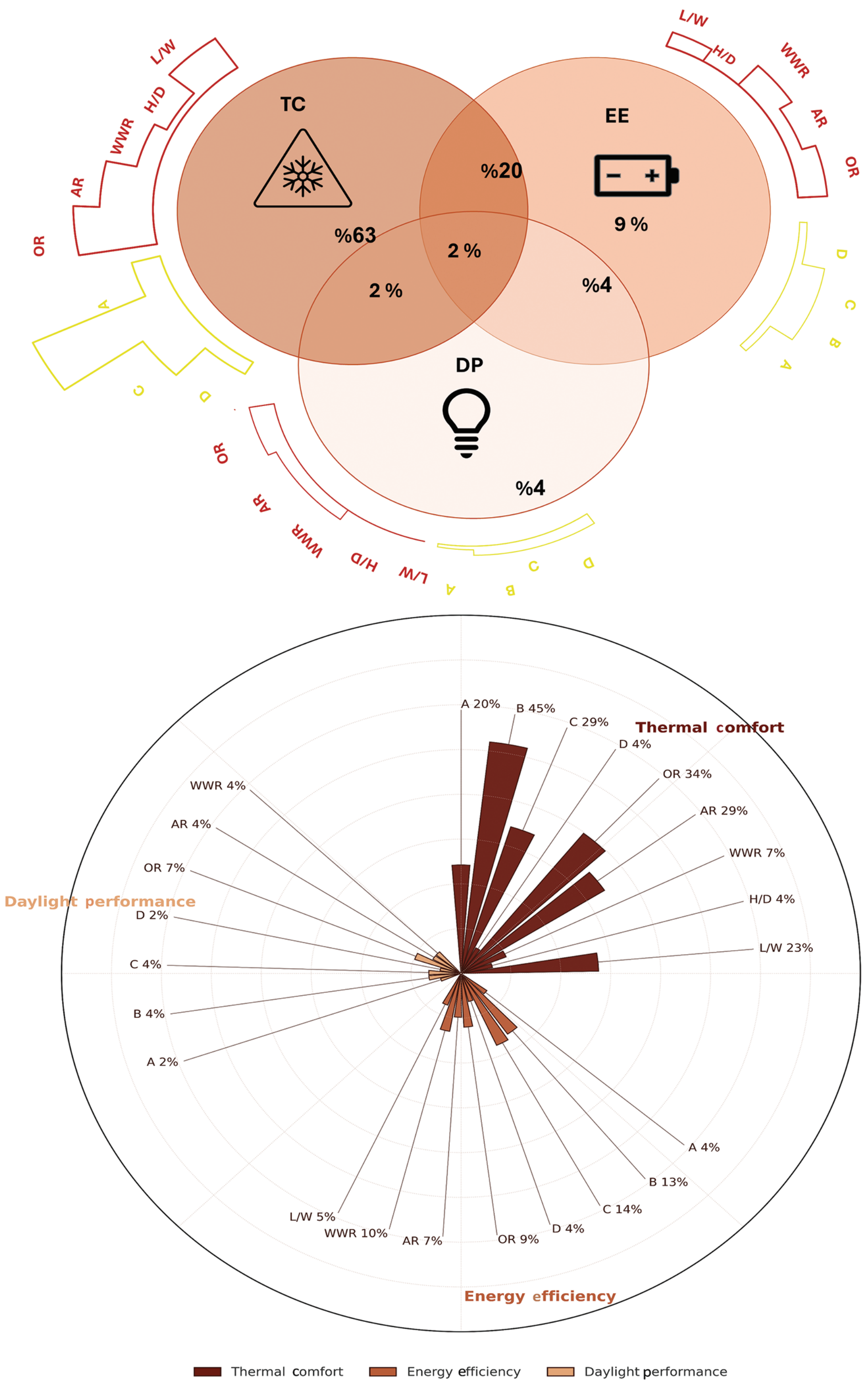

Figure 11. Overview of findings on courtyard housing buildings
Source: Image created by the authors.
Abbreviations: AR: Aspect ratio; DP: Daylight performance; EE: Energy efficiency; H/D: Height-to-depth ratio; L/W: Length-to-width ratio; OR: Orientation; TC: Thermal comfort; WWR: Window-to-wall ratio.

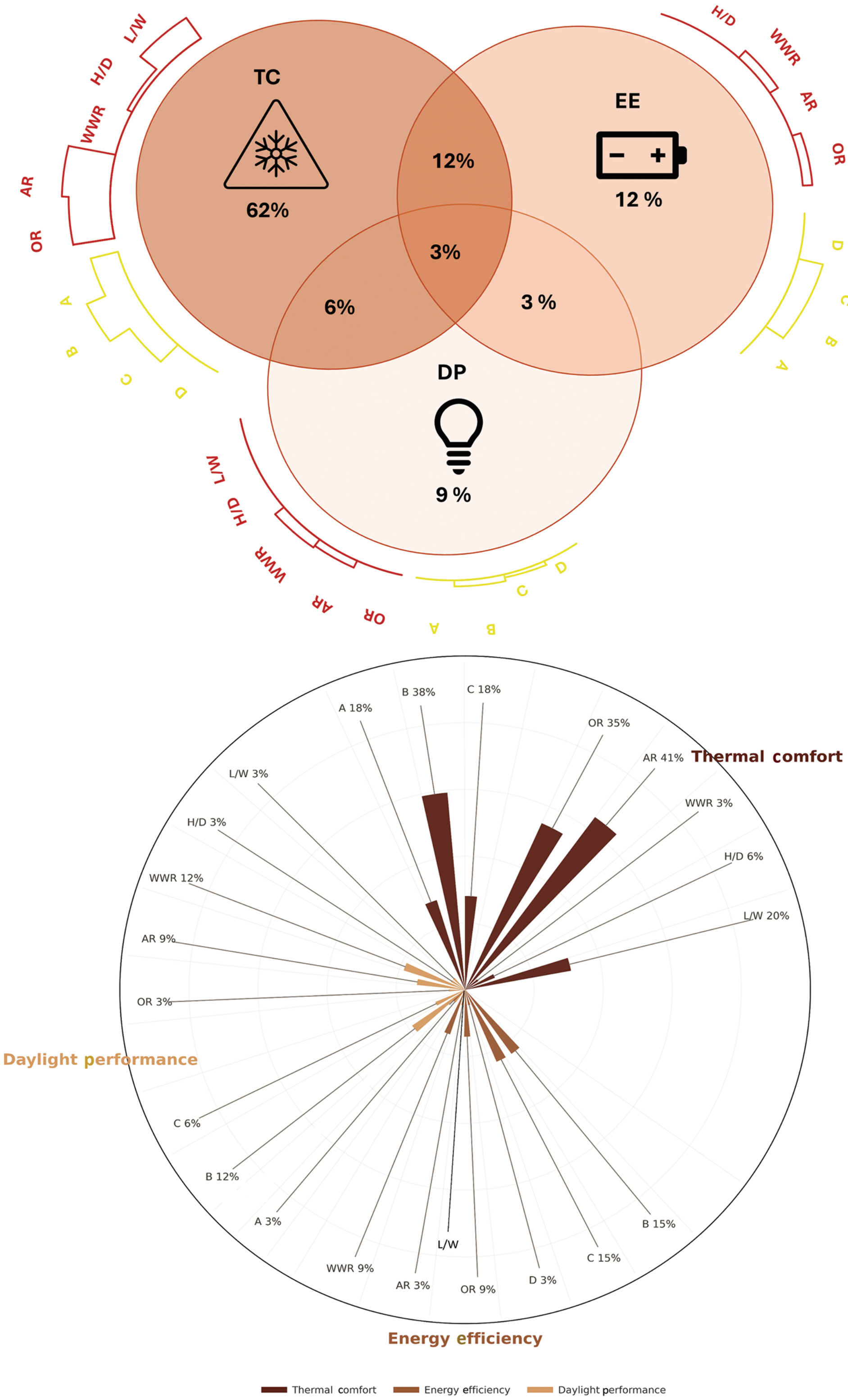

Figure 12. Overview of findings on courtyard tertiary buildings

Source: Image created by the authors.

Abbreviations: AR: Aspect ratio; DP: Daylight performance; EE: Energy efficiency; H/D: Height-to-depth ratio; L/W: Length-to-width ratio; OR: Orientation; TC: Thermal comfort; WWR: Window-to-wall ratio.

the assertion that courtyard typology is a salient subject in warm climates and is regarded as a potentially effective strategy for addressing overheating challenges.

Furthermore, the synthesis of the findings indicates the predominance of orientation and aspect ratio parameters for thermal comfort in both typologies (CHBs and CTBs), with orientation at around 35 percent in both and aspect ratio parameters at 29 percent and 41 percent, respectively. This is potentially because the courtyard orientation influences heating and cooling loads by dictating the amount and timing of solar radiation received. Proper orientation can maximize winter sun exposure or provide summer shading, thereby reducing energy demands. The aspect ratio may also affect this trend by influencing airflow patterns within the courtyard, thereby enhancing or limiting natural ventilation. Optimal proportions ensure effective heat dissipation, reducing reliance on mechanical cooling systems. Furthermore, the level of research interest is also influenced by the prevailing L/W, which affects thermal comfort by approximately 20 percent in both CHBs and CTBs. This illustrates how courtyard shape—whether elongated or square—affects the solar gain, shading efficiency, and airflow patterns, which directly impact heating, cooling, and ventilation performance.

Table 4. Classification of courtyard buildings

Courtyard building type	Type of study	Purpose			Climate zones		
		Thermal comfort	Energy efficiency	Daylight performance	Tropical (A)	Hot and arid (B)	Temperate (C)
Courtyard Housing Buildings	Review study	(Zamani *et al.*, 2018)	(Zamani *et al.*, 2018)	-	-	-	-
	Case study	(Soflaei *et al.*, 2016)	-	-	-	-	-
	Experimental study	(Gamage *et al.*, 2017; Hosham *et al.*, 2019; Mousli & Semprini, 2015; Toe & Kubota, 2015; Xu *et al.*, 2022; Zakaria *et al.*, 2015)	(Acosta *et al.*, 2018)	(Acosta *et al.*, 2018)	(Toe & Kubota, 2015)	(Gamage *et al.*, 2017; Hosham *et al.*, 2019; Mousli & Semprini, 2015)	(Acosta *et al.*, 2018; Xu *et al.*, 2022)
	Simulation study	(H. Akbari *et al.*, 2021; Al-Hafith *et al.*, 2019, 2023; Almhafdy *et al.*, 2019; Azimi & Shafaat, 2024; Bian *et al.*, 2022; Chohan *et al.*, 2024; Dai *et al.*, 2023; Defiana *et al.*, 2018; Diz-Mellado *et al.*, 2023b; Domínguez-Torres & Domínguez-Delgado, 2024; Elgheriani *et al.*, 2018; Gamage *et al.*, 2017; Ghaffarianhoseini *et al.*, 2015; Hao *et al.*, 2019; Kaihoul *et al.*, 2021; Khan *et al.*, 2023; Khastar & Taleghani, 2024; Li *et al.*, 2022; Lin & Gui, 2024; López-Cabeza *et al.*, 2022; Mirabi & Abarghuie, 2023; Nasrollahi *et al.*, 2017; Pilechiha *et al.*, 2021; Soflaei *et al.*, 2017; Soflaei *et al.*, 2020;	(Abuhussain *et al.*, 2022; Acosta *et al.*, 2018; Almhafdy *et al.*, 2019; Alshabanat & Omer, 2023; Bian *et al.*, 2022; Chohan *et al.*, 2024; Diz-Mellado *et al.*, 2023a; Guo *et al.*, 2022; Kaihoul *et al.*, 2021; Mirabi & Abarghuie, 2023; Tabadkani *et al.*, 2022; Taki & Alsheglawi, 2022; Taleghani *et al.*, 2014; Vaisman & Horvat, 2015; Xu *et al.*, 2025; Yaşa & Ok, 2014; Zhao *et al.*, 2022; Zhu *et al.*, 2020)	(Acosta *et al.*, 2018; Gunasagaran *et al.*, 2022; Khastar & Taleghani, 2024; Sheta *et al.*, 2024; Vaisman & Horvat, 2015; Zhu *et al.*, 2020)	(Almhafdy *et al.*, 2019; Defiana *et al.*, 2018; Elgheriani *et al.*, 2018; Ghaffarianhoseini *et al.*, 2015; Gunasagaran *et al.*, 2022; Sun *et al.*, 2023; Tabadkani *et al.*, 2022; Toris-Guitron *et al.*, 2022)	(Abuhussain *et al.*, 2022; H. Akbari *et al.*, 2021; Al-Hafith *et al.*, 2023; Alshabanat & Omer, 2023; Chohan *et al.*, 2024; Dai *et al.*, 2023; Gamage *et al.*, 2017; Hao *et al.*, 2019; Hosham *et al.*, 2019; Kaihoul *et al.*, 2021; Khan *et al.*, 2023; Khastar & Taleghani, 2024; Mirabi & Abarghuie, 2023; Nasrollahi *et al.*, 2017; Pilechiha *et al.*, 2021; Sheta *et al.*, 2024; Soflaei *et al.*, 2017; Soflaei *et al.*, 2020; Subhashini & Thirumaran, 2020; Sun *et al.*, 2021; Taki & Alsheglawi, 2022; Teshnehdel, Mirnezami, *et al.*, 2020; Teshnehdel, Soflaei, *et al.*, 2020; Yaşa & Ok, 2014)	(Acosta *et al.*, 2018; Azimi & Shafaat, 2024; Bian *et al.*, 2022; Diz- Mellado *et al.*, 2023a, 2023b; Domínguez-Torres & Domínguez-Delgado, 2024; Li *et al.*, 2022; Lin & Gui, 2024; López-Cabeza *et al.*, 2022; Tabadkani *et al.*, 2022; Taleghani *et al.*, 2014; Xu *et al.*, 2025; Yaşa & Ok, 2014; Zhao *et al.*, 2022; Zhu *et al.*, 2020)

