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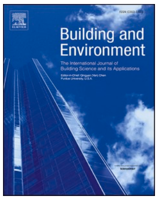

Passive cooling strategies to optimise sustainability and environmental ergonomics in Mediterranean schools based on a critical review

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ABSTRACT

This article identifies and compares the passive cooling strategies used and their relationship to optimising sustainability and environmental ergonomics based on 47 case studies. The analysis of the schools has resulted in the identification of 20 passive strategies, eight parameters related to sustainability and six related to environmental ergonomics. The results show that the most used passive strategies are natural ventilation, green roofs, low thermal transmittance windows and solar shading. In contrast, the least used strategies are ventilated façades and evaporative cooling systems. In terms of sustainability, energy efficiency is present in most case studies; in contrast, the circular economy is hardly considered in schools. In terms of environmental ergonomics, thermal comfort is present in most case studies, while acoustic comfort is not assessed. Furthermore, the results show an absence of optimisation of acoustic and visual comfort, climate change adaptation measures and involvement of the educational community. This work provides a detailed understanding of the status quo for researchers, practitioners and policymakers and predicts the dynamic directions of the field. It highlights the need to incorporate passive design protocols explicitly applied to schools to achieve a sustainable and climate-resilient educational building stock within the principles of the circular economy.

1. Introduction

Schools are microsystems where children spend 30% of their daily time and are heavily involved in their cognitive, physical and mental development [1]. These complex spaces are dependent on the scale and influenced by physical characteristics such as climate, urban design, and materials' thermal properties [2]. In most countries, schools were built in the second half of the 20th century [3]. Europe had many outdated educational buildings built between the 1950s and 1970s, a percentage that increased in the Mediterranean regions [4]. Specifically, in Greece, which currently has 15,446 schools, 4500 are more than 45 years old. In Italy, 67% of schools were built before 1974, before the first regulation, and about 8% were built in the last 20 years [5]. Most of the existing schools in warm regions are becoming obsolete concerning current sustainable design patterns, making them uncomfortable spaces under the scenario of global warming. So, most existing schools require exterior and interior action proposals at different levels [6,7].

Numerous public and private initiatives have emerged to achieve sustainable educational buildings to alleviate those problems. The initiative Education for Sustainable Development (SD of UNESCO is from intergovernmental institutions, a framework linked to the 2030 Agenda for SD. Whose objective is to provide sufficient knowledge to students to make informed and responsible actions to protect the environment economically viable and create a just society [8]. Other initiatives include Euronet 50/50 (Interreg European Union Programme), promoting energy savings in the educative framework at national, regional, and local scales. The ClimACT project (Interreg SUDOEProgramme, the EERDFCooperation Programme Interreg Southwest Europe) supports the transition to a low-carbon economy in schools. In Canada, the Best Practices Guide for School Facility Managers is part of a pilot energy benchmarking and best practices program for the school sector conducted by the Office of Energy Efficiency (OOEE of Natural Resources Canada (NRCan). The concern to conserve the environment for future generations has also led to the development of schemes from the

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non-governmental sphere, such as the Eco-school's initiative (The Global Forest Fund), which is targeted to provide tools to the entire educational community through learning and practical experience. Besides, in the United States (UUS, the Leadership in Energy and Environmental Design (LEED) for school buildings by the UUSGreen Building Council (UUSGBC [9].

In terms of identified research projects and guidelines, those experiences have addressed sustainability and climate change adaptation in schools and improved environmental ergonomics, significantly improving student learning and performance [10]. Environmental ergonomics could be defined as the synergy between thermal comfort, acoustic comfort, lighting comfort, visual comfort, indoor air quality (IAQ) and outdoor air quality (OOEQ experienced by students [11–13]. Those parameters are influenced mainly by the climate zone and passive rates of the building [14,15]. Therefore, countries should establish long-term improvement actions to support the renovation of their educational building stock.

In this sense, passive intervention strategies offer opportunities to optimise decision-making by directing design interests towards climate issues and environmental ergonomics [16,17]. Passive strategies can be incorporated within building elements [18] or by integrating external factors [18,19]. However, there is a complexity to the task of passive design, which requires a set of skills and abilities, inspiration and creativity, combining and appropriately modifying architectural parameters and climatic conditions [20]. While today, there are many programmes, standards and certifications on the market to guide, demonstrate and document efforts to design sustainable and energy-efficient buildings [21]. However, despite the benefits of such strategies, most existing schools are becoming obsolete in terms of sustainable design patterns and environmental ergonomics. It is due to restricted state budgets, high costs and lack of resources and information. However, adapting school buildings to climate change, reducing the urban heat island (UHI) effect and achieving environmental ergonomics standards are essential.

Numerous studies have analysed different passive intervention strategies to optimise environmental ergonomics in schools. Mumovic et al. [22] investigated the IAQ, thermal comfort and acoustic performance of nine newly built secondary schools in England. Stabile et al. [23] focused on assessing air permeability and ventilation rate in Italian classrooms. Pierpaoli and Fava [24] evaluated the effects of a passive adsorbent surface on the deposition rate of pollutants to improve IAQ in a classroom in Italy. Conceição et al. [25] applied an adaptive model and evaluated the thermal comfort in ventilated spaces in children's schools in a Mediterranean climate for cold and warm thermal conditions. However, these works focus on analysing, evaluating, and monitoring a limited number of strategies in many buildings, especially in cold climates. Besides, those studies ignore the urgent need for mitigation and adaptation of climate change impacts in temperate climates, especially in the Mediterranean region, where, according to the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IIPCC, the need for cooling of the building stock will increasingly increase [26].

Consequently, this study aims to identify and compare passive cooling strategies applied to optimise schools' sustainability and environmental ergonomics in a Mediterranean climate. To this end, the following specific objectives have been set (i) a systematic literature review (SSLR of literature records on passive cooling strategies in Mediterranean climate schools; (ii) the identification of passive cooling strategies and parameters related to sustainability and environmental ergonomics; and (iii) a comparative analysis between cases of studies.

This study reflects and clarifies the current passive design, sustainable and healthy design within the circular economy framework for the regeneration and new construction of schools in the Mediterranean. This work is novel as, so far, no work has been found in the academic literature that analyses and identifies all the works that apply passive design strategies in Mediterranean schools since 2008 and their relationship with sustainability and environmental ergonomics parameters. Consequently, this study will contribute to policy guidelines in the Mediterranean and other hot climates and provide essential knowledge for policymakers and other practitioners to promote resilient school models.

2. Materials and methods

This section will describe the three main phases of the methodology according to Fig. 1.

2.1. SSLRof bibliographic records on passive cooling strategies in Mediterranean schools

The SSLRis based on the guidelines contained in Kitchenham et al. [27] (Fig. 1), which consists of the following steps (i) identifying bibliographic databases, keywords, and search strings; and (ii) conducting the bibliographic search and selecting relevant documents according to the PPRISMAflow guidelines [28]. Relevant documents that contain case studies that meet the parameters for achieving the objectives of this research were identified and analysed.

2.2. Passive cooling strategies and parameters to compare

Once the relevant papers and case studies have been identified, this section identifies: (i) the passive cooling strategies of the case studies; (ii) the critical parameters related to sustainability; and (iiI) the critical parameters related to environmental ergonomics. According to Köppen's climate classification, this study will analyse the articles conducted for the Mediterranean climate subtypes (a) hot dry-summer climates (Csa); and (b) cool dry-summer climates (Csb) [29].

The Mediterranean climate is characterised by mild winters and cool summers, especially for island territories. Winter minimum temperatures rarely drop below 0 °C, with more frequent minimum temperatures above 5 °C. On the other hand, the average daily maximum temperature during summer is around 30 °C due to the cool winds from the sea and some regions, mainly in the eastern Mediterranean basin (Cyprus and the Middle East) and North Africa. These seasonally fluctuating mild climatic conditions result in the configuration of moderate but safe heating and cooling loads of buildings. These loads are restricted exclusively during winter and summer in most Mediterranean regions. In spring and fall, outdoor climatic conditions are close to indoor thermal comfort conditions, eliminating any need for active indoor space conditioning. However, despite this favourable climatic environment, the energy consumption in buildings in the Mediterranean region remains disproportionately high, mainly because of the inadequate or inexistent insulation of the existing building envelope, both on opaque and transparent surfaces [30].

2.3. Comparative analysis between the case of studies

Finally, based on the strategies and parameters identified in the previous phase, this section analyses and compares: (i) The geographical distribution of the case studies; (ii) the sustainability assessment tools applied in the case studies; (iii) the passive cooling strategies according to climate zone; (iv) the sustainability and environmental ergonomics parameters identified in the case studies; and (v) the relationship between the passive cooling strategies and the sustainability and environmental ergonomics parameters.

