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Research Article

The Role of Passive Techniques in Modern Sustainable Architecture

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ABSTRACT

Passive systems enabled the path towards energy efficient buildings, which further sustainably met both existing and future needs to halt the rapid rise in energy consumption on a global scale. Thus, passive strategies have been the subject of this research, which aims to analyze their contemporary and historical uses in various types of architecture, where architecture then be references and example to integrate with modernity. Also, strategies as building orientation, natural ventilation, daylighting, thermal mass, and envelope were discussed. Beside challenges building passive systems, which rely on climate contexts and their ineffective application if used exclusively, were also brought into consideration. By means of analyses on case studies and context of trends emerged from passive system applications, effort was made to ensure clear understanding about the issues related to passive strategies integration have been followed by the possibility practicing passive systems integration with active ones in a dominant role when in need for energy savings and comfort. Suggestions for future research directions and communities in the field of passive systems application set around innovative materials, community driven design, encouraging passive integration systems in urban resilience frameworks.

1. INTRODUCTION

The rapid development of the modern world has led to numerous environmental issues related to escalating energy consumption. Buildings are among the largest consumers of energy and can account for up to 48% of total energy usage in some regions, prompting a growing need for energy-efficient buildings. Passive techniques have been employed for decades, if not centuries, to create energy-efficient buildings. Thus, passive techniques play a major role within the realm of modern sustainable architecture and how passive techniques affect the environmental sustainability of buildings today. Aims to discuss and educate on the role passive techniques play in the framework of sustainable architecture. To accomplish this, a refined modern definition of sustainable architecture is provided, along with a discussion on key architectural considerations. This is followed by an overview of the passive design approach for buildings, exploring its purpose, method, and relevance today. A more detailed investigation into the historical and contemporary practices of passive techniques is done, particularly focusing on buildings with passive techniques integrated in their design. The goals and outcomes of passive practices are explored, along with a discussion of the important consideration that passive methods need to be integrated into the architectural design procedure. As current climate change looms, the role of passive techniques in sustainable architecture is imperative. Architecturally, passive techniques are the most cost-effective options with the lowest environmental impact. Incorporating passive techniques may drastically reduce a building's energy needs, but only if these methods are implemented in the initial phases of design, as opposed to the usual post-design adjustments[1-3].

2. HISTORICAL BACKGROUND OF PASSIVE TECHNIQUES IN ARCHITECTURE

As Architectural design was primarily concerned with passive techniques throughout ancient, medieval, and even more recent periods. The fundamentals and bases for constructing energy-efficient buildings were well-enough known before

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the discovery of electricity and fossil fuel sources. However, later societal tendencies diverted the attention of designers away from the passive concept of building toward the active approach. The passing of time restored the building concepts that take advantage of natural systems as a mainstay and foundation concern. Whatever the period, culture, or climate, buildings mostly comprised passive techniques or architectural elements that did not rely on mechanical energy but instead made the most of their immediate surroundings and natural forces [4]. This historical progress is traced in parallel with the cultural progression of society from the primitive to the modern. The epoch of time during which building passive techniques were reasonably satisfactory approaches to architectural design is outlined. The explanation includes the design and building techniques of past civilizations and how these techniques were completely suitable for the local conditions. Notable examples of well-suited passive design from ancient civilizations are sketched. The passage from traditional architecture to contemporary practices is followed, pointing out how a passive concept that was once so naturally embedded in design became a concern only of the specialists in recent time. Finally, the fundamental principles and bases of passive techniques as originally conceived are noted. It should be emphasized that passive techniques providing a basis for naturally controlled comfort have played a crucial role in the architectural design for so long and still do even though other techniques significantly supplement these techniques in contemporary architecture. Here, naturally controlled comfort refers to comfort attained by building design without the use of mechanical energy, hence analyzed in the context of local climate conditions. This last statement signifies that the integration of local climate conditions into the disposition and form of a building is the most important factor of design. It should be noted that the intention is to discuss the application of passive techniques historically rather than to examine their efficacy concerning energy performance or comfort [5].