(Cont'd...)

Table 4. *(Continued)*

Courtyard building type	Type of study	Purpose			Climate zones		
		Thermal comfort	Energy efficiency	Daylight performance	Tropical (A)	Hot and arid (B)	Temperate (C)
		Sun *et al.*, 2021; Sun *et al.*, 2023; Sun *et al.*, 2024; Tabadkani *et al.*, 2022; Taki & Alsheglawi, 2022; Taleghani *et al.*, 2014; Teshnehdel, Mirnezami, *et al.*, 2020; Teshnehdel, Soflaei, *et al.*, 2020; Toris-Guitron *et al.*, 2022; Xu *et al.*, 2025; Yaşa & Ok, 2014; Zhao *et al.*, 2022; Zhu *et al.*, 2020)					
Courtyard Tertiary Buildings	Review study	(Zamani *et al.*, 2018)	(Zamani *et al.*, 2018)	-	-	-	-
	Case study	(Guedouh & Zemmouri, 2017)	-	(Guedouh & Zemmouri, 2017)	(Bulus *et al.*, 2017)	(Guedouh & Zemmouri, 2017)	-
	Experimental study	(Abdallah *et al.*, 2019; Callejas & Krüger, 2022; Dai & Jiang, 2021; Diz-Mellado *et al.*, 2024; Forouzandeh & Richter, 2019; Gamage *et al.*, 2017; Jara *et al.*, 2017; Sahnoune & Benhassine, 2023; Subhashini & Thirumaran, 2020; Zakaria *et al.*, 2015)	(Forouzandeh & Richter, 2019)	-	(Callejas & Krüger, 2022; Subhashini & Thirumaran, 2020; Zakaria *et al.*, 2015)	(Abdallah *et al.*, 2019; Dai & Jiang, 2021; Gamage *et al.*, 2017; Jara *et al.*, 2017)	(Forouzandeh & Richter, 2019; Sahnoune & Benhassine, 2023)
	Simulation study	(Abdallah, 2022; Balah *et al.*, 2024; Cantón *et al.*, 2014; Diz-Mellado *et al.*, 2024; Forouzandeh & Richter, 2019; Gamage *et al.*, 2017; Gan *et al.*, 2024; Ghaffarianhoseini *et al.*, 2015; Guedouh *et al.*, 2019; Mahmoud & Ragab, 2021; Mahmoud & Abdallah, 2022; Mundra & Kannamma, 2019; Salameh *et al.*, 2024; Subhashini & Thirumaran, 2020; Sun *et al.*, 2023; Tabesh & Sertyesilisik, 2016; Taleb *et al.*, 2020; Zhu *et al.*, 2020)	(Asfour, 2020; Beyraghshamshir & Sarkardehei, 2023; Cantón *et al.*, 2014; Forouzandeh & Richter, 2019; He *et al.*, 2022; Tabesh & Sertyesilisik, 2016; Taleb *et al.*, 2020; Zhu *et al.*, 2020; Zhu *et al.*, 2024)	(Al-Sallal *et al.*, 2018; Asfour, 2020; Bin Dalmouk & Al-Sallal, 2020; Guedouh *et al.*, 2019; Talip *et al.*, 2021; Zhu *et al.*, 2020)	(Ghaffarianhoseini *et al.*, 2015; Subhashini & Thirumaran, 2020; Sun *et al.*, 2023; Talip *et al.*, 2021)	(Abdallah, 2022; Al-Sallal *et al.*, 2018; Asfour, 2020; Balah *et al.*, 2024; Beyraghshamshir & Sarkardehei, 2023; Bin Dalmouk & Al-Sallal, 2020; Cantón *et al.*, 2014; Gamage *et al.*, 2017; Guedouh *et al.*, 2019; Mahmoud & Ragab, 2021; Mahmoud & Abdallah, 2022; Mundra & Kannamma, 2019; Salameh *et al.*, 2024; Tabesh & Sertyesilisik, 2016; Taleb *et al.*, 2020)	(Diz-Mellado *et al.*, 2024; Forouzandeh & Richter, 2019; Gan *et al.*, 2024; He *et al.*, 2022; Zhu *et al.*, 2020; Zhu *et al.*, 2024)

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Table 4. ***(Continued)***

Courtyard building type	Type of study	Continental (D)	Courtyard configuration (parameters)				
		-	Orientation	Aspect ratio	Window-to-wall ratio	Height-to-depth ratio	Length-to- width ratio
Courtyard Housing Buildings	Review study	-	(Zamani *et al.*, 2018)	(Zamani *et al.*, 2018)	(Zamani *et al.*, 2018)	-	Zamani *et al.*, 2018)
	Case study	-	-	-	-	-	(Soflaei *et al.*, 2016)
	Experimental study	-	-	(Acosta *et al.*, 2018; Hosham *et al.*, 2019)	-	-	-
	Simulation study	(Teshnehdel, Mirnezami, *et al.*, 2020; Vaisman & Horvat, 2015; Yaşa & Ok, 2014)	(H. Akbari *et al.*, 2021; Al-Hafith *et al.*, 2019; Almhafdy *et al.*, 2019; Azimi & Shafaat, 2024; Dai *et al.*, 2023; Domínguez-Torres & Domínguez-Delgado, 2024; Ghaffarianhoseini *et al.*, 2015; Gunasagaran *et al.*, 2022; Khastar & Taleghani, 2024; Mirabi & Abarghuie, 2023; Pilechiha *et al.*, 2021; Sheta *et al.*, 2024; Soflaei *et al.*, 2020; Taki & Alsheglawi, 2022; Teshnehdel, Soflaei, *et al.*, 2020; Toris-Guitron *et al.*, 2022; Vaisman & Horvat, 2015; Xu *et al.*, 2025)	(Acosta *et al.*, 2018; H. Akbari *et al.*, 2021; Al-Hafith *et al.*, 2019, 2023; Azimi & Shafaat, 2024; Benchekroun *et al.*, 2020; Defiana *et al.*, 2018; Diz-Mellado *et al.*, 2023a; Hosham *et al.*, 2019; Khan *et al.*, 2023; Lin & Gui, 2024; Sheta *et al.*, 2024; Soflaei *et al.*, 2020; Sun *et al.*, 2023; Tabadkani *et al.*, 2022; Toris-Guitron *et al.*, 2022; Xu *et al.*, 2025)	(Almhafdy *et al.*, 2019; Guo *et al.*, 2022; Khastar & Taleghani, 2024; Pilechiha *et al.*, 2021; Tabadkani *et al.*, 2022; Vaisman & Horvat, 2015)	(Sun *et al.*, 2023; Xu *et al.*, 2025)	(H. Akbari *et al.*, 2021; Al-Hafith *et al.*, 2019, 2023; Azimi & Shafaat, 2024; Soflaei *et al.*, 2017; Soflaei *et al.*, 2020; Tabadkani *et al.*, 2022; Teshnehdel, Soflaei, *et al.*, 2020; Toris-Guitron *et al.*, 2022; Yaşa & Ok, 2014)
Courtyard Tertiary Buildings	Review study	-	(Zamani *et al.*, 2018)	(Zamani *et al.*, 2018)	(Zamani *et al.*, 2018)	-	(Zamani *et al.*, 2018)
	Case study	-	(Bulus *et al.*, 2017)	(Guedouh & Zemmouri, 2017)	-	-	(Bulus *et al.*, 2017)

(Cont'd...)

Table 4. *(Continued)*

Courtyard building type	Type of study	Continental (D)	Courtyard configuration (parameters)				
		-	**Orientation**	**Aspect ratio**	**Window-to-wall ratio**	**Height-to-depth ratio**	**Length-to- width ratio**
	Experimental study	(Tabesh & Sertyesilisik, 2016)	(Abdallah *et al.*, 2019; Callejas & Krüger, 2022; Sahnoune & Benhassine, 2023)	(Abdallah *et al.*, 2019; Callejas & Krüger, 2022; Diz-Mellado *et al.*, 2024; Forouzandeh & Richter, 2019; Sahnoune & Benhassine, 2023; Subhashini & Thirumaran, 2020)	-	-	-
	Simulation study		(Abdallah, 2022; Balah *et al.*, 2024; Bin Dalmouk & Al-Sallal, 2020; Cantón *et al.*, 2014; Diz-Mellado *et al.*, 2024; Ghaffarianhoseini *et al.*, 2015; He *et al.*, 2022; Mahmoud & Ragab, 2021; Mundra & Kannamma, 2019; Salameh *et al.*, 2024; Zhu *et al.*, 2024)	(Abdallah, 2022; Al-Sallal *et al.*, 2018; Balah *et al.*, 2024; Diz-Mellado *et al.*, 2024; Forouzandeh & Richter, 2019; Guedouh *et al.*, 2019; Mahmoud & Abdallah, 2022; Subhashini & Thirumaran, 2020; Sun *et al.*, 2023)	(Al-Sallal *et al.*, 2018; Asfour, 2020; Bin Dalmouk & Al-Sallal, 2020; He *et al.*, 2022; Tabesh & Sertyesilisik, 2016; Talip *et al.*, 2021; Zhu *et al.*, 2024)	(Guedouh *et al.*, 2019; Sun *et al.*, 2023)	(Bin Dalmouk & Al-Sallal, 2020; Cantón *et al.*, 2014; Gan *et al.*, 2024; Mahmoud & Abdallah, 2022; Salameh *et al.*, 2024)

Since the CBs presented serve diverse functions, Table 4 shows the types of CBs examined in this study, along with the corresponding literature references for each type. As CBs do not always have the same configuration and the identified studies emphasize different aspects in various climate zones, researchers have adopted different approaches in their studies. Review studies (R) entail examining previously published scholarship on a particular subject without proposing specific solutions. Case studies (C) involve thoroughly analyzing an individual building within its actual context to derive insights or evaluate theories. Experimental studies (E) comprise executing experiments or assessments, collecting data, and analysing findings. Simulation/modeling studies (S) entail exploring real-world conditions or hypothetical scenarios employing simulation models. Figure 13 compiles the classified results, including the number of studies, building function, emphases of the articles, types of studies, and tools and testing methods.