3. Results

Once the steps of the previous sections have been applied, the results are analysed in Fig. 2–6 and Table 1–7.

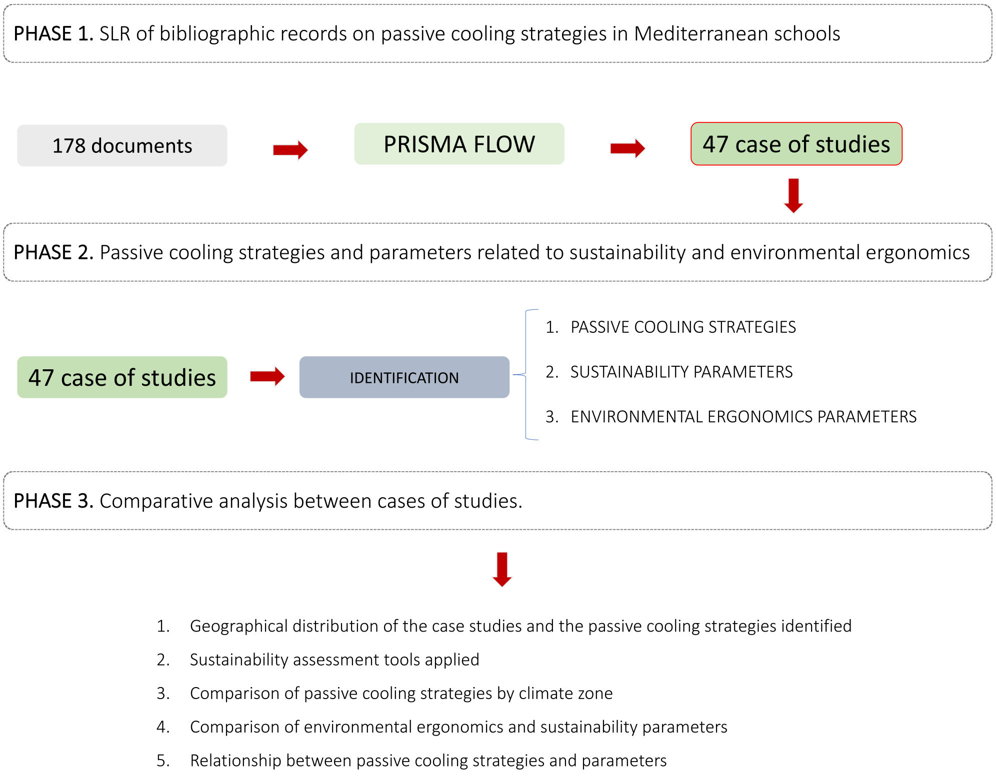


Fig. 1. Methodology.

3.1. *SLR of bibliographic records on passive cooling strategies in Mediterranean schools*

Passive cooling strategies consider the parameters related to sustainability and environmental ergonomics by adapting to the site's climatic conditions and taking advantage of natural resources, such as the sun, wind, and vegetation [14,31,32]. These strategies are framed within ecological, green, sustainable, or bioclimatic construction philosophy.

The Web of Science (WoS) and SCOPUS databases were selected for this study. To have all the research themes in the search string. Keywords related to each of the five pieces were established in Table 1. The keywords must include the topics from their origin and the satellite topics.

According to the PPRISMAflow diagram, 178 bibliographic records were retrieved from the two selected databases. After eliminating 76 duplicates, 33 of the remaining 102 records were excluded, as they did not refer to areas with a Mediterranean climate. The remaining 69 records were then examined in a second round, and 21 additional documents were excluded because they were not within the scope of this review, resulting in a total of 43 relevant articles, with 47 case studies (Fig. 2).

Table 1
Keywords related to the research topics.

Topics	Related Keywords
Passive strategy	passive strategy; bioclimatic strategy; bioclimatic architecture; passive architecture; passive construction; bioclimatic construction; ecological architecture; ecological construction; passive measures; passive system
Sustainability	Ecological construction; green construction; sustainable construction; bioclimatic construction.
Environmental Ergonomics	Environmental ergonomics; thermal comfort; acoustic comfort; light comfort; indoor air quality; outdoor air quality
School	school; educational institution; kindergarten
Mediterranean climate	Mediterranean climate; temperate climate; Spain; Portugal; France; Italy; Greece; Albania; Croatia; Montenegro; Slovenia; Bosnia-Herzegovina; Chile; Australia; California; Egypt; Morocco; Iraq, Iran; Algeria; Tunisia; Libya; Syria; Jordan; Israel; Australia

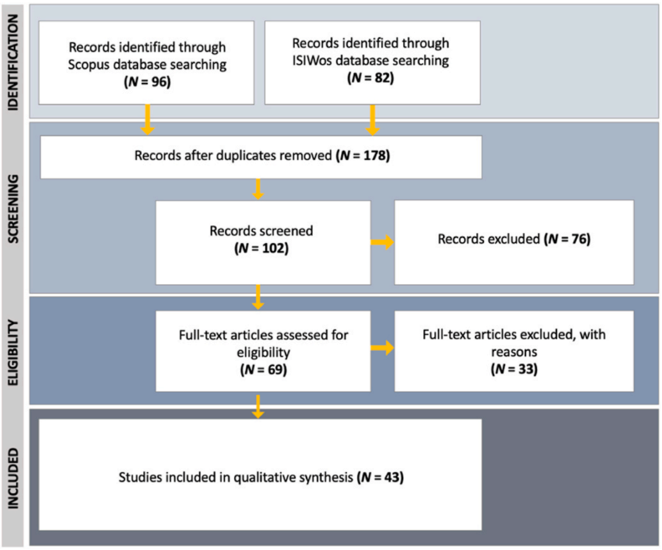


Fig. 2. Prisma flow diagram.

3.2. *Passive cooling strategies and parameters related to sustainability and environmental ergonomics*

This section identifies twenty passive cooling strategies in schools (Table 2), eight sustainability parameters and six environmental ergonomics parameters based on the 47 case studies.

3.2.1. *Passive cooling strategies*

Table 2 defines 20 passive cooling strategies based on the 47 case studies. These strategies will provide the scientific community with an overview of the research field of passive design applied to school buildings. Due to the characteristics of the Mediterranean climate and the impact that climate change is having and will have on the Mediterranean region, these measures are focused on reducing cooling consumption. However, some of these strategies can reduce both cooling and heating loads. While the list of passive cooling strategies applied to buildings is more extensive in the academic literature, the number of passive cooling strategies used in school buildings is reduced due to economic, logistical, and maintenance issues.

At the same time, some of the strategies identified in the studies negatively affect Mediterranean climates if not designed correctly. For example, a disproportionate increase in insulation is leading to overheating problems. Similarly, for environments with mild temperatures and a prolonged period of sunshine, heat losses or gains no longer interfere in the same proportion with the energy balance because the incident solar energy flux through the glazing is high. Therefore, the influence of the envelope is weak, and the relationship between energy consumption and compactness is not as efficient as in colder climates. In addition, preliminary designs in temperate climates that do not consider the environment either in origin or form have a lower impact in terms of energy efficiency.

Consequently, specific passive strategies inverse to compactness converges significantly for warm climates such as the Mediterranean. Such is the case of natural and night ventilation and ventilated facades that significantly impact the energy consumption of climates [35,44]. It uses local, abundant natural resources, air and oil, thus avoiding activating acts with a high environmental impact. In addition, the system maintains a good level of air renewal and humidity [44].

3.2.2. *Sustainability parameters*

Sustainable construction involves a systematic approach that considers climate, society, and local raw materials [51], as well as incorporating technologies that reduce resource use, ecological footprint and associated life cycle cost (LCC) [52]. Besides, an essential aspect of sustainability is the adaptation of the building to climate change. Due to climate change and the UHI, the cooling needs of schools in southern Europe will double by 2050 and far outweigh the decrease in heating needs, leading to an increase in total energy consumption [53–55] and a reduction in energy efficiency [56], and increased life cycle cost.

A sustainable design is closely related to the principles of the circular economy. The circular economy seeks to maintain building components and resources at their highest intrinsic value for as long as possible. Thus, building components are kept in continuous use, reuse, repair, and recycling cycle. It is about reducing waste and carbon footprint and preventing CO_2 emissions [57] Consequently, if schools are designed under the precept of the Net Zero Energy Building (NZEB without considering their adaptation to climate change, these services' advantages will lose value throughout their useful life.