3. PRINCIPLES OF PASSIVE DESIGN

As the adverse impacts of climate change become more prominent, architects are becoming increasingly involved in sustainable design. In this context, sustainability refers to a holistic approach to design that considers the social, environmental, and economic impacts over the entire lifespan of a building, from inception and construction to ongoing maintenance, demolition, and beyond. While consideration of these factors is critical, it is equally important to recognize that the design of a building should, first and foremost, provide an appropriate response to its intended function. A good building is one that effectively meets the needs of its occupants and allows them to excel in their activities. The passive design principles outlined below are an effective starting point for any building type. Their careful implementation will result in a building that consumes no more energy than is absolutely necessary, for its form, orientation, and other energy-saving features have been optimized. Furthermore, these principles have been tested in various climates, so that, with small adjustments, they can be applied effectively in any location [6-7].
Figure 1 shows the design of any building involves a series of interrelated decisions, addressing aspects such as building orientation and layout, choice of construction materials, inclusion of openings, and size and position of overhangs. Decisions regarding one aspect will inevitably impact the others, and therefore, the implications of each choice must be fully considered in a holistic manner. The passive design principles presented here are the backbone of effective sustainable architecture. There are five key components of passive design: energy efficiency through building layout and orientation; natural ventilation; daylighting; thermal mass; and good quality building materials [8].

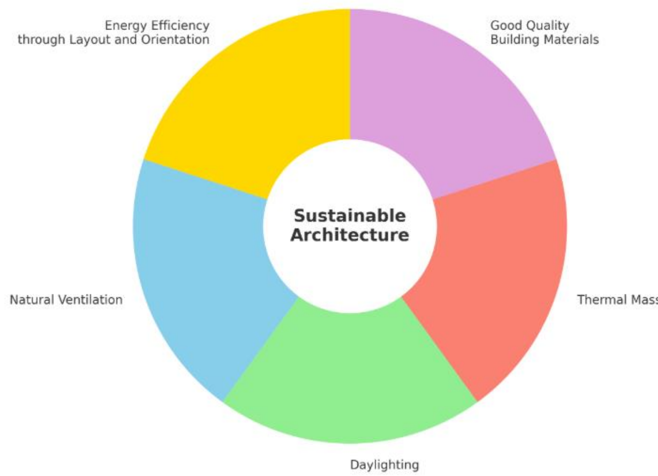

Fig.1.Sustainable design of buildings

3.1 Orientation and Layout

Orientation and layout are among the most fundamental and important passive design principles, principally because a great number of natural phenomena light, heat, wind, rain, etc. influence the building environment in one, directional way. This means that it is possible to minimize the effects of some phenomena while maximizing the effects of others by making strategic design choices. In such a collection of natural phenomena, the building or collection of buildings is always statically aligned toward a particular point in geographical space. The shape of the structures then determines which of those influences are aggregated and which are kept outside. For example, heat gain and loss due to direct sun exposure is mostly determined by the angle and orientation of the building surfaces, the placement and proportion of the openings in these surfaces, and even the shape of the building itself. Therefore, judicious care must be taken in choosing a building's alignment and layout, as this alone can significantly enhance a structure's energy performance, regardless of the applied technological measures [9].