According to Table 4, it becomes evident that simulation and modeling investigations are the predominant methodologies within the CB research domain compared to case study and experimental-based approaches. Notably, several critical simulation studies merit attention. Soflaei *et al.* (2020) and Tabadkani *et al.* (2022) addressed improvements in thermal comfort and energy efficiency by evaluating the "orientation, aspect ratio, and L/W" and "aspect ratio, and WWR, L/W" parameters for CHBs in climate zones B and C, respectively. Several other significant experimental works can also be identified. Zakaria *et al.* (2015) and Forouzandeh and Richter (2019) examined CTBs to evaluate thermal comfort and energy efficiency in tropical and temperate climates. Most investigations prioritizing experimental

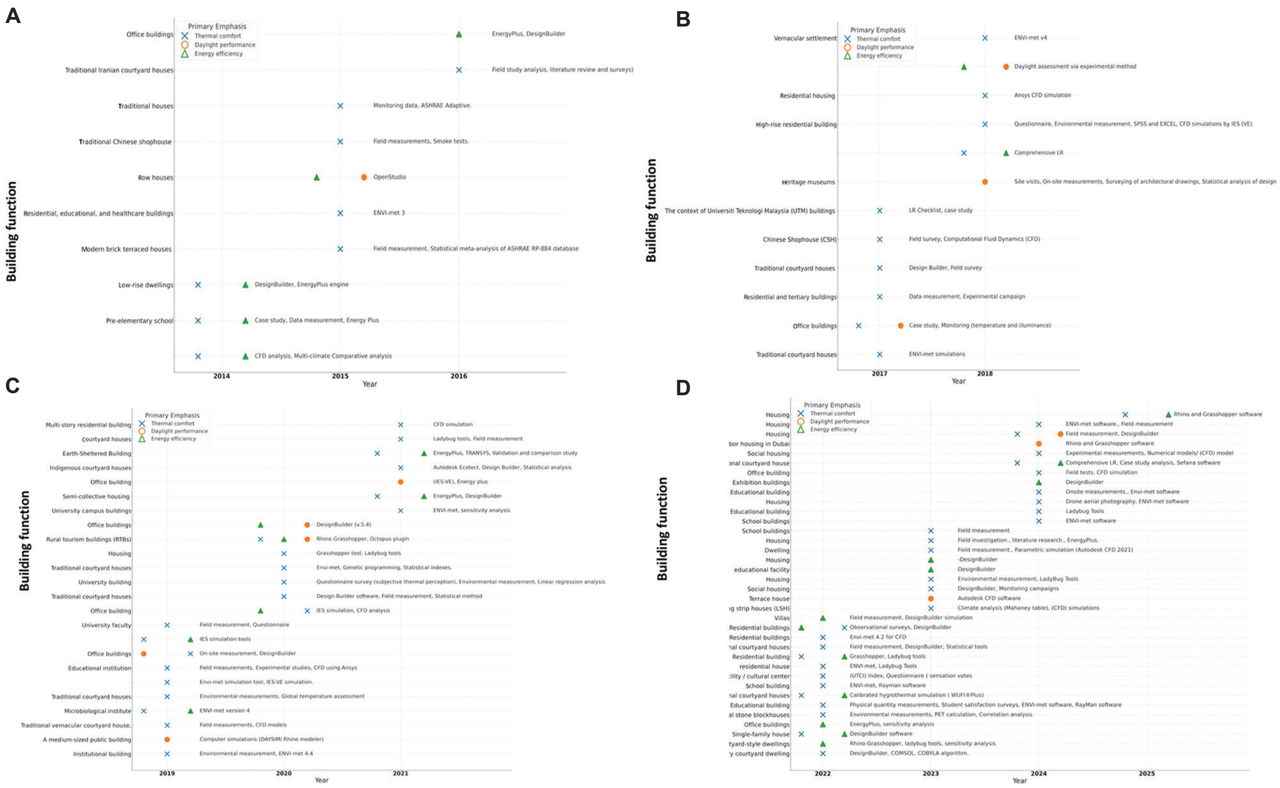

Figure 13. Evolution of tools and testing methods over the following periods: (A) 2014–2016, (B) 2017–2018, (C) 2019–2021, and (D) 2022–2025
Source: Images created by the authors.

advancement and evaluation incorporate the thermal comfort performance, the arid climatic classification (B), and the courtyard parameter aspect ratio.

Notably, an examination of the data in Table 4 revealed that review articles and multi-objective studies addressing CBs from the perspectives of thermal comfort, energy efficiency, and daylight performance are clearly scarce. In addition, the majority of works focus on a single climate, while studies analyzing multiple climate zones are rare.

Based on the data presented in Figure 13, research in the CB field showed minimal growth between 2014 and 2021, with a slight dip in 2016. However, since 2021, there has been a significant surge in interest within the scientific community regarding CBs. In 2022, the graph indicates a peak value of 16 articles, the highest point in the dataset. This peak is nine studies higher than in 2021, and 14 studies higher than in 2016. Throughout the review period, empirical research significantly outpaced theoretical approaches. Over the past five years, there has been a notable shift in the scientific community toward simulation-based studies. Using full-scale prototypes to assess performance in real-world settings is often impractical due to the significant time requirements, material limitations, and substantial financial implications. Conversely, simulation-based analyses provide an efficient and cost-effective alternative that enables the exploration of hypothetical scenarios with enhanced flexibility. These simulations play a pivotal role in facilitating informed decision-making by evaluating the most promising variables. Among the various tools employed, CFD software, DesignBuilder, and Integrated Environmental Solutions were identified as the most frequently used platforms. The rise of Ladybug Tools is particularly remarkable; it offers an integrated solution that combines 3D computer-aided design interfaces with validated simulation engines.

3.3. Research indicators and metrics evaluated for the assessment of thermal comfort, energy efficiency, and daylight performance

The evaluation of CBs based on thermal comfort, energy efficiency, and daylight performance requires an in-depth analysis of various performance metrics. These metrics not only indicate design effectiveness but also serve as proxies for user experience, operational sustainability, and climatic adaptability.

As quality indicators, these metrics span multiple domains, including environmental impact, system performance, indoor environmental quality, and energy consumption. Their presence in comparative analyses strengthens design decision-making processes and supports evidence-based architectural practices that optimize both passive strategies and occupant well-being (Gonçalves *et al*., 2024; O'Brien *et al*., 2017). Consequently,

Table 5. Variables evaluated for the different performance indicators (TC, EE, and DP)

Metrics	Articles	Variables
TC	(Abdallah, 2022; Abdallah *et al*., 2019; Al-Hafith *et al*., 2023; Bian *et al*., 2022; Cantón *et al*., 2014; Domínguez-Torres & Domínguez-Delgado, 2024; Elgheriani *et al*., 2018; Forouzandeh & Richter, 2019; Gamage *et al*., 2017; Gan *et al*., 2024; Guedouh & Zemmouri, 2017; Guedouh *et al*., 2019; Hao *et al*., 2019; Hosham *et al*., 2019; Kaihoul *et al*., 2021; Khastar & Taleghani, 2024; Lin & Gui, 2024; Mahmoud & Abdallah, 2022; Mirabi & Abarghuie, 2023; Mousli & Semprini, 2015; Mundra & Kannamma, 2019; Salameh *et al*., 2024; Soflaei *et al*., 2017; Subhashini & Thirumaran, 2020; Sun *et al*., 2023; Sun *et al*., 2024; Toe & Kubota, 2015; Xu *et al*., 2022; Zakaria *et al*., 2015; Zhao *et al*., 2022)	Indoor air temperature (°C)
	(Khastar & Taleghani, 2024; Toris-Guitron *et al*., 2022)	Solar gain (kWh)
	(Domínguez-Torres & Domínguez-Delgado, 2024)	Courtyard surface temperature (°C)
	(Domínguez-Torres & Domínguez-Delgado, 2024)	Thermal load (Wh/sqm)
	(Chohan *et al*., 2024; Subhashini & Thirumaran, 2020)	Annual net CO2 emission (ppm)
	(Balah *et al*., 2024; Chohan *et al*., 2024; Dai *et al*., 2023; Ghaffarianhoseini *et al*., 2015; Li *et al*., 2022; Sahnoune & Benhassine, 2023; Tabadkani *et al*., 2022; Taki & Alsheglawi, 2022; Taleb *et al*., 2020; Teshnehdel, Mirnezami, *et al*., 2020)	Predicted mean vote
	(Abdallah, 2022; Azimi & Shafaat, 2024; Balah *et al*., 2024; Diz-Mellado *et al*., 2023b; Ghaffarianhoseini *et al*., 2015; Mahmoud & Ragab, 2021; Mahmoud & Abdallah, 2022; Mundra & Kannamma, 2019; Sözen & Koçlar Oral, 2019; Teshnehdel, Mirnezami, *et al*., 2020; Xu *et al*., 2022; Xu *et al*., 2025)	Physiologically equivalent (°C)
	(Abdallah *et al*., 2019; Defiana *et al*., 2018; Hao *et al*., 2019; Lin & Gui, 2024; Mousli & Semprini, 2015; Sheta *et al*., 2024; Subhashini & Thirumaran, 2020; Sun *et al*., 2023; Sun *et al*., 2024; Toris-Guitron *et al*., 2022)	Wind speed (m/s)
	(Al-Hafith *et al*., 2023; Mahmoud & Abdallah, 2022; Sözen & Koçlar Oral, 2019; Subhashini & Thirumaran, 2020; Sun *et al*., 2023; Xu *et al*., 2022; Xu *et al*., 2025)	Mean radiant temperature (°C)
	(Abdallah, 2022; Abdallah *et al*., 2019; Diz-Mellado *et al*., 2024; Hao *et al*., 2019; Hosham *et al*., 2019; Kaihoul *et al*., 2021; Lin & Gui, 2024; Mousli & Semprini, 2015; Subhashini & Thirumaran, 2020; Sun *et al*., 2024; Toe & Kubota, 2015; Zakaria *et al*., 2015; Zhao *et al*., 2022)	Relative humidity (%)
	(Dai *et al*., 2023)	Comfort hours (%)
	(Li *et al*., 2022; Sun *et al*., 2023; Sun *et al*., 2024)	Adaptive predicted mean vote
	(Diz-Mellado *et al*., 2023a, 2023b; López-Cabeza *et al*., 2022)	Thermal gap (°C)
	(Diz-Mellado *et al*., 2023a)	Diurnal thermal range (°C)
	(Diz-Mellado *et al*., 2023a)	Thermal balance (kW)
	(Taki & Alsheglawi, 2022)	The actual mean vote
	(Subhashini & Thirumaran, 2020; Taki & Alsheglawi, 2022)	Globe temperature (°C)
	(Taleghani *et al*., 2014; Toris-Guitron *et al*., 2022)	The percentage of discomfort hours (%)
	(Azimi & Shafaat, 2024; Callejas & Krüger, 2022; López-Cabeza *et al*., 2022; Nasrollahi *et al*., 2017)	Universal thermal climate index (°C)
	(Mahmoud & Abdallah, 2022)	The standard effective temperature (°C)
	(Abdallah, 2022; Callejas & Krüger, 2022; Dai & Jiang, 2021)	Thermal sensation votes
	(Toris-Guitron *et al*., 2022)	Operative temperature of indoor spaces (°C)
	(Li *et al*., 2022)	Mean thermal sensation
	(Khan *et al*., 2023)	Night-time effectiveness ratio (%)
	(Khan *et al*., 2023)	Time constant (h)
	(Sun *et al*., 2021)	Indoor air-dry bulb temperature (°C)
	(Sun *et al*., 2021; Zhu *et al*., 2020)	Predicted percentage of dissatisfied (%)

(Cont'd...)