Finally, in the social framework of sustainability, school buildings and the shelter they provide have an educational function as pupils can learn from their first educational steps to be environmentally friendly and be aware of energy consumption and its results. This consideration raises concerns across Europe and promotes sustainable solutions in school buildings involving bioclimatic technologies and strategies [58]. Table 3 identifies eight sustainability parameters based on the 47 case studies.

3.2.3. *Environmental ergonomics parameters*

Table 4 defines six environmental ergonomics parameters based on the 47 case studies. For a school to have high standards of environmental ergonomics, it must promote a positive balance between different parameters, namely thermal comfort, acoustic comfort, visual comfort, and indoor and outdoor air quality, among others.

In the case of thermal comfort, it is observed that it changes from one geographical space to another depending on the climate of the study area, the geographical location, the built environment and the subjects [65]. Thermal comfort, related to productivity and well-being and energy conservation in schools, has gained importance in recent years [66]. Current comfort standards, such as ISO 7730, EN 15251 and ASHRAE Standard 55, determine design values for operating temperatures and comfort equations based on rational and adaptive thermal comfort models.

Regarding air quality, CO_2 concentration is limited, and the number of suspended particles. Air quality in schools directly impacts student performance and wellbeing [71]. In 2020, the health emergency forced a review of indoor ventilation conditions, especially in educational buildings. School buildings, characterised by a high density of occupied spaces, require adequate IAQ to ensure students' and teachers' best performance and wellbeing [67].

In the case of OAQ, evidence shows that the school population is more vulnerable to polluted air, which increases the risk of asthma, especially if they live near busy roads. Air pollution can also affect the heart, brain, and nervous system development. For example, the air quality inside and outside primary schools in Europe does not protect children's health or ensure optimal learning, according to a new report by the non-governmental organisation Health and Environment Alliance (HEAL) entitled "Healthy Air, Healthier Children" [68].

In the case of visual comfort, the relationship between indoors and outdoors is aesthetically pleasing. It improves user performance, with students with a view performing 10–25% better on tests than those without [69]. The relationship between indoors and outdoors can be maximised by making the right decisions about size, orientation, shading structures, interior partitions, glazing and circulation patterns. In terms of acoustic comfort, the conditions are limited to protection against unwanted noise from the outdoor and indoor environment and the conditioning of indoor environments to adapt sound perception to use [70].

Finally, comfort values related to lighting are determined by an adequate distribution of illuminance over the work surface and the absence of glare. It is an influential factor that significantly impacts the child's wellbeing and stimulates and regulates the circadian system [71]. Daylighting provides healthy and high-quality working environments. It also provides variations in luminance and colour that influence the attractiveness and desirability of spaces [72,73]. Daylighting can reduce reliance on artificial lighting, which has been shown to help reduce the building's cooling load and energy demand.

3.3. *Comparative analysis between cases of studies*

This section compares the case studies based on the climate zones in which they are located and the ergonomics and environmental sustainability parameters they consider. The results are shown in Table 5–7 and Fig. 3–6 below.

3.3.1. *Geographical distribution of the case studies and the passive cooling strategies identified*

Table 5 shows the geographical distribution of the 47 case studies. In terms of the number of case studies, most come from the Mediterranean region of Southern Europe and Western Asia, and to a lesser extent from the Americas due to the small number of Mediterranean climate regions in these countries. Spain stands out as the country with the highest number of case studies, 15, followed by Greece with six centres. In Greece, since 2004, the Greek School Building Organisation has

Table 2
Passive cooling strategies identified in the case studies.

	Strategy	Description	Influence on the building and built environment				Ref.
			according to climate	Energy efficiency	IAQ	UHI	
S1	Improved Thermal Insulation	A passive strategy reduces heat losses to the external environment during the heating period and minimises heat gains during the cooling period, thus improving thermal comfort.	Incorrectly increasing insulation is generating overheating problems.	•			[33]
S2	Compactness	It is the ratio between the volume of spaces and the surface area of their envelope.	In cold climates, the lower the compactness, the lower the energy demand; while in the warm climate zone, the best energy efficiency is achieved by the confluence of several variables, namely total openings, orientation and (to a lesser extent) compactness.	•			[34, 35]
S3	Ventilated facades	The construction system leaves a ventilated chamber between the cladding and the insulation and eliminates thermal bridges and condensation problems. This way, excellent thermal performance is achieved, and dampness is prevented.	Ventilated Facades are ideal for both cold and warm areas. It avoids heat accumulation in the façade with consequent energy saving in warm climates. In cold temperatures, it contributes to the thermal stability of the system.	•	•		[36]
S4	Green facades	A system consisting of a structure adjacent to another wall characterised by its primary material, vegetation, provides the building with added protection.	Green facades in hot climates reduce the internal temperature of buildings due to the shade it produces. This system also protects from low temperatures and cold wind and wind in cold climates, the vegetation acting as a thermal insulator, preventing internal heat loss. Besides, acting as an acoustic insulator and reduces UHI.	•		•	[37]
S5	Trombe wall	A Trombe wall consists of a glass panel separated from a dark masonry wall, usually brick, stone, or concrete. Solar heat passes through the glass, is absorbed by the thermal mass wall, and is slowly released into the building.	It provides the option of using passive heating and cooling to achieve the desired thermal conditions within the building.	•			[38]
S6	Facades and roofs with high thermal inertia	During the summer, a construction system can absorb heat inside the building and release it at night to be expelled through natural ventilation, extracting the heat accumulated in the enclosures for recharging the following day.	The system has some aspects with the capacity to store heat, conserve it, and release it gradually, allowing less use of mechanical heating and even cooling systems.	•			[5]
S7	Green Roof	The system added to the roof of a building allows vegetation to grow.	It provides increased energy performance of buildings, improved UHI, stormwater management, microclimate mitigation, pollution remediation, and biodiversity restoration.	•		•	[39]
S8	Reflective Roof	High-reflective, environmentally friendly, and cost-effective roof system with highly reflective materials.	Contributes to energy efficiency by reducing cooling energy demand and mitigating UHI	•		•	[40]
S9	Pergola	A pergola is an open lattice grid of cross beams and beams supported by columns and without walls.	The system provides shade for temperature reduction in the built environment.				[41]
S10	Vegetation	A passive cooling strategy mitigates UHI increases and improves environmental conditions for human wellbeing.	A system that provides shade for temperature reduction in the built environment.			•	[41]
S11	Window with low thermal transmittance	Window systems are composed of materials with low thermal transmittance.	The thermal transmittance determines the amount of heat exchanged with the outside environment. The lower the thermal transmittance of the window, the less energy is exchanged, and the more efficient it is.	•			[42]
S12	Window Sun Protection	A system to protect glass surfaces from direct sunlight.	Reduces undesirable energy gains and increases cooling requirements. Solar shading systems, in most cases, increase the heating demand as a result of reduced solar gains and decrease the cooling load.	•			[43]
S13	Natural ventilation	Natural ventilation allows external air to enter and leave the interior of a building, promoting its circulation and renewal without the intervention of mechanical factors.	Opening in warm climates on opposite facades forces warm air and introduces fresh air at different temperatures, reducing thermal loads.	•	•		[41, 44]
S14	Night cooling	Ventilation takes advantage of the drop in temperature during the night to evacuate the heat accumulated during the day in the thermal mass of the construction elements.	It avoids the progressive increase in temperature inside the building during the hottest periods.	•	•		[45]
S15	Evaporative cooling system	An Evaporative cooling system is a process that uses the effect of water evaporation as a thermal well.	Evaporation of water causes cooling of the air and water. When water evaporates in contact with an airflow without an external energy supply, there is a decrease in temperature and an increase in air humidity.	•			[46]
S16	Solar chimney	An elongated ventilated cavity is painted black to favour the absorption of the sun's heat and, in most cases, located above the hottest part of the building. Solar radiation heats the air inside the chimney, which increases buoyancy forces, directing the air to the top and then out of the chimney.	Increases energy savings and utilises passive solar energy with no environmental impact. It is suitable for small spaces.	•			[47]

(*continued on next page*)

Table 2 (*continued*)

	Strategy	Description	Influence on the building and built environment				Ref.
			according to climate	Energy efficiency	IAQ	UHI	
S17	Buried ducts	Cool the building through buried air ducts. Thus, if a stream of air passes through these buried ducts for a long enough time, it will reach the temperature of the surrounding ground and the temperature of the soil. The operation is based on taking advantage of the Earth's thermal inertia, and the stable temperature reaches a shallow depth.	It uses local, abundant and natural resources such as air and soil, thus avoiding activating the whole chain of acts with a high environmental impact. In addition, the system maintains a good level of air renewal and humidity.	•	•		[47]
S18	Courtyards	The courtyards will generate specific microclimates, especially in warmer regions.	This system increases the porosity of cities, porosity being understood as the construction of voids. In addition, they reduce the UHI effect by generating micro islands of urban cooling.	•	•	•	[48]
S19	Materials with high albedo	Materials with a high surface reflectance coefficient	They reduce cooling energy demand in air-conditioned buildings and improve the comfort of open spaces, contributing to environmental sustainability.	•		•	[49]
S20	Phase-change materials (PPCM	PPMs are substances that can store and release large amounts of thermal energy.	They act as energy storage materials that provide an effective way to save energy by reducing the electricity required for heating and cooling.	•			[50]

developed bioclimatic pilot plans for planning its school infrastructures, which promote passive strategies with positive results [77]. In contrast, with only one case study, Lebanon presents a complex socio-political and cultural context that directly affects the country's development progress, especially sustainable construction [78].