The Earth's surface is unevenly heated, which in turn causes an uneven circulation of the atmosphere. Because of this, there is a system of prevailing winds that can be utilized for natural ventilation. On locations where natural ventilation is not sufficient, a hydronic passive cooling system can be designed that relies on evaporative cooling as an effect of high temperatures on wind speed, which is also highly dependent on the geographical location. Consequently, the buildings mainly relate to the cardinal points of the compass because that is the system in which most natural phenomena are aligned. For instance, sunlight comes from the east in the morning, reaches the south in the noon, and sets in the west in the evening. Thus, knowledge of sun-path diagrams for different geographical locations reveals at what angle and from which cardinal point the sun will shine upon the building throughout the day and the seasons. Usually, most natural phenomena are considered only in relation to cardinal points, neglecting the fact that each site has its local characteristics. In addition to these phenomena, there are a number of local geographical aspects that must be considered: the topography of the site, soil properties, vegetation, natural and artificial obstacles, neighboring buildings, and so on. All of these influence the microclimate of the site and, therefore, must also be considered when determining the building orientation and layout [10]. Zoning regulations mostly define the shape and layout of the lot. However, even when the building footprint is constrained, an effort should be made to explore all possible options for siting the building within the lot. A long structure built parallel to the edge of a lot can, for example, completely shade the outside space between it and the neighboring building, rendering it unusable. On the other hand, when it is built too close to the edge, a free space is created that is highly exposed to the sun's rays, thus promoting glare and overheating. The building's exterior spaces ought to relate to the building design in such a way as to promote the usability of the outdoors as much as possible, while at the same time preventing excessive dependence on energy-consuming systems. The overall form of a building is as important for a passive design as its alignment; a well-oriented building may function poorly if its shape is inappropriate. In general, a design effort should be made to minimize the building's surface area while at the same time maximizing its volume. Essentially, to achieve a good ratio between surface area and volume, the building shape should be kept simple, regular, and compact. As the form becomes more complex, the surface area increases disproportionately in relation to the volume, resulting in a higher energy demand. Also, protruding elements, such as canopies and balconies, become less effective in shading windows as the building form becomes more complex. In accordance with this, an effort should be made to minimize any variation in the building's basic shape or footprint. However, if the basic shape is indisputable, the footprint should be made as compact as possible; for example, the elongated form should be avoided if the depth exceeds two times its height [11].

3.2 Natural Ventilation

Natural ventilation is one of the most important passive design strategies for environmental control, which employs natural forces to maintain a desired condition for building occupants. This approach is aimed primarily at enhancing indoor air quality, while still reducing energy demand on heating and cooling systems. Natural ventilation strategies use wind and buoyancy-induced forces to move air into and out of buildings. Wind-generated forces create pressure differences on building surfaces, allowing air to flow through the building's openings. Cross-ventilation achieves airflow by placing openings on opposite façades, while single-sided ventilation relies on the pressure difference between a building's opening and its surfaces. Another strategy involves stack effect, which creates airflow by placing vents at different levels. Heated air is buoyed to rise up through the building and escape from roof-level openings, encouraging the influx of cooler air through low-level openings. The effectiveness of natural ventilation design relies heavily on the building's openings; thus, careful consideration must be applied to the placement, size, and form of openings to achieve desired air movement throughout the spaces. In conjunction with the design of the building openings, the local climate is one of the most important influences on the success of natural ventilation strategies. Despite its limitations in ill conditions, submitted to good climatic circumstances, and reasonable design efforts, natural ventilation can provide many benefits over a completely sealed building. Reducing reliance on mechanical systems, natural ventilation can lead to lower operating and capital costs, generally providing environmental and economic savings for building owners. Moreover, less dependency on energy-consuming systems results in a lower environmental impact through pollution mitigation [12]. Nevertheless, artificial elements like noise, dust, and exhaust fumes could disturb the good effects of a natural strategy. Therefore, an unconsidered natural ventilation strategy might create adverse effects rather than improve comfort. Designers seeking to implement this strategy must strive to minimize these disadvantages through careful design. On the whole, natural ventilation represents a more sustainable approach to environmental control, as long as its challenges are duly considered. A good number of case studies can provide successful precedents for this strategy in modern architecture [13].

3.3 Daylighting

Daylighting, the controlled use of natural light for illumination, is a key component of passive architecture. The amount of fully daylit space directly affects energy efficiency and occupant comfort [14]. Maximizing natural light penetration to building interiors is crucial for architects. This chapter delves into various techniques for controlling daylight, including skylights, clerestory windows, and light tubes. These methods effectively brighten spaces that windows alone cannot reach. Skylights, fit within roof slopes, capture light from above and enhance open space experiences. Clerestory windows located high near roofs transmit light far in and down. Light tubes bend and reflect light down into spaces. A well-planned daylighting design can minimize the need for artificial lighting, thus reducing energy costs. However, consideration of glare and heat gain in spaces is crucial. Therefore, daylighting design should address these concerns. An effective daylighting system should be integrated with other passive systems, like thermal mass, to create a harmonious environment . This chapter highlights significant projects to better understand daylighting techniques, presenting basic principles and successful application case studies. Daylighting is a vital and invaluable component in the quest for sustainable architecture [15].