Table 5. ***(Continued)***

Metrics	Articles	Variables
	(Pilechiha *et al*., 2021)	Indoor adaptive thermal comfort (%)
	(Akbari *et al*., 2021; Soflaei *et al*., 2017; Teshnehdel, Soflaei, *et al*., 2020)	The shading index for summer (%)
	(Akbari *et al*., 2021)	The sun lit index for winter (%)
	(Soflaei *et al*., 2020)	Air flow volume (m^3/s)
	(Abdallah *et al*., 2019; Soflaei *et al*., 2020)	Outdoor temperature (°C)
	(Teshnehdel, Mirnezami, *et al*., 2020)	The shading percentage of the surfaces (%)
	(Teshnehdel, Mirnezami, *et al*., 2020)	The sunlit percentage of the surfaces (%)
	(Dai & Jiang, 2021)	The thermal acceptability (%)
	(Dai & Jiang, 2021)	The comfort temperature (%)
	(Subhashini & Thirumaran, 2020)	The air change rates (h)
	(Hosham *et al*., 2019; Taleghani *et al*., 2014; Zakaria *et al*., 2015)	The operative temperature (°C)
	(Jara *et al*., 2017)	ΔTmax (°C)
	(Toe & Kubota, 2015)	The outdoor absolute humidity (g/kg)
	(Lin & Gui, 2024)	Pressure perturbation (dPa)
EE	(Chohan *et al*., 2024)	Annual net electricity use (kWh)
	(Beyraghshamshir & Sarkardehei, 2023; Bian *et al*., 2022; Chohan *et al*., 2024; Guo *et al*., 2022; He *et al*., 2022; Kaihoul *et al*., 2021; Tabadkani *et al*., 2022; Talip *et al*., 2021; Zhao *et al*., 2022; Zhu *et al*., 2024)	Yearly cooling energy (kWh)
	(Chohan *et al*., 2024)	Energy use intensity (kWh/sqm/yr)
	(Abuhussain *et al*., 2022; Bian *et al*., 2022; He *et al*., 2022; Mirabi & Abarghuie, 2023; Tabesh & Sertyesilisik, 2016; Taleb *et al*., 2020; Zhu *et al*., 2020; Zhu *et al*., 2024)	Total annual energy consumption (kWh/sqm)
	(Beyraghshamshir & Sarkardehei, 2023; Bian *et al*., 2022; He *et al*., 2022; Kaihoul *et al*., 2021; Tabadkani *et al*., 2022; Taleghani *et al*., 2014; Zhao *et al*., 2022; Zhu *et al*., 2024)	Annual heating energy consumption (kWh/sqm)
	(Asfour, 2020; Beyraghshamshir & Sarkardehei, 2023; He *et al*., 2022; Talip *et al*., 2021; Vaisman & Horvat, 2015; Zhu *et al*., 2024)	Lighting energy consumption (kWh/sqm)
	(Zhu *et al*., 2024)	Internal electrical equipment consumption (kWh/sqm)
	(Alshabanat & Omer, 2023; Taki & Alsheglawi, 2022)	Annual energy consumption (kWh/sqm)
	(Asfour, 2020; Khastar & Taleghani, 2024; Yaşa & Ok, 2014)	Solar gain (kWh)
	(Tabadkani *et al*., 2022)	Utility costs ($/kWh)
	(Vaisman & Horvat, 2015)	Heating energy demand (natural gas consumption)
DP	(Acosta *et al*., 2018; Asfour, 2020; Chohan *et al*., 2024; Khastar & Taleghani, 2024)	The daylight factor (%)
	(Guedouh & Zemmouri, 2017; Guedouh *et al*., 2019; Khastar & Taleghani, 2024; Sheta *et al*., 2024; Vaisman & Horvat, 2015)	Illuminance (lux)
	(Acosta *et al*., 2018; Al-Sallal *et al*., 2018; Asfour, 2020; Bin Dalmouk & Al-Sallal, 2020; Sheta *et al*., 2024; Talip *et al*., 2021; Zhu *et al*., 2020)	Spatial daylight autonomy (DA) (%)
	(Al-Sallal *et al*., 2018; Sheta *et al*., 2024)	Daylight glare probability (%)
	(Gunasagaran *et al*., 2022) 3Sp	Daylight availability (lux)
	(Al-Sallal *et al*., 2018; Asfour, 2020; Talip *et al*., 2021)	Annual sunshine exposure (lux)
	(Bin Dalmouk & Al-Sallal, 2020)	DACon (%)
	(Bin Dalmouk & Al-Sallal, 2020)	DAmax (%)
	(Bin Dalmouk & Al-Sallal, 2020)	Useful daylight illuminance (%)

Abbreviations: DP: Daylight performance; EE: Energy efficiency; TC: Thermal comfort.

Table 5 encapsulates the variables identified in the reviewed articles relevant to the assessment of thermal comfort, energy efficiency, and daylight performance.

3.3.1. Thermal comfort metrics

The assessment of thermal comfort in CBs primarily focuses on the interaction between indoor and outdoor conditions, especially under varying climatic conditions. The following indicators were most frequently used across the reviewed studies:

- Indoor air temperature: The most fundamental metric for gauging the thermal environment and its regulation within enclosed courtyard spaces
- Relative humidity: Influences heat perception and the efficiency of natural ventilation strategies
- Physiologically equivalent temperature: An integrative index that considers human energy balance and thermoregulation. Used in outdoor and semi-outdoor courtyard spaces
- Predicted mean vote and mean radiant temperature: These are widely accepted in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and the International Organization for Standardization standards, offering a more nuanced view of perceived thermal conditions
- Wind speed and ventilation rate: These are often used in CFD-based simulations to understand how courtyard geometry impacts air movement and cooling potential.

Though highly relevant for occupant-centric assessments, the following are notably underutilized:

- Thermal sensation vote: Empirical subjective comfort ratings by occupants
- Adaptive thermal comfort: This metric reflects occupants' acclimatization and behavioral adaptations in naturally ventilated spaces, making it a particularly pertinent metric for passive architecture.

This suggests an imbalance in the subjective and behavioral assessment approaches within the CB performance literature.

3.3.2. Energy efficiency metrics

The energy efficiency analysis focused heavily on energy demand profiling for cooling and lighting. Key variables extracted from simulations and empirical studies included:

- Annual cooling load and cooling energy demand (kWh/sqm•year): This is the most frequently reported variable due to the frequent application of CBs in hot/arid and temperate zones, where overheating is a central concern
- Heating energy consumption: Although less emphasized, especially in warm climates, some temperate and continental cases accounted for annual heating loads
- Lighting energy consumption: Frequently modeled in conjunction with daylighting analysis, especially in CTBs
- Energy use intensity: An integrative variable allowing cross-case comparisons of overall building energy performance.

Interestingly, multi-objective optimizations that evaluate trade-offs between passive cooling benefits and daylighting gains are scarce. This reflects a methodological bias toward thermal analysis and calls for more integrative simulations that co-model light and heat dynamics.

3.3.3. Daylight performance metrics

In recent years, there has been a noticeable increase in evaluations focused on daylight performance, especially in tertiary buildings where glare control and visual comfort are critical. Leading performance indicators include:

- Spatial daylight autonomy: The most prevalent daylighting metric in the reviewed corpus. It quantifies the percentage of occupied space receiving sufficient daylight for a specified portion of the occupied period
- Daylight factor: A traditional, static metric that remains widely used due to its simplicity and regulatory acceptance
- Annual sunlight exposure: Used less frequently, it is useful for identifying risks of glare and overheating from direct sunlight
- Useful daylight illuminance: Occasionally employed to evaluate light quality thresholds, especially in office or educational settings.

Daylight performance assessment tools often integrate Radiance, Honeybee, or Daysim, which offer refined daylight simulations embedded in popular platforms such as Ladybug Tools.

3.4. Cross-cutting observations

It was observed that:

- Dominance of simulated over empirical data: Although simulations allow for the efficient manipulation of variables, there is still a significant shortage of field validation studies involving *in situ* temperature, lux levels, and occupant surveys
- Underexplored combined indicators: Very few studies holistically assess thermal comfort, energy efficiency, and daylight performance together using linked metrics. For example, balancing daylight autonomy with the increase in cooling load due to solar gain is an underdeveloped approach
- Temporal resolution: Most studies report annual or seasonal averages. However, diurnal variations and

transient responses (e.g., peak summer hours or winter mornings) are crucial for CBs with dynamic microclimates and are seldom analyzed.

4. Discussion

The systematic review of articles on CBs from the aspects of building functionality (CHBs and CTBs), purposes (thermal comfort, energy efficiency, daylight performance, climate zones [A, B, C, and D]), and courtyard configuration (orientation, aspect ratio, H/D, WWR, and L/W) has uncovered outcomes and trends that reveal key areas of limitations and discrepancies. In this section, several research gaps are identified (Figure 14): the lack of multi-objective assessments, fragmented theoretical frameworks, overreliance on simulation without field validation, underrepresentation of climate zones A and D, and limited population-sensitive analyses. A conceptual framework (Figure 15) was proposed to integrate passive design parameters with performance outcomes. This framework will guide future multi-objective, multi-climatic research and the development of parametric building information modeling tools.

4.1. Courtyard buildings for a new theoretical frame

Despite extensive research on CBs, studies are unevenly distributed across climate zones, performance metrics, and building types. Most studies concentrate on hot-arid (B) and temperate (C) regions, leaving a significant gap in research pertaining to tropical (A) and continental (D) climates. This disparity limits the applicability of the findings and raises concerns about climatic representativeness. Furthermore, among the 83 studies reviewed, few employed multi-objective evaluations that simultaneously consider thermal comfort, energy efficiency, and daylight performance. The absence of comprehensive performance assessments hinders the establishment of robust conclusions regarding courtyard effectiveness in diverse environmental and operational contexts.

As expected, the analysis revealed significant fragmentation in the knowledge base concerning the relationship between courtyard parameters and environmental performance metrics. Although orientation and aspect ratio are commonly studied, their interactions with variables such as the H/D, WWR, and H/L have not been adequately explored theoretically. Furthermore, research rarely clarifies the mechanisms connecting geometric changes to thermal and visual comfort, resulting in literature that is more descriptive than explanatory. The lack of interdisciplinary knowledge integration, especially among building physics, architectural morphology, and human-environment interaction, exacerbates this epistemic gap.

Surprisingly, few studies identified in this SLR have substantial theoretical foundations (Bulus *et al.*, 2017; Soflaei *et al.*, 2016; Zamani *et al.*, 2018). The frameworks for evaluating courtyard performance are often vague or inadequately developed. For example, although adaptive

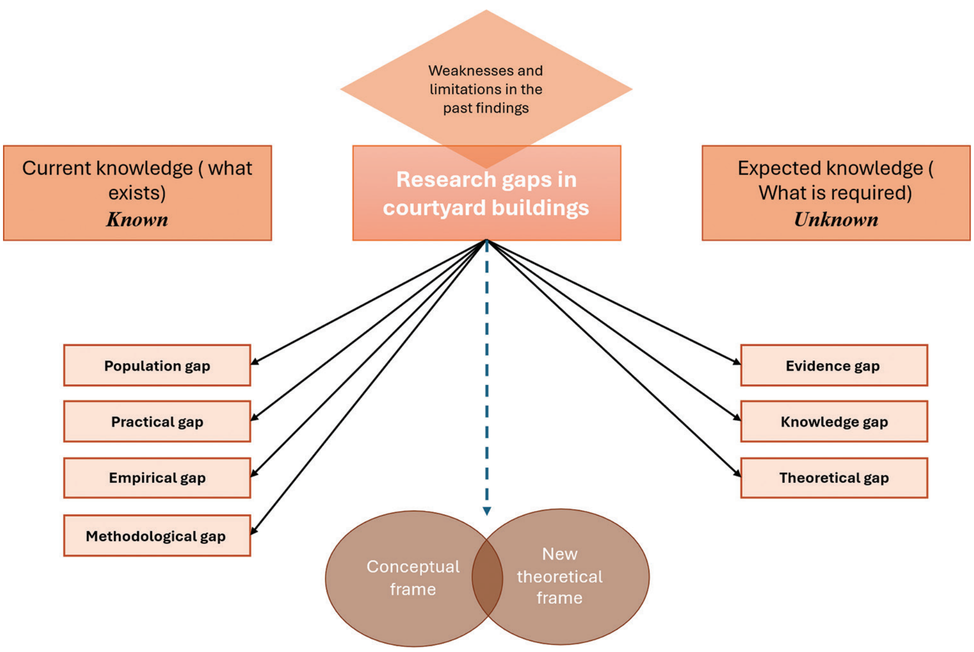

Figure 14. Identified areas of the research gaps
Source: Image created by the authors.