In terms of the number of strategies considered (Table 2), schools in Spain present the highest number of strategies, 18, except the strategies compactness (S2) and evaporative cooling system (S15), with natural ventilation (S13) being the most used strategy, followed by the strategy on windows sun protection (S11). This high number is since openings in the building envelope are considered weak points from a thermal insulation point of view, allowing high heat losses in winter and excessive solar radiation in summer. Therefore, installing energy-efficient windows minimises heat gains during the cooling period. This glazing installation saves between 3 and 6% of the cooling demand in Mediterranean climates [64]. However, this type of strategy must be accompanied by solar protection systems, most of which require regular maintenance to prevent deterioration.

In the case of Portuguese schools, with half of the strategies identified, natural ventilation (S13) is again the most popular, compared to night ventilation (S14), courtyards (S18) and buried ducts (S17). Buried ducts, such as Air-to-Earth Heat Exchangers (EEAHE, where the air is forced to flow and exchange heat with the ground, can reduce the cooling load of a building by using them. Due to the Earth's thermal inertia, the near-surface region of the land can serve as a heat source or sink. This thermal energy available in the surface soil layer comes from solar radiation incidents on the Earth. In this way, the air is exhausted through the ducts at milder temperatures, which helps reduce the use of traditional air conditioning systems. However, such systems tend to be expensive, so they are not very popular for renovating educational facilities [79].

Traditionally, air renewal in schools has been achieved by natural air currents. However, mechanical ventilation has been a widespread solution in recent decades due to the simplicity of the implementation process, cheaper equipment, and better access to electricity supply. Thus, natural ventilation has been relegated to a secondary role, even disappearing from the regulations in some cases. It has also been partly due to the increased difficulty of the design, which makes it less attractive to designers and developers [80]. In the case of Italy, with seven strategies, natural ventilation (S13) is again the most popular.

In Greece, green roofs (S7) are the most prolific strategy, despite having the driest climate and high costs compared to other strategies. Building roofs have proven valuable for stormwater management, energy conservation, microclimate mitigation, pollution remediation and biodiversity restoration, but their diffusion in Mediterranean cities is minimal. However, as urban areas continue to expand and free space at the street level becomes increasingly limited, there is a greater need for innovative solutions. Thus, green roofs could create sustainable urban ecosystems [81].

The development of solar chimneys is relatively recent and highly dependent on the climate where it is located [82]. In Palestine, solar chimneys (S16) are the most popular. Few studies have analysed the performance of a solar chimney in hot climates. Sudprasert et al. [83] performed a study testing different heights and a reduced backward flow at the opening. The yield of ventilated airflow was 15.4–26.2% less than chimneys in dry-warm climates, while the overall air temperature was higher for a solar chimney with moist air.

In the United States, with four strategies, PPCMsare starting to be applied in schools. However, the right balance between the average melting temperature of the material, the climate and the temperature fluctuation between day and night make these strategies more limited in different regions [84].

3.3.2. *Sustainability assessment tools applied*

This section identifies and compares the sustainability assessment tools applied in the case studies. The assessment tools are not intended to provide certification, a rating or compliance with minimum requirements but rather to provide designers with a mechanism to promote sustainable building patterns, improve the energy rating of the building, and optimise decision-making on building design, building materials and local service options (energy supply, waste management and type of transport) [85].

EnergyPlus is a building energy simulation programme that calculates the energy consumption for heating, cooling, ventilation, lighting, plug loads, process loads, and water use in buildings. Its development is funded by the Building Technologies Office (BBTO of the UUSDepartment of Energy [86]. Table 6 shows how the Energy Plus tool is the most widely used by the authors, present in all countries except Cyprus, Lebanon, and Palestine.

Also noteworthy is the DesignBuilder tool, which has a modular structure, with an advanced 3D modeller at its core and a set of analysis modules coupled to it. The programme currently has nine modules, each offering a specific type of task or analysis. This approach gives DesignBuilder great flexibility to meet the requirements of each educational institution [87]. It explains its use in most case studies. In addition, the transient system simulation tool (TTRNSYS stands out. TTRYNNSwas the first sustainability assessment method, from which many different approaches have been developed to assess, qualify, and certify the

Table 3
Sustainability parameters identified in the case studies.

Parameters	Definition	Ref.
Energy efficiency	Energy efficiency means using less energy to perform the same task, eliminating energy waste. Energy efficiency brings various benefits: reducing greenhouse gas emissions, reducing demand for energy imports, and lowering our costs on a household and economy-wide level.	[43]
UHI	The UHI effect is related to higher urban temperatures than surrounding rural or suburban areas in the city centres. The phenomenon is mainly related to the high density of buildings and urban structures that absorb solar radiation, highly absorbent materials, the lack of green spaces, the characteristics of urban canyons and the emission of anthropogenic heat.	[59]
Adaptation to climate change	Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or benefit from climate change opportunities.	[60]
Circular Economy	The Circular Economy Applied to buildings seeks to maintain building components and resources at their highest intrinsic value for as long as possible. It involves reducing waste and carbon footprint and preventing CO2 emissions. Building components are kept in a continuous cycle of use, reuse, repair and recycling.	[61]
NZEB	Nearly zero-emission building means a building with very high energy performance. In contrast, the nearly zero or very low amount of energy required should be covered significantly by energy from renewable sources, including energy produced on-site or nearby.	[62]
LCC	LCC is an approach that assesses the total cost of an asset over its life cycle, including initial capital costs, maintenance costs, operating costs and the asset's residual value at the end of its life.	[63]
Comfort surveys	Surveys that relate specifically to the occupants are performed to develop an accurate representation of the environmental conditions perceived by the occupants against those parameters defined by standards.	[59]
Educational community participation	Community participation is a concept that attempts to bring different people together for community problem solving and decision making. Community participation is a way to take responsibility and accountability, identify the problem, and design and implement a programme for the development of society.	[64]

sustainability of different types of buildings. Finally, country-specific tools are a little present, such as the LIDER/CALENER Unified Tool (HHULC provided by the Spanish Government to verify its current CTE DB-HE 2019.

Although, except GenOpt [88], they focus on energy and indoor environmental quality, related to the environmental aspects of sustainability. It is the most influential and easily accessible aspect of sustainability. Thus, the social and economic approaches are far less prevalent, due in part to the limited knowledge or vagueness of the concept of sustainability itself, the more incredible difficulty in assessing aspects and categories related to social and economic approaches, and to the fact that the methods traditionally focus on purely environmental sustainability [85].

3.3.3. Comparison of passive cooling strategies by climate zone

This section compares the passive cooling strategies applied according to climate zone. In Figs. 5 and 40 schools (85%) are in the Csa climate zone, and seven schools (15%) are in the Csb zone. In terms of passive cooling strategies in the two climate zones, the most used are natural ventilation (S13), which is resent in 51% of the schools, as well as green roofs (S7), windows with low thermal transmittance (S11) and windows sun protection (S12), present in 26% of the schools in both zones. In contrast, the least used strategies, ventilated facade (S3) and evaporative cooling systems (S15), are only found in 2% of the case studies.

Table 4
Environmental ergonomic parameters identified in the case studies.

Parameters	Definition	Ref.
Thermal comfort	Thermal comfort is the mental condition that expresses satisfaction with the thermal environment and is assessed by a subjective evaluation.	[43]
Visual Comfort	Visual comfort is usually defined through parameters based on the light level in a room, the balance of contrasts, the colour' temperature' and the absence or presence of glare.	[74]
Light comfort	Light comfort is defined as perception through the sense of sight, i.e., it refers predominantly to the physical, physiological and psychological aspects of light. It refers to the psychological aspects of spatial perception and perception of objects around the individual.	[74]
Acoustic comfort	Acoustic comfort is the perceived state of wellbeing and satisfaction with the acoustic conditions in an environment.	[75]
OAQ	Outdoor air quality is a measure of the impact on the atmosphere of outdoor air pollution. Outdoor air quality may be affected by car exhaust, emissions from factory smokestacks, and road dust. Pollen in the atmosphere also contributes to a reduction in outdoor air quality. A range of instruments is available for measuring outdoor air quality using sensor-based tools.	[64]
IAQ	Indoor air quality is defined by depicting concentrations of pollutants and thermal conditions that may negatively affect health, comfort, and performance.	[76]

Specifically, for climate zone, Csa, natural ventilation (S13) is the most used strategy in 50% of the schools, followed by green roofs (S7) in 25% of the case studies, and low thermal transmittance windows (S11) and windows sun protection (S12) in 20% of the schools. In contrast, the least used strategies are ventilated facade (S3) and evaporative cooling systems (S15) in only 3% of the schools. For climate zone Csb, the most used strategy is windows with low thermal transmittance (S11) in 57% of the schools, followed by improved thermal insulation (S1), window sun protection (S12) and natural ventilation (S13) in 43% of the case studies. In contrast, the least used strategies, green facade (S4), facades and roofs with high thermal inertia (S6), reflective roof (S8), and vegetation (S10), were only used in 14% of the schools. The scientific literature analysed for the climate zone Csb shows no examples of applying the other strategies in schools.

The high application rate of the natural ventilation strategy (S13) is due to its specific characteristics of daily and seasonal use and the high occupancy densities of the schools. These favourable natural ventilation characteristics are reinforced in climates like the Mediterranean, with mild temperatures throughout service. Moreover, the COVID-19 health emergency required a review of indoor ventilation conditions, especially for educational buildings. Therefore, natural ventilation is an opportunity to ensure healthy IAQ in classrooms [99]. Similarly, the high number of green roof applications in the Mediterranean effectively reduces summer energy consumption and UHI. This effect is due to reduced solar absorption and increased evapotranspiration by soil and vegetation [100].

However, the low rate of yard application (S18), only 13%, stands out. Passive vernacular strategies, such as patios, have proven to help generate specific microclimates, especially in warmer regions. Courtyards increase the porosity of cities; porosity is understood as the construction of voids. The low implementation rate of the vegetation strategy (S10) is also striking, considering the benefits of such measures. Thus, vegetation obstructs, filters and reflects radiation modifies and air movement by obstructing, filtering and guiding it. It also changes the

Table 5
The geographical distribution of the case studies analysed.

	Chile	Chipre	USA	Greece	Israel	Italy	Lebanon	Palestine	Portugal	Spain	Turkey
Climate zone	Csa/Csb	Csa	Csa	Csa	Csa	Csa	Csb	Csa	Csa/Csb	Csa/Csb	Csa/Csb
Schools	3	1	2	7	1	6	1	3	6	15	2
Sustainability parameters											
Energy efficiency	1	1	–	1	1	3	1	1	2	7	2
UHI	–	–	–	2	–	–	–	–	–	1	1
Adaptation climate change	–	1	–	–	–	1	–	–	–	1	1
Circular Economy	–	–	–	–	–	–	–	–	–	1	–
NZEB	–	–	–	–	–	4	–	–	–	3	–
LCC	–	–	–	–	–	–	–	–	3	3	–
Comfort survey	–	–	–	1	–	–	–	–	2	2	1
Participation educative community	–	–	1	–	–	–	–	–	1	2	–
Environmental ergonomics parameters											
Thermal comfort	2	1	2	4	1	5	1	2	4	9	2
Visual comfort	1	–	–	–	–	–	–	–	–	–	–
Light comfort	1	–	–	–	–	–	1	–	–	1	1
Acoustic comfort	–	–	–	–	–	–	–	–	–	–	–
OAQ	–	–	–	1	1	2	–	–	1	2	–
IAQ	1	–	–	3	1	4	–	2	4	7	1
Passive cooling strategies											
S1.	1	1	–	1	–	1	–	–	–	3	1
S2	–	–	–	–	–	1	–	–	–	–	1
S3	–	–	–	–	–	–	–	–	–	1	–
S4	–	–	–	–	–	–	–	–	3	2	–
S5	–	–	–	–	–	–	–	1	–	1	–
S6	–	–	–	–	–	–	–	–	2	2	–
S7	–	–	–	4	–	1	–	–	3	3	1
S8	–	–	–	–	–	–	–	–	2	1	–
S9	–	–	–	2	–	1	–	1	–	2	–
S10	–	–	–	2	–	–	–	–	–	1	1
S11	1	1	–	1	1	–	–	–	2	5	1
S12	–	1	1	–	–	3	1	–	2	3	1
S13	2	1	1	–	1	4	–	2	5	7	1
S14	–	–	–	–	–	2	–	1	1	1	–
S15	–	–	1	–	–	–	–	–	–	–	–
S16	–	–	–	–	–	–	–	2	–	1	–
S17	–	–	–	–	–	–	–	1	1	1	–
S18	–	–	–	2	–	–	–	1	1	2	–
S19	–	–	–	1	1	–	–	–	–	1	–
S20	–	–	1	–	–	–	–	–	–	2	–

Table 6
Environmental impact simulation tools used in case studies.

Tool	Chile	Chipre	USA	Greece	Israel	Italy	Lebanon	Palestine	Portugal	Spain	Turkey	Ref.
EDILCLIMA						■						[89]
Virtual Environment (VE)		■										[90]
Rhinoceros											■	[91]
Energy Plus	■		■	■	■				■	■	■	[86]
Design Builder							■		■	■		[87]
Autodesk Revit										■		[92]
TTRNSYS				■		■						[93]
Baseline Building (BBB			■							■		[94]
HHULC										■		[95]
CCONTAM	■											[96]
GenOpt						■						[88]
ENVI-met				■								[97]
Conto Termico 2.0						■						[98]

impact of rain, ice, snow, and water evaporation from the soil. It controls annual, seasonal, and daily temperature variations by controlling radiation, wind, and precipitation. However, the effectiveness of each vegetation depends on the shape and character of the plants and the climate. Therefore, their study in schools will be essential to reducing the UHI effect by generating micro-islands for urban cooling.

3.3.4. *Comparison of environmental ergonomics and sustainability parameters*

This section analyses each case study's sustainability and environmental ergonomics parameters. Regarding sustainability parameters, for both climate zones (Fig. 4), energy efficiency is present in 43% of the 47 case studies, followed by LCC and NZEB in 15%. In addition to their significant impact on energy efficiency requirements, passive design strategies can significantly reduce economic bills. In this respect, LCC is among the most widely used methods for assessing the economic

Table 7
Case studies and scope of environmental ergonomics and sustainability parameters.

case studies	Ref.	City	Country	Year	environmental ergonomics parameters						sustainability parameters							
					Thermal comfort	Visual comfort	Light comfort	Acoustic comfort	OAQ	IAQ	Energy-efficiency	UHI	Adaptation to climate change	Circular Economy	NZEB	LCC	comfort Survey	Participation educative community
1	[43]	Nicosia	Cyprus	2021	■						■		■					
2	[59]	Ankara	Turkey	2021	■		■				■	■	■				■	
3	[109]	Rome	Italy	2021	■				■	■					■			
4	[109]	Palermo	Italy	2021	■				■	■					■			
5	[64]	Malaga	Spain	2021						■							■	■
6	[64]	Seville	Spain	2021						■							■	■
7	[63]	Badajoz	Spain	2021	■					■						■		
8	[63]	Evora	Portugal	2021	■					■						■		
9	[63]	Porto	Portugal	2021	■					■						■		
10	[110]	Lisbon	Portugal	2021					■	■						■	■	
11	[111]	Athens	Greece	2020						■								
12	[48]	Seville	Spain	2020	■							■						
13	[112]	Barcelona	Spain	2020						■								
14	[113]	Crete	Greece	2020														
15	[114]	Ankara	Turkey	2020	■					■	■							
16	[115]	Seville	Spain	2019	■		■				■		■					
17	[116]	Solsona	Spain	2019	■						■			■	■	■		
18	[78]	Koura	Lebanon	2019	■		■				■					■		
19	[47]	Gaza	Palestine	2019	■					■								
20	[41]	Almeria	Spain	2019	■											■		
21	[46]	Sacramento	USA	2019	■					■								
22	[117]	Cassino	Italy	2019						■	■				■			
23	[118]	Egaleo	Greece	2019					■	■		■						
24	[119]	Volos	Greece	2018	■												■	
25	[120]	Athens	Greece	2018	■					■								
26	[67]	Seville	Spain	2017	■					■	■				■			
27	[121]	Barcelona	Spain	2017	■						■				■			
28	[122]	Rome	Italy	2017	■						■		■		■			
29	[123]	Covilhã	Portugal	2016	■						■							
30	[124]	Santiago	Chile	2016	■													
31	[49]	Volos	Greece	2016	■							■						
32	[125]	Rancagua	Chile	2015						■								
33	[126]	Palermo	Italy	2015	■					■	■							
34	[81]	Pireus	Greece	2015	■						■							
35	[127]	Barcelona	Spain	2014					■	■								
36	[128]	Gaza	Palestine	2014						■								
37	[45]	Xativa	Spain	2014	■						■							
38	[129]	Gaza	Palestine	2014	■						■							
39	[130]	Rome	Italy	2011	■													
40	[25]	Algarve	Portugal	2012	■						■						■	■
41	[131]	Barcelona	Spain	2012	■						■							
42	[74]	Santiago	Chile	2012	■				■		■							
43	[132]	A Coruña	Galicia	2012							■							
44	[133]	Lisbon	Portugal	2011						■								
45	[134]	San Rafael	USA	2009	■													■
46	[135]	La Coruña	Spain	2009	■				■	■	■							
47	[136]	Jerusalem	Israel	2008	■				■	■	■							