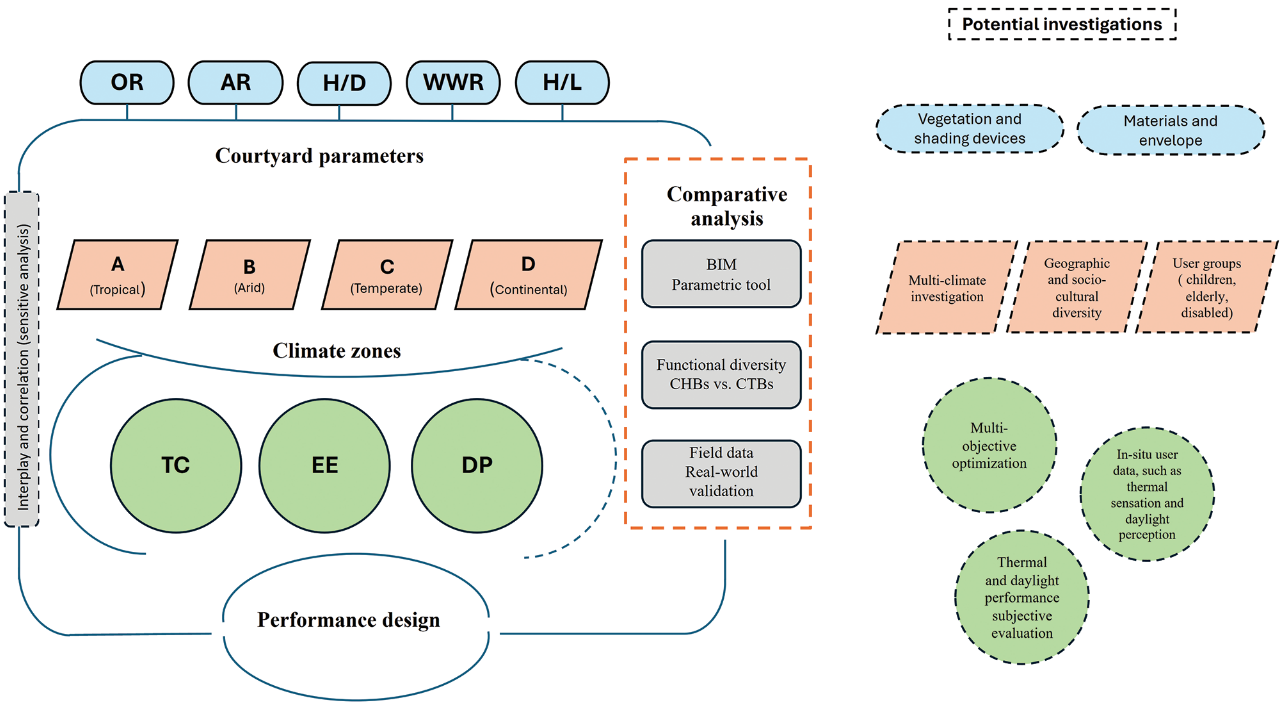

Figure 15. Conceptual framework illustrating the relationship between courtyard geometric parameters (e.g., orientation [OR], aspect ratio [AR], height-to-depth ratio [H/D], window-to-wall ratio [WWR], and height-to-length ratio [H/L]), climatic zones (A–D), and the resulting impacts on thermal comfort (TC), energy efficiency (EE), and daylight performance (DP)
Source: Image created by the authors.
Abbreviations: BIM: Building information modeling; CHB: Courtyard housing building; CTB: Courtyard tertiary building.

thermal comfort models and daylight autonomy metrics are referenced, they lack consistent integration into a unified theoretical framework. The absence of theory-based typologies for courtyard configurations and climatic adaptation limits the analytical rigor of existing studies. A more thorough engagement with theories of passive design, climate adaptation, and spatial morphology theories would enhance the intellectual sophistication of the CB field.

4.2. Courtyard buildings for the conceptual frame

Based on the results of the current study, the CB research methodology predominantly favors simulation methods, with limited representation of experimental or mixed-methods approaches. While computational tools such as DesignBuilder, EnergyPlus, and ENVI-met offer valuable insights, relying exclusively on them can lead to over-dependence on hypothetical scenarios. Few studies have used field measurements or post-occupancy evaluations to validate simulation models (Zhao *et al.*, 2022). Additionally, variability in input parameters, software configurations, and climate data sources makes it difficult to compare results. The absence of standardized methodological frameworks for assessing courtyard performance hampers the development of reproducible and generalizable outcomes.

Moreover, a notable empirical gap exists in the application of courtyard design across various socio-cultural and geographical contexts. Empirical research is primarily limited to a few countries and often lacks comparative analyses across different climatic zones or urban environments. In addition, the reliance on single-case analyses limits the external validity of the conclusions. Studies examining seasonal variations, climate adaptation strategies, and energy consumption patterns over time are scarce. The inadequate inclusion of *in situ* user data (e.g., thermal sensation, adaptive comfort thresholds, and lighting preferences) might intensify this empirical deficiency. Furthermore, there is a significant divergence between academic research outputs and their practical application. Simulation-based studies are prevalent but often devoid of contextual relevance and practical guidance for professionals. Research findings rarely evolve into implementable design principles or parametric tools for architects and engineers during the preliminary design phases. Furthermore, simulation outcomes often overlook critical factors such as construction materials, occupant behavior, and economic limitations that influence real-world efficacy. Consequently, the practical impact on design and implementation is limited.

There is a scarce number of studies, such as that by Abdallah (2022), in which the thermal sensation vote was evaluated using a questionnaire survey in a school building. However, most studies either neglect demographic variability or are limited to specific climates, such as arid zones. These studies focus on generic user profiles without considering the specific needs of populations such as children, the elderly, and individuals with disabilities. In the context of courtyard housing, where occupancy patterns and physiological responses vary considerably, the lack of population-sensitive analyses is a critical omission. Additionally, the overwhelming focus on residential typologies (CHBs) rather than institutional or public buildings (CTBs) limits functional insight diversity. Rarely do studies examine how different user groups perceive and adapt to courtyard environments, which undermines the development of inclusive and universally applicable design solutions.

4.3. Implications for Chinese courtyard architecture and urban contexts

The systematic review's results have substantial implications for Chinese courtyard architecture, which includes climatically adapted typologies such as the *siheyuan*, *sanheyuan*, and *tulou*. These typologies reflect spatial principles established in global studies, including courtyard enclosure, H/W, orientation, and openness, which affect thermal comfort, ventilation, and daylight performance in China's varied climatic zones.

Despite their architectural significance, Chinese CBs are usually researched from historical or morphological

Table 6. Summary of research gaps across key aspects of the literature (performance focus, courtyard configuration, and climate context)

Research gaps	Research variables		
	Performance focus	Courtyard configuration	Climatic context
Evidence gap	- Lack of triangulated (TC, EE, DP) and comprehensive performance assessments - Limited experimental studies	- Lack of parametric assessments	- Lack of multi-climate analyses
Knowledge gap		- Dynamic interactions among parameters (e.g., AR, OR, and L/W) are underexplored - Mechanisms linking geometric alterations to thermal dynamics are often examined at the expense of visual comfort	
Theoretical gap	- Adaptive thermal comfort models and daylight autonomy metrics are rarely referenced	- Lack of theory-informed typologies of courtyard configurations and climatic responsiveness	- Limited consideration of spatial morphology - Limited engagement with theories of passive design and climate adaptation
Methodological gap	- Lack of multi-objective optimization	- Lack of sensitive analysis (parameter–purpose correlation assessment) - Lack of multi-objective optimization - Limited representation of experimental or mixed-methods approaches - Limited evaluation of daylighting in courtyard housing buildings	
Practical gap		- Disconnect between research outputs and real-world implementation - Findings are rarely translated into actionable design principles	
Empirical gap	- Insufficient incorporation of *in situ* user data (e.g., thermal sensation, adaptive comfort thresholds, and lighting preferences)	- Lack of real-world validation - Limited application of courtyard design principles across diverse socio-cultural and geographical contexts - Lack of comparative analyses across climatic zones or urban settings	- Longitudinal investigations capturing seasonal variations, climate adaptation behaviors, and energy use patterns are rare
Population gap	- Limited coverage of diverse building typologies and occupant comfort satisfaction (subjective comfort assessment)	- Lack of population-sensitive analyses	

viewpoints, with limited systematic examination of their environmental performance using integrated quantitative metrics. This review demonstrates the potential of utilizing global performance-based evidence to reconsider traditional courtyard designs in contemporary Chinese residential and tertiary buildings, as well as in heritage and rural contexts. By linking worldwide research findings to Chinese architectural traditions, the study provides a formal platform for performance-oriented adaptation and future research in Chinese courtyard design.

4.4. Future directions

Addressing these research gaps requires a more interdisciplinary, context-aware, and methodologically pluralistic approach. Future research should prioritize multi-objective, multi-climatic studies that integrate empirical validation with insights from simulation. Developing open-access databases, standardized testing protocols, and theory-informed design tools can bridge the gap between academic inquiry and professional practice. Moreover, expanding the focus to underrepresented climates, user groups, and building functions will ensure a more comprehensive understanding of the potential of courtyard architecture to advance sustainability and occupant well-being. This novel framework enables an accurate assessment of deficiencies in existing literature, providing a clear and structured view of the current challenges in the field. These research gaps are summarized in Table 6, providing a helpful overview of the areas needing further exploration. The identification of trends in these gaps not only highlights unexplored opportunities but also establishes a foundation for future research aimed at improving energy efficiency and building performance through CB designs.

5. Conclusion

This systematic review examined 83 studies on CBs published between 2014 and 2025, applying the PRISMA method, thematic analysis, and an analytical framework to assess trends and performance across typology (CHBs and CTBs), design purposes (thermal comfort, energy efficiency, and daylight performance), climate zones (A–D), and configuration parameters (orientation, aspect ratio, H/D, WWR, and L/W).

The key trends identified are as follows:

- CHBs dominated the literature (68%), with a primary focus on improving thermal comfort
- CTBs received comparatively less attention (41%), though studies addressing daylight performance were more prominent, potentially due to unified lighting systems in institutional typologies
- Tropical (A) and continental (D) climates remain underrepresented, while arid regions (B) account for the majority of the studies due to pronounced thermal fluctuations
- Orientation and aspect ratio emerged as the most frequently assessed parameters, reflecting their influence on solar exposure, shading, and ventilation
- Simulation and modeling approaches prevail across the corpus, potentially due to practical limitations of full-scale prototyping
- Integrated assessments of thermal comfort, energy efficiency, and daylight performance remain rare. Interactions—such as trade-offs between daylight autonomy and increased cooling demand—are still insufficiently explored.