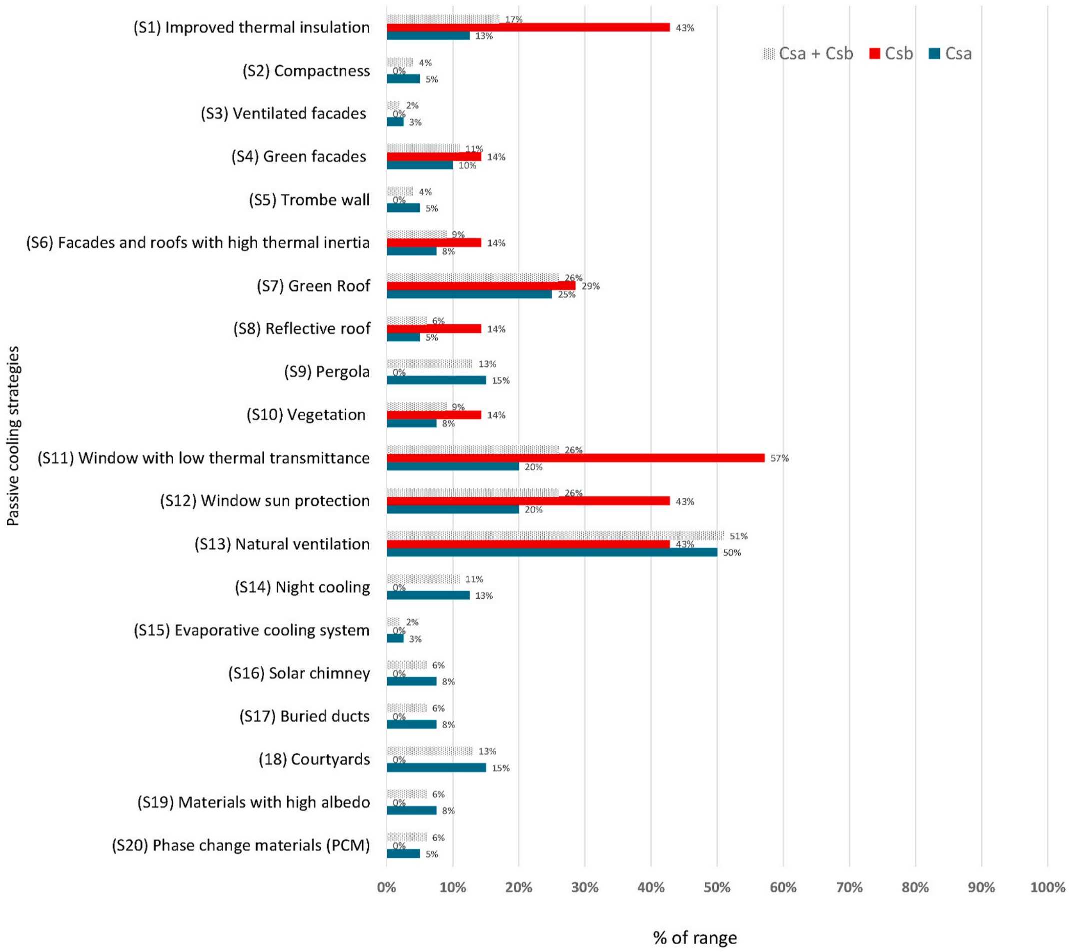


Fig. 3. Percentage of range of passive cooling strategies by Köppen climate zone.

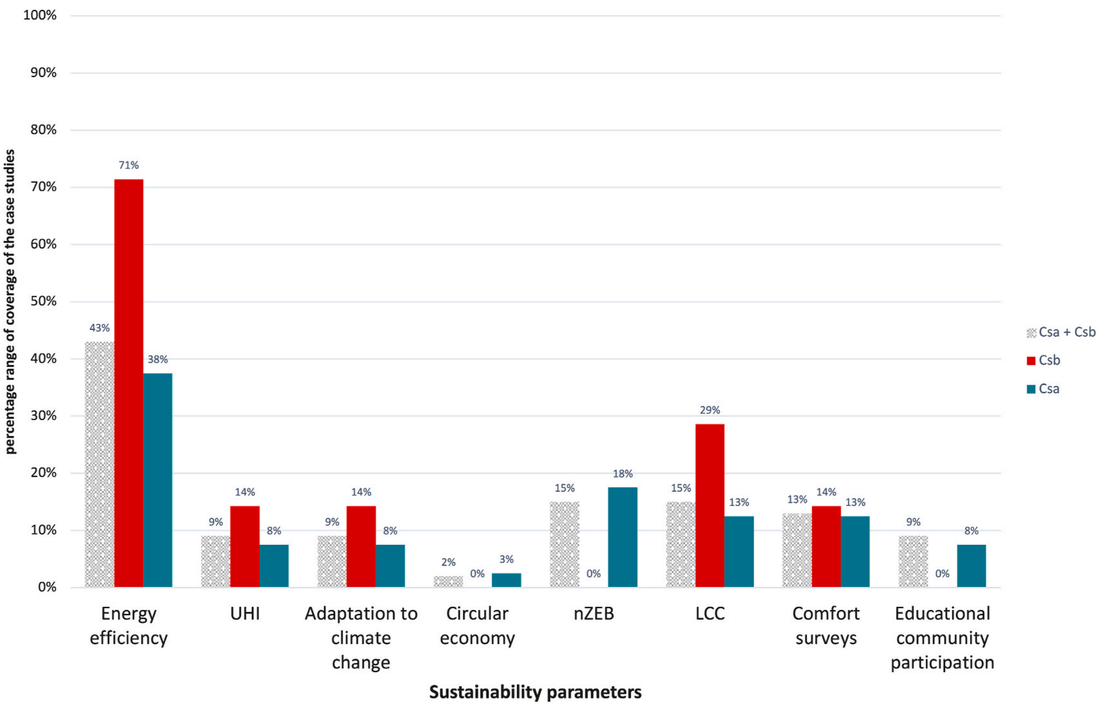


Fig. 4. Percentage of assessed sustainability parameters per case study and Köppen climate zone.

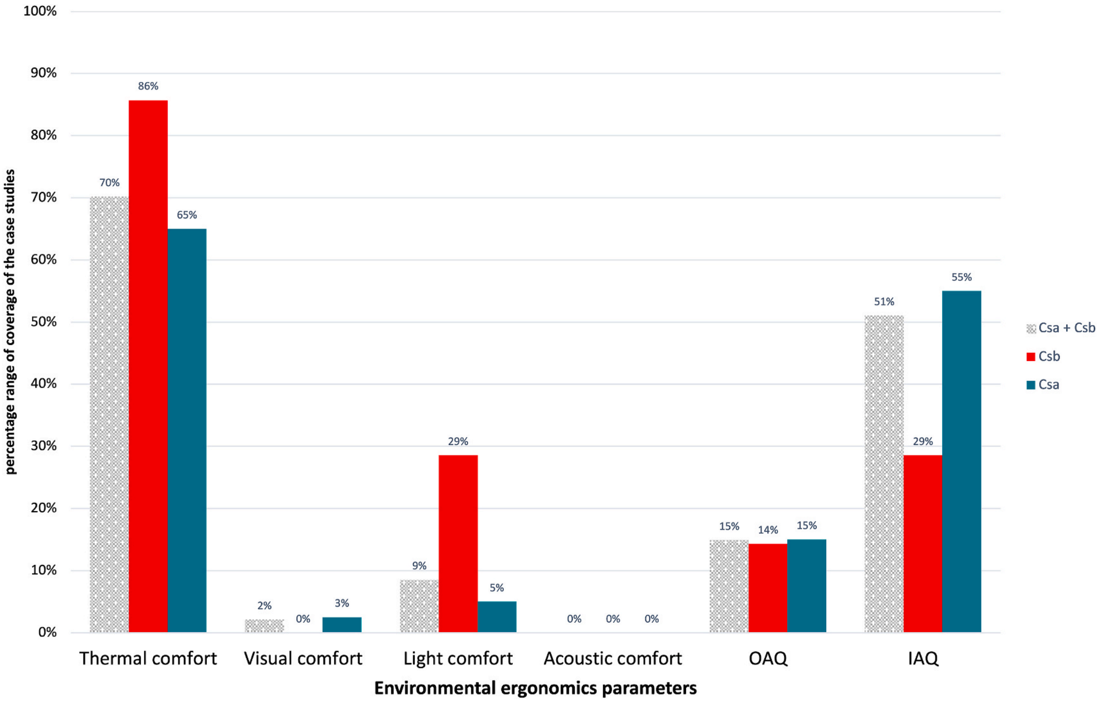
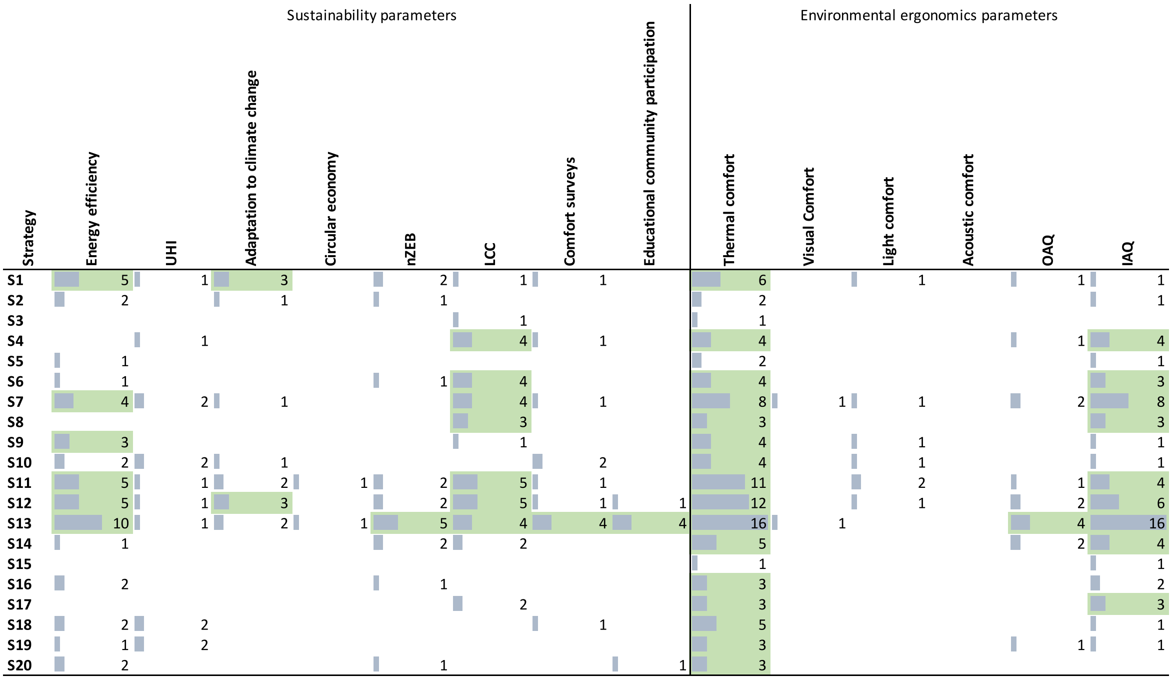


Fig. 5. Percentage of assessed environmental ergonomics parameters per case study and Köppen climate zone.



	Sustainability parameters								Environmental ergonomics parameters					
Strategy	Energy efficiency	UHI	Adaptation to climate change	Circular economy	nZEB	LCC	Comfort surveys	Educational community participation	Thermal comfort	Visual Comfort	Light comfort	Acoustic comfort	OAQ	IAQ
S1	5	1	3		2	1	1		6		1		1	1
S2	2		1		1				2					1
S3						1			1					
S4		1				4	1		4				1	4
S5	1								2					1
S6	1				1	4			4					3
S7	4	2	1			4	1		8	1	1		2	8
S8						3			3					3
S9	3					1			4		1			1
S10	2	2	1				2		4		1			1
S11	5	1	2	1	2	5	1		11		2		1	4
S12	5	1	3		2	5	1	1	12		1		2	6
S13	10	1	2	1	5	4	4	4	16	1			4	16
S14	1				2	2			5				2	4
S15									1					1
S16	2				1				3					2
S17						2			3					3
S18	2	2					1		5					1
S19	1	2							3				1	1
S20	2				1			1	3					

Fig. 6. Number of sustainability parameters and environmental ergonomics parameters associated with each passive cooling strategy.

benefits of a given design. It is worth noting that NZEBs are vital for EEUpolicy [101], and many research programmes have been conducted, such as the CoNZEBs EU H2020 programme [101]. One of its scopes was the identification of potential cost reductions in design and construction processes for an NZEB, and it seems that the proposed NZEB technologies have also started to be thoroughly implemented in school buildings [102–104].

In contrast, circular economy parameters are hardly considered in schools. It may be because the field of circular economy research applied to buildings is still developing, evolving from a concern with economic aspects to more recent developments in the assessment of sustainable deconstruction [105]. However, the advantages of using circular economy principles in buildings are widely demonstrated, with a very significant reduction of the ecological footprint of buildings throughout the whole life cycle.

It also highlights the low rate of participation of the educational community, adaptation to climate change and reduction of UHI in only 9% of schools. Administrations have been developing frameworks and models of teaching competencies in sustainability education to identify, examine, apply and evaluate these competencies [106]. These initiatives encourage the education community to design and renovate buildings using circular economy principles. Still, equally, schools need to raise awareness and organise awareness campaigns on the benefits of climate-sensitive buildings. Specifically, for climate zone, Csa, energy efficiency remains the parameter most evaluated by the authors in 38% of the buildings, followed by the NZEB in 18%, and the comfort surveys in 13% of the buildings. In the case of the Csb climate zone, energy efficiency is again the most predominant, where 71% of the schools assess it, followed by LCCin 29% of the schools, and mitigation UHI, adaptation to climate change and comfort surveys in 15%. In contrast, NZEB, circular economy and community involvement are not present in any school.

Regarding environmental ergonomics parameters, for both climate zones (Fig. 5), thermal comfort is present in 70% of the schools, followed by IAQ and OAQ in 51% and 15% of the case studies. On the other hand, acoustic comfort was not analysed in any buildings. However, the application of passive strategies must meet minimum standards of acoustic and visual comfort. Thus, in the early 1990s, Astolfi et al. [107] found low acoustic satisfaction in non-renovated secondary classrooms, where pupils were more annoyed by intermittent noise than constant noise. In contrast, speech intelligibility scores increased with reverberation times and type of noise in primary classrooms. Furthermore, visual comfort in classrooms is crucial for learning and is recognised to enhance the educational process. More than 20 years ago, Miguel et al. [108] investigated the daylighting performance of a typical education school in Cyprus and proposed solutions to improve visual comfort in classrooms.

Specifically, for the climate zone Csa, thermal comfort remains the most evaluated parameter by the authors in 65% of the buildings, followed by IAQ in 55% of the buildings. However, visual comfort is only present in one case study and lighting comfort in two. In the case of the Csb climate zone, thermal comfort is again the most predominant, with 86% of the schools assessing it, followed, unlike in the Csa zone, by lighting comfort in 29% of the schools. On the other hand, visual comfort is not considered in any cases studied.