The identified research gaps are as follows:

(i) Theoretical gaps:
  - Limited coverage of climate zones A and D reduces the generalizability of findings across diverse climatic contexts
  - The scarcity of multi-objective assessments prevents a holistic evaluation of courtyard efficacy
  - Parameter interplay (e.g., orientation × aspect ratio × L/W) lacks theoretical explanation and interdisciplinary grounding
  - Frameworks often default to descriptive accounts without causal insight or integration of building physics, morphology, or human perception
  - Adaptive comfort models and daylight metrics are inconsistently applied across studies.

(ii) Conceptual and empirical gaps:
  - Simulation-heavy methodologies often overshadow experimental and mixed-methods research, thereby challenging real-world validation
  - Lack of standardized protocols and input variability hinders comparative analysis and reproducibility
  - Geographic and socio-cultural diversity is limited, with a preponderance of single-case, non-longitudinal studies
  - *In situ* user data, such as thermal sensation and daylight perception, are rarely captured
  - Most studies fall short of translating their results into actionable design principles or toolsets for practical application
  - Functional diversity is skewed toward CHBs, with CTBs underrepresented.

By synthesizing global evidence on courtyard configuration and environmental performance, this study provides a performance-oriented lens through which traditional Chinese CBs can be reassessed, conserved, and adapted to contemporary residential and tertiary building contexts. The results highlight opportunities for integrating empirical validation, multi-objective optimization, and climate-sensitive design strategies to support sustainable architectural development in both urban and rural settings in China. Moreover, studies seldom investigate the impact of irregular courtyard geometries or vegetation-based microclimatic interventions. These omissions, coupled with the constrained dataset, limit the applicability of findings to broader contexts.

This review lays the groundwork for future interdisciplinary research, policy guidance, and tool development. It calls for empirically validated, theory-informed approaches to climate-responsive design—positioning CBs as a critical typology in shaping sustainable Chinese and global architectural practice.

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Conflict of interest

The authors declare they have no competing interests.

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Further disclosure

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References

Abdallah, A.S.H. (2022). Passive design strategies to improve student thermal comfort in Assiut University: A field study in the faculty of physical education in hot season. *Sustainable Cities and Society*, *86*:104110.

https://doi.org/10.1016/j.scs.2022.104110

Abdallah, A.S.H., Mohammad, D.A., & Ali, A.M.M. (2019). The influence of different courtyard ratios in university buildings on their thermal performance during the hot period: (Faculties of agriculture and education, New Sohag University, Egypt as a case study). *IOP Conference Series Earth and Environmental Science*, *397*(1):012019.

https://doi.org/10.1088/1755-1315/397/1/012019

Abuhussain, M.A., Al-Tamimi, N., Alotaibi, B.S., Singh, M.K., Kumar, S., & Elnaklah, R. (2022). Impact of courtyard concept on energy efficiency and home privacy in Saudi Arabia. *Energies*, *15*(15):5637.

https://doi.org/10.3390/en15155637

Acosta, I., Varela, C., Molina, J.F., Navarro, J., & Sendra, J.J. (2018). Energy efficiency and lighting design in courtyards and atriums: A predictive method for daylight factors. *Applied Energy*, *211*:1216-1228.

https://doi.org/10.1016/j.apenergy.2017.11.104

Akbari, H., Cherati, S.M., Monazam, N.H., & Noguchi, M. (2021). Effect of courtyards' geometrical parameters on climate adaptability and shading performance in hot-arid climate of Yazd (Iran). *Suxtanable Energy Technologies and Assessments*, *48*:101594.

https://doi.org/10.1016/j.seta.2021.101594

Akhlaghinezhad, F., Mohajerani, M., & Bagheri Sabzevar, H. (2023). Optimizing courtyard design for thermal performance: A study on shadow and sunlight dynamics in traditional houses. *International Journal of Urban Management and Energy Sustainability*, *5*(1):31-53.

https://doi.org/10.22034/ijumes.2024.2019088.1190

Al-Hafith, O., Satish, B.K., & De Wilde, P. (2019). The impact of courtyard geometry on its mean radiant temperature. *Journal of Physics Conference Series*, *1343*:012022.

https://doi.org/10.1088/1742-6596/1343/1/012022

Al-Hafith, O., Satish, B.K., & De Wilde, P. (2023). Assessing annual thermal comfort extent in central courtyards: Baghdad as a case study. *Smart and Sustainable Built Environment*, *12*(3):660-681.

https://doi.org/10.1108/SASBE-09-2021-0154

Al-Masri, N., & Abu-Hijleh, B. (2012). Courtyard housing in midrise buildings: An environmental assessment in hot-arid climate. *Renewable and Sustainable Energy Reviews*, *16*(4):1892-1898.

https://doi.org/10.1016/j.rser.2012.01.008

Al-Sallal, K.A., AbouElhamd, A.R., & Bin Dalmouk, M. (2018). UAE heritage buildings converted into museums: Evaluation of daylighting effectiveness and potential risks on artifacts and visual comfort. *Energy and Buildings*, *176*:333-359.

https://doi.org/10.1016/j.enbuild.2018.06.067

Almhafdy, A., Ibrahim, N., & Ahmad, S.S. (2019). Impacts of courtyard geometrical configurations on energy performance of buildings. *Environment-Behaviour Proceedings Journal, 4*(10):29-36.

https://doi.org/10.21834/e-bpj.v4i10.1637

Almhafdy, A., Ibrahim, N., Ahmad, S.S., & Yahya, J. (2013). Courtyard design variants and microclimate performance. *Procedia-Social and Behavioral Sciences*, *101*:170-180.

https://doi.org/10.1016/j.sbspro.2013.07.190

Alshabanat, A., & Omer, S. (2023). The potential of green engineering solutions for energy conservation in residential buildings towards sustainability: A case study of Saudi Arabia. *Architecturale Switzerland*, *3*(4):713-738.

https://doi.org/10.3390/architecture3040039

Asfour, O.S. (2020). A comparison between the daylighting and energy performance of courtyard and atrium buildings considering the hot climate of Saudi Arabia. *Journal of Building Engineering*, *30*:101299.

https://doi.org/10.1016/j.jobe.2020.101299

Azimi, Z., & Shafaat, A. (2024). Proposing design strategies for contemporary courtyards based on thermal comfort in cold and semi-arid climate zones. *Building and Environment*, *266*:112150.

https://doi.org/10.1016/j.buildenv.2024.112150

Balah, E.M., Shokry, H., Hagishima, A., & Mahmoud, H. (2024). Reversed cooling and heating performance of modernized courtyard envelope in hot-arid climates: A case study at an educational campus. *Clean Technologies and Environmental Policy*, *26*:4521-4542.

https://doi.org/10.1007/s10098-024-02833-y

Benchekroun, M., Chergui, S., Ruggiero, F., & Di Turi, S. (2020). Indoor microclimate conditions and the impact of transformations on hygrothermal comfort in the Old Ottoman houses in algiers. *International Journal of Architectural Heritage*, *14*(9):1296-1319.

https://doi.org/10.1080/15583058.2019.1606362

Bencherif, A.M.M. (2023). A strategy to improve comfort level and optimize the thermal behavior of the building; Learning from M'zab architecture. *Prostor*, *31*(2):210-223.

https://doi.org/10.31522/p.31.2(66).6

Berardi, U. (2015). Building energy consumption in US, EU, and BRIC countries. *Procedia Engineering*, *118*:128-136.

https://doi.org/10.1016/j.proeng.2015.08.411

Beyraghshamshir, M., & Sarkardehei, E. (2023). A comparison of the cooling and heating performance of two passive systems of central courtyards and atriums at an elementary school in Yazd City. *Solar Energy, 252*:156-162.

https://doi.org/10.1016/j.solener.2023.01.034

Bian, M.Y., Huang, Z.J., Chen, Q., Liu, G., Zhang, Y., & Ding, S.S. (2022). Optimization of plane and space of new dwellings in Southern Anhui Province based on indoor thermal environment. *Sustainability*, *14*(9):5694.

https://doi.org/10.3390/su14095694

Bin Dalmouk, M., & Al-Sallal, K. (2020). Modelling Daylight in Adjacent Spaces of the Courtyard Under Clear Sky Conditions. In: *Proceedings of Building Simulation 2019: 16TH Conference if IBPSA*, *Italy*. p. 990-995.

https://doi.org/10.26868/25222708.2019.210307

Bulus, M., Hamid, M., & Lim, Y.W. (2017). Courtyard as a passive cooling strategy in buildings. *International Journal of Built Environment and Sustainability*, *4*(1):48.

https://doi.org/10.11113/ijbes.v4.n1.159

Callejas, I.J.A., & Krüger, E. (2022). Microclimate and thermal perception in courtyards located in a tropical savannah climate. *International Journal of Biometrology*, *66*(9):1877-1890.

https://doi.org/10.1007/s00484-022-02329-8

Cantón, M.A., Ganem, C., Barea, G., & Llano, J.F. (2014). Courtyards as a passive strategy in semi dry areas. Assessment of summer energy and thermal conditions in a refurbished school building. *Renewable Energy*, *69*:437-446.

https://doi.org/10.1016/j.renene.2014.03.065

Chohan, A.H., Awad, J., Ismail, M.A., & Arar, M.S. (2024). Integrating technology and heritage design for climate resilient courtyard house in arid region. *Civil Engineering Journal Tehran*, *10*(3):928-952.

https://doi.org/10.28991/CEJ-2024-010-03-018

Chuc, A.G.U., & Riveroll, A.M.A. (2022). Emergent remote education in Urban and rural primaries. Systematic review 2019-2021. *Cpu-E Revista De Investigation Educativa*, *35*:53-89.

https://doi.org/10.25009/cpue.v0i35.2820

Dai, J., & Jiang, S.G. (2021). Passive space design, building environment and thermal comfort: A university building under severe cold climate, China. *Indoor and Built Environment*, *30*(9):1323-1343.

https://doi.org/10.1177/1420326X20939234

Dai, J.L., Wang, J.M., Bart, D., & Gao, W.J. (2023). The impact of building enclosure type and building orientation on indoor thermal comfort ---A case study of Kashgar in China. *Case Studies in Thermal Engineering, 49*:103291.

https://doi.org/10.1016/j.csite.2023.103291

Dastoum, M., Sanchez Guevara, C., & Arranz, B. (2024). Efficient daylighting and thermal performance through tessellation of geometric patterns in building façade: A systematic review. *Energy for Sustainable Development*, *83*:101563.

https://doi.org/10.1016/j.esd.2024.101563

Defiana, I., Samodra, F., Setyawan, W., & Iop. (2018). Night ventilation at courtyard housing estate in warm humid tropic for sustainable environment. *IOP Conference Series Earth and Environmental Science*, *126*:012029.

https://doi.org/10.1088/1755-1315/126/1/012029

Diz-Mellado, E., López-Cabeza, V.P., Rivera-Gómez, C., & Galán-Marín, C. (2023a). Performance evaluation and users' perception of courtyards role in indoor areas of mediterranean social housing. *Journal of Envieonmental Management*, *345*:118788.

https://doi.org/10.1016/j.jenvman.2023.118788

Diz-Mellado, E., López-Cabeza, V.P., Rivera-Gómez, C., & Galán-Marín, C. (2023b). Seasonal analysis of thermal comfort in Mediterranean social courtyards: A comparative study. *Journal of Building Engineering*, *78*:107756.

https://doi.org/10.1016/j.jobe.2023.107756

Diz-Mellado, E., López-Cabeza, V.P., Rivera-Gómez, C., Naboni, E., & Galán-Marín, C. (2024). Optimizing a courtyard microclimate with adaptable shading and evaporative cooling in a hot mediterranean climate. *Journal of Building Engineering*, *88*:109167.

https://doi.org/10.1016/j.jobe.2024.109167

Domínguez-Torres, C.A., & Domínguez-Delgado, A. (2024). Impact of radiative cooling on the energy performance of courtyards in Mediterranean climate. *Building Simulation*, *17*:1491-1513.

https://doi.org/10.1007/s12273-024-1153-2

Dona, C.G.W., Mohan, G., & Fukushi, K. (2021). Promoting Urban agriculture and its opportunities and challenges-a global review. *Sustainability*, *13*(17):9609.

https://doi.org/10.3390/su13179609

Drici, H., & Carpio-Pinedo, J. (2025). Urban land use mix and AI: A systematic review. *Cities*, *165*:106102.

https://doi.org/10.1016/j.cities.2025.106102

Elgheriani, L.H., Bin Sudin, P.W., & Almhafdy, A.A. (2018). Thermal performance of a high-rise residential building with internal courtyard in tropical climate. *Environment-Behaviour Proceedings Journal*, *3*(7):357-366.

https://doi.org/10.21834/e-bpj.v3i7.1240

Fathy, H. (1986). *Natural Energy and Vernacular Architecture.* Urban: United Nations University.