Finally, Table 5 identifies the case studies and the scope of sustainability and environmental ergonomics parameters. Thus, the school analysed by Akkose et al. [59] in Ankara, Turkey, has the highest number of identified parameters. This work demonstrated the effectiveness of passive regeneration for UHI mitigation and climate change adaptation. The results obtained indicated that the total energy consumption could be reduced by up to 50% with passive cooling strategies the improved thermal insulation (S1), Green Roof (S7), vegetation (S10), window with low thermal transmittance (S11), Window Sun Protection (S12) natural ventilation (S13). At the same time, the optimisation of environmental ergonomics is even more pronounced.

On the other hand, Crespo et al. (Crespo Sanchez et al., 2019) designed a new school in Solsona using strategy S6 and employing a brick curtain wall as a facade, which allows the use of thermal mass to cool the building during the night and helps to guarantee the airtightness of the envelope to minimise air leakage. In the south orientations, the use of the S11 strategy, through double glazing, achieves a low energy demand optimising the overall economic cost of the building. In addition, this case study is the only one that applies circular economy parameters using a biomass boiler, which works with thermal inertia in analogy with the mass construction system, depending on the thermal demand of the building due to its use and climate.

3.3.5. Relationship between passive cooling strategies and parameters

Fig. 6 identifies the relationship between passive cooling strategies and sustainability parameters, and environmental ergonomics parameters in this section. The size of the grey bars indicates the number of schools assessing these variables, and the green colour indicates that this number is above the average.

Regarding the number of related parameters, no strategy reaches all parameters, with the natural ventilation strategy (S13) reaching the most, except for acoustic comfort. It is followed by the window sun protection (S12) strategy, which, unlike the previous strategy, is not related to visual comfort or circular economy. Similarly, the strategy windows with low thermal inertia (S11), although associated with the circular economy principles, are not related to the involvement of the educational community.

In contrast, the ventilated facade strategy (S3) is the most minor related to the parameters, only to thermal comfort and LCC. Interestingly, this passive strategy is unrelated to other parameters such as noise or energy efficiency. Theodosioua et al. [137] mention that ventilated facades have advantages over simple facades, such as reducing noise levels inside buildings and transmission between spaces and outside. Besides allowing natural ventilation in places where it usually is not possible due to high noise levels, protection against solar radiation, pollution, and adverse weather conditions; reduction of wind pressure effects; fire resistance, and structural efficiency. Similarly, the evaporative cooling system strategy (S15) is only related to thermal comfort and air quality, ignoring parameters such as UHI mitigation. Kaboré et al. [138] studied the positive relationship between passive cooling systems and indoor thermal comfort, energy consumption, and their interactions with surrounding environments, contributing to understanding urban climate and building interactions. These results offer vital outcomes and findings regarding the most used design trends in educational buildings and the implications for designers and technicians to introduce sustainable patterns and ensure the environmental ergonomics of the built environment.

4. Discussion

The results show that to achieve sustainable and efficient school buildings from the point of view of environmental ergonomics, designs capable of absorbing the peculiarities that each passive strategy entails and their relationship to each other are necessary. Thus, the effective ventilation rates required in crowded spaces to provide adequate IAQ could cause significant energy losses in school buildings. It would therefore be necessary to establish a set of design variables for schools that are energy efficient while providing IAQ levels as well as thermal and visual comfort and a set of preferred ventilation schemes that improve energy efficiency without reducing other performance levels. Therefore, the optimal design is based on the synergy of several passive strategies to balance essential parameters such as IAQ, energy efficiency, and environmental ergonomics criteria. In addition, the design of these strategies must consider the location's climate and socio-economic.

Thus, for climates with colder winters, renovation to more efficient windows, improved airtightness of the enclosure, and increased thermal insulation of the envelope reduce consumption, whereas in climates such as Csa, oversized insulation and high airtightness rates can lead to overheating. While there are optimal strategies for both zones, for example, design versatility in natural ventilation, from unilateral ventilation, cross ventilation, solar chimney or double façade, provides significant energy optimisation rates and IAQ quality. However, the exclusive use of natural ventilation is inefficient in ensuring hygrothermal comfort in a building with high thermal loads in a Mediterranean climate. However, by using a hybrid system, natural ventilation/dehumidification and cooling, the cooling energy consumption can be reduced without compromising the hygrothermal comfort of the occupants [139].

Regarding the built environment, when hot weather, intense solar radiation and UHI prevail, physiologically equivalent temperature values can be high, especially in climate change scenarios, which can induce dangerous and unsafe conditions for children [140]. Therefore, increased shade can increase physical activity and protect children from hot surfaces, thermal discomfort and ultraviolet radiation [141]. Revegetation is increasingly favoured as a practical solution through patterns and types of trees, among other landscape elements, that improve the microclimate inside and outside schools, significantly attenuate direct radiation, modify wind speed and direction, and significantly reduce temperature and humidity. In addition, this benefits the community by mitigating the UHI effect, filtering pollutants, masking noise and preventing soil erosion. It highlights the importance of the school as a critical focal point for critical issues such as environmental education and urban resilience, thanks to the gradual replacement of the ubiquitous asphalt with vegetation.

However, the maintenance of these green masses (staffing, technical infrastructure, budget, low water availability, inadequate space for root systems and soil compaction due to high impermeability) sometimes limits their use. However, an alternative for maintenance optimisation could be the sustainable management of greywater in the building, considerably reducing economic and environmental costs. In addition, many countries have begun to incorporate passive schoolyard retrofitting interventions into national shade guidelines that include the use of shade and good practices adapted to local climates [142].

While research, policy and technology must be increasingly directed towards activities aimed at mitigating and adapting to climate change. It is explained by accelerating climate change, where winters will become milder and summers warmer. Thus, the demand for heating in schools will decrease in the future, while there will be a very significant increase in the demand for cooling. It highlights the need to apply bioclimatic techniques in school buildings, building on the progress already made, identifying the most optimised measures, and encouraging the creation of guidelines to serve as a protocol to be followed in future studies. Based on strategies adopted in different climate zones, these guidelines could serve as a standardised procedure for the eco-efficient refurbishment and retrofitting of the building stock. It should be noted that the strategies identified can be extrapolated to other buildings such as dwellings.

5. Conclusions

This article identifies passive cooling strategies used and demonstrates the usefulness of these actions in the under-applied field of schools, which has been identified as a research gap until now. This work has carried out an SLR of the research field of passive cooling strategies in Mediterranean schools. Forty-three papers and 47 case studies related to schools have been identified. The analysis of the case studies has resulted in the identification of 20 passive cooling strategies, eight parameters about sustainability and six related to environmental ergonomics. The results show that, although the application of passive strategies is well developed in the academic literature, the low number of relevant documents identified for schools compared to other building typologies reveals that this field is still developing.

Regarding the implementation of the strategies in the 11 countries analysed, it is worth noting that most of the studies come from the Mediterranean region of Southern Europe and Western Asia and three case studies from Chile and two from the United States. Spain stands out as the country with the highest number of case studies.

The most used are passive cooling strategies in the Csa and Csb climate zones, natural ventilation, green roofs, low thermal transmittance windows, and solar shading. In contrast, the least used strategies are ventilated facades and evaporative cooling systems.

In terms of sustainability parameters, energy efficiency is present in most case studies, followed by LCC. In contrast, circular economy parameters are hardly considered in schools. As for the parameters related to environmental ergonomics, thermal comfort is present in most of the case studies, followed by IAQ. On the other hand, acoustic comfort was not analysed in any buildings.

Regarding the relationship between the passive cooling strategies and the environmental ergonomics and sustainability parameters assessed in the different case studies, the natural ventilation strategy is related to all parameters except acoustic comfort. The number of case studies assessing these parameters is above average. Unlike the previous one, followed by the window shading strategy, it is neither related to visual comfort nor the circular economy. On the contrary, the ventilated façade strategy is the most minor in evaluating parameters, only to thermal comfort and LCC. Similarly, evaporative cooling systems are only related to thermal comfort and IAQ.

The results highlight that those growing concerns about climate change, sustainable development, and environmental simulation tools have driven the implementation of passive cooling strategies to optimise the educational community's comfort and air quality. Besides, research has been conducted on passive versus active design's cost overruns and payback. However, the results show an absence of circular economy principles, acoustic and visual comfort optimisation parameters, climate change adaptation measures, and the educational community's involvement. The above findings provide a detailed understanding of the status quo for researchers, practitioners and policymakers and predict the dynamic directions of the field. So, it highlights the need to incorporate design protocols applied explicitly to schools to achieve an educational building stock that is sustainable, adapted to climate change and within the principles of the circular economy.

CRediT authorship contribution statement

Carmen Díaz-López: Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Antonio Serrano-Jiménez:** Writing – original draft, Visualization, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Konstantin Verichev:** Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ángela Barrios-Padura:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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