Forouzandeh, A., & Richter, T. (2019). Accurate prediction of heating energy demand of courtyard's surrounding envelopes using temperature correction factor. *Energy and Buildings*, *193*:49-68.

https://doi.org/10.1016/j.enbuild.2019.03.030

Freitag, A.E.B., Anholon, R., De Oliveira, V.M., & Larrain, T.V. (2017). Integration of concepts about lean construction, sustainability and life cycle of buildings: A literature review. *Brazilian Journal of Operations and Production Management*, *14*(4):486-499.

https://doi.org/10.14488/BJOPM.2017.v14.n4.a5

Gamage, W., Lau, S., Qin, H., & Gou, Z.H. (2017). Effectiveness of air-well type courtyards on moderating thermal environments in tropical Chinese Shophouse. *Architectural Science Review*, *60*(6):493-506.

https://doi.org/10.1080/00038628.2017.1383230

Gan, S.Q., Chen, W.X., & Feng, J.W. (2024). Case study of space optimization simulation of existing office buildings based on thermal buffer effect. *Buildings*, *14*(6):1611.

https://doi.org/10.3390/buildings14061611

Ghaffarianhoseini, A., Berardi, U., & Ghaffarianhoseini, A. (2015). Thermal performance characteristics of unshaded courtyards in hot and humid climates. *Building and Environment*, *87*:154-168.

https://doi.org/10.1016/j.buildenv.2015.02.001

Gonçalves, M., Figueiredo, A., Almeida, R.M.S.F., & Vicente, R. (2024). Dynamic façades in buildings: A systematic review across thermal comfort, energy efficiency and daylight performance. *Renewable and Sustainable Energy Reviews*, *199*:114474.

https://doi.org/10.1016/j.rser.2024.114474

Guedouh, M.S., & Zemmouri, N. (2017). Courtyard building's morphology impact on thermal and luminous environments in hot and arid region. *Energy Procedia*, *119*:153-162.

https://doi.org/10.1016/j.egypro.2017.07.063

Guedouh, M.S., Zemmouri, N., Hanafi, A., & Qaoud, R. (2019). Passive strategy based on courtyard building morphology impact on thermal and luminous environments in hot and arid region. *Energy Procedia*, *157*:435-442.

https://doi.org/10.1016/j.egypro.2018.11.208

Gunasagaran, S., Saw, E.S., Mari, T., Srirangam, S., & Ng, V. (2022). Courtyard configuration to optimize shading, daylight and ventilation in a tropical terrace house using simulation. *Archnet-IJAR International Journal of Architectural Research*, *17*:109-123.

https://doi.org/10.1108/ARCH-12-2021-0354

Guo, J., Li, M., Jin, Y., Shi, C., & Wang, Z. (2022). Energy prediction and optimization based on sequential global sensitivity analysis: The case study of courtyard-style dwellings in cold regions of China. *Buildings*, *12*(8):1132.

https://doi.org/10.3390/buildings12081132

Han, S., Song, D., Xu, L., Ye, Y., Yan, S., Shi, F., *et al.* (2022). Behaviour in public open spaces: A systematic review of studies with quantitative research methods. *Building and Environment*, *223*:109444.

https://doi.org/10.1016/j.buildenv.2022.109444

Hao, S., Yu, C., Xu, Y., & Song, Y. (2019). The effects of courtyards on the thermal performance of a vernacular house in a hot-summer and cold-winter climate. *Energies*, *12*(6):1042.

https://doi.org/10.3390/en12061042

He, C., Tian, W., & Shao, Z.B. (2022). Impacts of courtyard envelope design on energy performance in the hot summer-cold winter region of China. *Buidlings*, *12*(2):173.

https://doi.org/10.3390/buildings12020173

Hosham, A.F., Kubota, T., & Iop. (2019). Field study of passive techniques and adaptive behaviour in the traditional courtyard houses of Kabul. *IOP Conference Series Earth and Environmental Science*, *294*:012039.

https://doi.org/10.1088/1755-1315/294/1/012039

Intergovernmental Panel on Climate Change. (2021). *Climate Change Widespread, Rapid, and Intensifying - IPCC*. IPCC. Available from: https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr [Last accessed on 2025 May 18].

Jara, E.A.R., De La Flor, F.J.S., Domínguez, S.A., Lissén, J.M.S., & Casado, A.R. (2017). Characterizing the air temperature drop in mediterranean courtyards from monitoring campaigns. *Sustainability*, *9*(8):1401.

https://doi.org/10.3390/su9081401

Kaihoul, A., Sriti, L., Amraoui, K., Di Turi, S., & Ruggiero, F. (2021). The effect of climate-responsive design on thermal and energy performance: A simulation based study in the hot-dry Algerian South region. *Journal of Building Engineering*, *43*:103023.

https://doi.org/10.1016/j.jobe.2021.103023

Khan, H.M., Lane-Serff, G.F., & Dewsbury, J. (2023). Optimizing the design of courtyard houses for passive cooling in hot, dry regions. *Journal of Building Performance Simulation*, *16*(2):231-247.

https://doi.org/10.1080/19401493.2022.2134460

Khastar, S., & Taleghani, M. (2024). Thermal conditions and daylight availability in different zones of courtyard buildings; A study in Iran. *Advances in Building Energy Research*, *18*(4):384-402.

https://doi.org/10.1080/17512549.2024.2363878

Kirby, A. (2023). Exploratory bibliometrics: Using VOSviewer as a preliminary research tool. *Publications*, *11*(1):10.

https://doi.org/10.3390/publications11010010

Li, M., Jin, Y., & Guo, J. (2022). Dynamic characteristics and adaptive design methods of enclosed courtyard: A case study of a single-story courtyard dwelling in China. *Building and Environment*, *223*:109445.

https://doi.org/10.1016/j.buildenv.2022.109445

Lin, L.K., & Gui, Y. (2024). Why does the courtyard spaces of same ethnic group present diverse characteristics in different regions: Evidence based on ENVI-met climate modeling. *Journal of Clearner Production*, *466*:142703.

https://doi.org/10.1016/j.jclepro.2024.142703

López-Cabeza, V.P., Diz-Mellado, E., Rivera-Gómez, C.A., & Galán-Marín, C. (2022). Shade and thermal comfort in courtyards: Experimental versus simulation results. *Buildings*, *12*(11):1961.

https://doi.org/10.3390/buildings12111961

M'Saouri El Bat, A., Romani, Z., Bozonnet, E., Draoui, A., & Allard, F. (2023). Optimizing urban courtyard form through the coupling of outdoor zonal approach and building energy modeling. *Energy*, *264*:126176.

https://doi.org/10.1016/j.energy.2022.126176

Mahaya, C., Zemmouri, N., Benharra, H., & Elnokaly, A. (2022). Solar access assessment in semi-arid Urban context: An application study for ten Urban forms of existing apartment buildings Districts in Batna City, Algeria. *Sustainable Cities and Society*, *83*:103909.

https://doi.org/10.1016/j.scs.2022.103909

Mahmoud, H., & Ragab, A. (2021). Thermal performance evaluation of unshaded courtyards in egyptian arid regions. In: Bisello, A., Vettorato, D., Haarstad, H., & Borsboom-Van Beurden, J., (eds). *Smart and Sustainable Planning for Cities and Regions. SSPCR 2019*. Green Energy and Technology. Cham: Springer.

https://doi.org/10.1007/978-3-030-57332-4_8

Mahmoud, R.M.A., & Abdallah, A.S.H. (2022). Assessment of outdoor shading strategies to improve outdoor thermal comfort in school courtyards in hot and arid climates. *Sustainable Cities and Society*, *86*:104147.

https://doi.org/10.1016/j.scs.2022.104147

Maier, D. (2021). Building materials made of wood waste a solution to achieve the sustainable development goals. *Materials*, *14*(24):7638.

https://doi.org/10.3390/ma14247638

Maier, D. (2022). Perspective of using green walls to achieve better energy efficiency levels. A bibliometric review of the literature. *Energy and Buildings*, *264*:112070.

https://doi.org/10.1016/j.enbuild.2022.112070

Maldonado-Erazo, C.P., Del Rio-Rama, M.D., Alvarez-Garcia, J., & Flores-Mancheno, A.C. (2022). Use of natural and cultural resources by Tourism as a strategy for regional development: Bibliometric analysis. *Land*, *11*(8):1162.

https://doi.org/10.3390/land11081162

Meir, I. (2000). Courtyard Microclimate: A Hot Arid Region Case Study. *17th PLEA Int. Conf.*: Cambridge, UK, p. 218-222.

https://doi.org/10.13140/2.1.3085.4403

Mesa, J.A., Fuquene-Retamoso, C., & Maury-Ramirez, A. (2021). Life cycle assessment on construction and demolition waste: A systematic literature review. *Sustainability*, *13*(14):7676.

https://doi.org/10.3390/su13147676

Mirabi, E., & Abarghuie, F.A. (2023). Investigating the climate-adaptive design strategies of residential earth-sheltered buildings in Iran. *International Journal of Building Pathology and Adaptatin*, *41*(5):1029-1048.

https://doi.org/10.1108/IJBPA-05-2021-0076

Mousli, K., & Semprini, G. (2015). Thermal performances of traditional houses in dry hot arid climate and the effect of natural ventilation on thermal comfort: A case study in damascus. *Energy Procedia*, *78*:2893-2898.

https://doi.org/10.1016/j.egypro.2015.11.661

Muhaisen, A.S., & Gadi, M.B. (2006). Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate of Rome. *Building and Environmrnt*, *41*(3):245-253.

https://doi.org/10.1016/j.buildenv.2005.01.031

Mundra, S., & Kannamma, D. (2019). Effect of Courtyard on Comfort - Study of Thermal Performance Characteristics of Courtyards in Hot and Humid Climate. In: *Proceedings of the International Conference of Architectural Science Association*.

Nasrollahi, N., Hatami, M., Khastar, S.R., & Taleghani, M. (2017). Numerical evaluation of thermal comfort in traditional courtyards to develop new microclimate design in a hot and dry climate. *Sustainable Cities and Society*, *35*:449-467.

https://doi.org/10.1016/j.scs.2017.08.017

Nowell, L.S., Norris, J.M., White, D.E., & Moules, N.J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods*, *16*(1):1-13.

https://doi.org/10.1177/1609406917733847

O'Brien, W., Gaetani, I., Carlucci, S., Hoes, P.J., & Hensen, J.L.M. (2017). On occupant-centric building performance metrics. *Building and Environment*, *122*:373-385.

https://doi.org/10.1016/j.buildenv.2017.06.028

Oktay, D. (2002). Design with the climate in housing environments: An analysis in Northern Cyprus. *Building and Environmrnt*, *37*(10):1003-1012.

https://doi.org/10.1016/S0360-1323(01)00086-5

Omrany, H., Ghaffarianhoseini, A., Ghaffarianhoseini, A., & Clements-Croome, D.J. (2023). The uptake of city information modelling (CIM): A comprehensive review of current implementations, challenges and future outlook. *Smart and Sustainable built Environment*, *12*(5):1090-1116.

https://doi.org/10.1108/SASBE-06-2022-0116

Ouahchi, S., Ghafar, N., Mohd-Sahabuddin, M.F.M., Zemmouri, N., Mahaya, C., & Priya, R.S. (2025). Thermal comfort in Algeria's vernacular built environment-a systematic review. *International Journal of Environmental Studies*, *82*(3):1099-1122.

https://doi.org/10.1080/00207233.2025.2480511

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., *et al*. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, *372*:n71.

https://doi.org/10.1136/bmj.n71

Pilechiha, P., Norouziasas, A., Ghorbani Naeini, H., & Jolma, K. (2021). Evaluation of occupant's adaptive thermal comfort behaviour in naturally ventilated courtyard houses. *Smart* and *Sustainable Built Environment*, *11*(4):793-811.

https://doi.org/10.1108/SASBE-02-2021-0020

Rivera-Gómez, C., Diz-Mellado, E., Galán-Marín, C., & López-Cabeza, V. (2019). Tempering potential-based evaluation of the courtyard microclimate as a combined function of aspect ratio and outdoor temperature. *Sustainable Cities and Society*, *51*:101740.

https://doi.org/10.1016/j.scs.2019.101740

Sahnoune, S., & Benhassine, N. (2023). Winter thermal comfort of a typical courtyard geometry in a semi-arid climate. *Journal of Green Building*, *18*(1):95-117.

https://doi.org/10.3992/jgb.18.1.95

Salameh, M., Abu-Hijleh, B., & Touqan, B. (2024). Impact of courtyard orientation on thermal performance of school buildings ' temperature. *Urban Climate*, *54*:101853.

https://doi.org/10.1016/j.uclim.2024.101853

Saleh, Y., Mahat, H., Hashim, M., Nayan, N., Suhaily, S., & Ghazali, M.K.A. (2022). Sustainable heritage city: An empirical study to address study limitations in previous studies. *Journal of Urban Culture Research*, *24*:48-63.

https://doi.org/10.14456/jucr.2022.3

Shaheen, N., Shaheen, A., Ramadan, A., Hefnawy, M.T., Ramadan, A., Ibrahim, I.A., *et al.* (2023). Appraising systematic reviews: A comprehensive guide to ensuring validity and reliability. *Frontiers in Research Metrics and Analytics*, *8*:1268045.

https://doi.org/10.3389/frma.2023.1268045

Sheta, W., El Hussainy, M., & Abdelwahab, S. (2024). Labor camps in Dubai: Implications of courtyard regulations on daylight performance. *Open House International, 50*(1):2-19.

https://doi.org/10.1108/OHI-11-2023-0265

Soflaei, F., Shokouhian, M., Abraveshdar, H., & Alipour, A. (2017). The impact of courtyard design variants on shading performance in hot- arid climates of Iran. *Energy and Buildings*, *143*:71-83.

https://doi.org/10.1016/j.enbuild.2017.03.027

Soflaei, F., Shokouhian, M., & Mofidi Shemirani, S.M. (2016). Traditional Iranian courtyards as microclimate modifiers by considering orientation, dimensions, and proportions. *Frontiers of Architectural Research*, *5*(2):225-238.

https://doi.org/10.1016/j.foar.2016.02.002

Soflaei, F., Shokouhian, M., Tabadkani, A., Moslehi, H., & Berardi, U. (2020). A simulation-based model for courtyard housing design based on adaptive thermal comfort. *Journal of Building Engineering*, *31*:101335.

https://doi.org/10.1016/j.jobe.2020.101335

Sözen, İ., & Koçlar Oral, G. (2019). Outdoor thermal comfort in urban canyon and courtyard in hot arid climate: A parametric study based on the vernacular settlement of Mardin. *Sustainable Cities and Society*, *48*:101398.

https://doi.org/10.1016/j.scs.2018.12.026

Stewart, L. *Framework Analysis: Methods and use Cases*. Available from: https://atlasti.com/research-hub/framework-analysis#implementing-the-framework-analysis-methodology [Last accessed on 2025 May 22].

Subhashini, S., & Thirumaran, K. (2020). CFD simulations for examining natural ventilation in the learning spaces of an educational building with courtyards in Madurai. *Building Services Engineering Research Technology*, *41*(4):466-479.

https://doi.org/10.1177/0143624419878798

Sun, H., Jimenez-Bescos, C., Mohammadi, M., Zhong, F.L., & Calautit, J.K. (2021). Numerical investigation of the influence of vegetation on the aero-thermal performance of buildings with courtyards in hot climates. *Energies*, *14*(17):5388.

https://doi.org/10.3390/en14175388

Sun, Q., Luo, Z., & Bai, L. (2023). The impact of internal courtyard configuration on thermal performance of long strip houses. *Bulidings*, *13*(2):371.

https://doi.org/10.3390/buildings13020371

Sun, Q.Q., Fan, Z.Y., & Bai, L.J. (2024). Influence of space properties of enclosed patio on thermal performance in hot-humid areas of China. *Ain Shams Engineering Journal*, *15*(2):102370.

https://doi.org/10.1016/j.asej.2023.102370

Tabadkani, A., Aghasizadeh, S., Banihashemi, S., & Hajirasouli, A. (2022). Courtyard design impact on indoor thermal comfort and utility costs for residential households: Comparative analysis and deep-learning predictive model. *Frotiers of Architectural Research*, *11*(5):963-980.

https://doi.org/10.1016/j.foar.2022.02.006

Tabesh, T., & Sertyesilisik, B. (2016). An investigation into energy performance with the integrated usage of a courtyard and atrium. *Buildings*, *6*(2):21.

https://doi.org/10.3390/buildings6020021

Taki, A., & Alsheglawi, B. (2022). Toward energy-efficient houses considering social cultural needs in Bahrain: A new framework approach. *Sustainability*, *14*(11):6842.

https://doi.org/10.3390/su14116842

Taleb, H.M., Wriekat, T., & Hashaykeh, H. (2020). Optimising natural ventilation using courtyard strategies: CFD simulation of a G. *International Journal of sustainable Energy*, *39*(7):659-684.

https://doi.org/10.1080/14786451.2020.1748027

Taleghani, M., Tenpierik, M., & Van Den Dobbelsteen, A. (2012). Environmental impact of courtyards-a review and comparison of residential courtyard buildings in different climates. *Journal of Green Building*, *7*(2):113-136.

Taleghani, M., Tenpierik, M., & Van Den Dobbelsteen, A. (2014). Energy performance and thermal comfort of courtyard/atrium dwellings in the Netherlands in the light of climate change. *Renewable Energy*, *63*:486-497.

https://doi.org/10.1016/j.renene.2013.09.028

Talip, M.S., Shaari, M.F., Ahmad, S.S., & Sanchez, R.B. (2021). Optimising daylighting performance in tropical courtyard and atrium buildings for occupants' wellbeing. *Environment-Behaviour Proceedings Journal*, *6*:93-102.

Teshnehdel, S., Mirnezami, S., Saber, A., Pourzangbar, A., & Olabi, A.G. (2020). Data-driven and numerical approaches to predict thermal comfort in traditional courtyards. *Sustaiable Energy and Technologies and Assessement*, *37*:100569.

https://doi.org/10.1016/j.seta.2019.100569

Teshnehdel, S., Soflaei, F., & Shokouhian, M. (2020). Assessment of solar shading performance of courtyard houses in desert climate of Kashan, Iran. *Architectural Engineering and Design Management*, *16*(6):473-492.

https://doi.org/10.1080/17452007.2020.1758025

Toe, D.H.C., & Kubota, T. (2015). Comparative assessment of vernacular passive cooling techniques for improving indoor thermal comfort of modern terraced houses in hot-humid climate of Malaysia. *Solar Energy*, *114*:229-258.

https://doi.org/10.1016/j.solener.2015.01.035

Toris-Guitron, M.G., Esparza-López, C.J., Luna-León, A., & Escobar-Del Pozo, C. (2022). Evaluation of the thermal performance of traditional courtyard houses in a warm humid climate: Colima, Mexico. *Heritage Science*, *10*(1):187.

https://doi.org/10.1186/s40494-022-00820-4

United Nations High Commissioner for Refugees. (2023). *Defining the Analytical Framework*. UNHCR Assessment and Monitoring Resource Centre. Available fom: https://www.unhcr.org/handbooks/assessment/design/defining-analytical-framework [Last accessed on 2025 May 18].

Vaisman, G., & Horvat, M. (2015). Influence of internal courtyards on the energy load and hours of illuminance in row houses in toronto. *Energy Procedia, 78*:1799-1804.

https://doi.org/10.1016/j.egypro.2015.11.312

Wahed, W.J.E., Saad, N., Yusoff, S.B.M., & Pitil, P.P. (2021). "Please stay, Don't Leave!": A systematic literature review of safeguarding intangible cultural heritage in the fourth industrial revolution. *Pertanka Journal of Social Science and Humanities*, *29*(3):1723-1744.

https://doi.org/10.47836/pjssh.29.3.14

Xu, S., Cheng, B., Huang, Z.F., & Shen, C.Y. (2022). An investigation on the thermal environment of residential courtyards in the cold Area of Western Sichuan Plateau. *Buildings*, *12*(1):49.

https://doi.org/10.3390/buildings12010049

Xu, Z., Zheng, X., & Li, X. (2025). Optimal design strategy of traditional courtyard based on performance and data-driven method-a case study of Yanshen ancient town, China. *Frontiers of Architectural Research*, *14*(5):1168-1195.

https://doi.org/10.1016/j.foar.2025.01.004

Yaşa, E., & Ok, V. (2014). Evaluation of the effects of courtyard building shapes on solar heat gains and energy efficiency according to different climatic regions. *Energy and Buildings*, *73*:192-199.

https://doi.org/10.1016/j.enbuild.2013.12.042

Zabelskyte, G., Kabisch, N., & Stasiskiene, Z. (2022). Patterns of Urban green space use applying social media data: A systematic literature review. *Land*, *11*(2):238.

https://doi.org/10.3390/land11020238

Zakaria, M.A., Kubota, T., & Toe, D.H.C. (2015). The effects of courtyards on indoor thermal conditions of Chinese shophouse in Malacca. *Procedia Engineering*, *121*:468-476.

https://doi.org/10.1016/j.proeng.2015.08.1094

Zamani, Z., Heidari, S., Azmoodeh, M., & Taleghani, M. (2019). Energy performance and summer thermal comfort of traditional courtyard buildings in a desert climate. *Environmental Progress and Sustainable Energy*, *38*(6):e13256.

https://doi.org/10.1002/ep.13256

Zamani, Z., Heidari, S., & Hanachi, P. (2018). Reviewing the thermal and microclimatic function of courtyards. *Renewable and Sustainable Energy Reviews*, *93*:580-595.

https://doi.org/10.1016/j.rser.2018.05.055

Zhao, M., Mehra, S.R., & Künzel, H.M. (2022). Energy-saving potential of deeply retrofitting building enclosures of traditional courtyard houses - a case study in the Chinese Hot-Summer-Cold-Winter zone. *Building and Environment*, *217*:109106.

https://doi.org/10.1016/j.buildenv.2022.109106

Zhao, Y., & Taib, N. (2022). Cloud-based building information modelling (cloud-BIM): Systematic literature review and bibliometric-qualitative Analysis. *Automation in Construction*, *142*:104468.

https://doi.org/10.1016/j.autcon.2022.104468

Zhu, L., Wang, B., & Sun, Y. (2020). Multi-objective optimization for energy consumption, daylighting and thermal comfort performance of rural tourism buildings in North China. *Buildingand Environment*, *176*:106841.

https://doi.org/10.1016/j.buildenv.2020.106841

Zhu, W., Han, X.Y., Ying, X.Y., Tan, Y., Shen, L.Y., & Huangfu, F.Y. (2024). Low energy consumption layout of exhibition buildings in Yangtze River Delta region. *Scientific Reports*, *14*(1):5935.

https://doi.org/10.1038/s41598-024-53439-9