3.4 Thermal Mass

Thermal mass is the capacity of a material to absorb, store and release heat over time, and is used to regulate indoor temperatures. Heavy materials, such as concrete and masonry, absorb heat during periods of high temperature and release it later when the environment cools down. As a result, thermal mass moderate's fluctuations in temperature and can be used to achieve a comfortable indoor climate while minimizing energy consumption. In passive designs, thermal mass is most effective when combined with good daylighting practices. For example, a concrete slab on the floor will only be effective if it is exposed to direct sun and there is also a provision to allow it to cool down. Thus, in addition to the choice of materials, the timing of solar exposure and building orientation are also crucial to the effectiveness of thermal mass. In a well-orientated building, sun moves through the sky at different angles throughout the day, being lower in the morning and at sunset and higher at noon. That means that east and west façades will only be exposed to direct sun for a couple of hours in the morning and evening, while during noon the sun will shine directly into the south façade. In those times, when sun is at its highest angle, thermal mass on the south side will absorb most of the heat and will consequently be less effective in cooling down during the night. Therefore, in hot climates, it is advised to keep thermal mass on the northern side of the building and allow it to cool down at night [16]. On the other hand, in a temperate climate with distinct summer and winter seasons, it is better to have thermal mass on the south side of the building, where it can absorb heat during sunny winter days. The sun’s rays can be directed onto thermal mass inside the building only if they pass through windows, which is why it is necessary to avoid direct sun exposure to thermal mass on the outside. So, exterior overhangs or other shading devices are used to prevent overheating in summer, while exposing the south side windows to the sun is desirable in winter. Although thermal mass can be very beneficial, it does not substitute for well thought-out ventilation, shading, and other solutions. It is important to understand that an effective application of thermal mass requires precise design since, without good design, thermal mass can easily cause more problems than it resolves and lead to overheating. Thermal mass is not enough by itself; it needs to be combined with ventilation and shading in order to reach maximum performance. To gain a broader insight into the issues related to the application of thermal mass, two case studies will be analyzed. The first one presents an unrenovated building with thermal mass applied on the south side, with an overview of problems that occurred, while the second presents a recently renovated building where thermal mass is used effectively. Both examples were selected from the recently completed Design Studio projects at the Faculty of Architecture in Belgrade, and aim to contribute to a better understanding of the topic and encourage deeper consideration of thermal mass usage [17].

4. PASSIVE TECHNIQUES IN BUILDING ENVELOPE DESIGN

The building envelope is the physical barrier between the interior environment of a building and the exterior environment. Understanding the impacts of envelope design is crucial to establishing energy performance in a building. Envelopes conserve energy by reducing heat transfer between exterior and interior environments. Depending on the seasonal design, heat may need to be either gained or lost in the building. For passive techniques targeted at the envelope, it is desired that heating or cooling loads be eliminated or minimized. In hot climates, the goal is to avoid thermal gain and keep the interior space cool, while in cold climates, it is to retain heat and maintain warmth. This section outlines a variety of passive techniques targeted at the building envelope. Various envelope elements are discussed that work toward improving insulation, keeping heat in or out, and other ways to reduce thermal loss or gain. Perhaps the most crucial part of the building and the first consideration in envelope design is the selection and application of insulation materials. Insulation materials are the cheapest and most common way to maintain thermal comfort. To ensure maximum effectiveness, it is important to consider the placement and integrity of insulation, as thermal bridges can significantly impact heat transfer. Thermal bridges, areas of reduced thermal resistance, often occur where insulation is absent, incorrectly installed, or due to conductive building elements. Thermal bridging can be avoided through envelope design, modeling, and careful detailing of construction joints. Another great concern in passive architecture is to keep the interior space cool in the summer and avoid unwanted heat gain while still allowing for beneficial daylight. Windows allow for passive solar heat gain in the winter; however, shading devices are most effective at avoiding overheating from direct exposure to sunlight in the warmer months. Shading devices can take the form of overhangs, awnings, trellises, vertical fins, and other applications, some of which can be movable or adjustable. The performance of shading devices should be expressed in terms of their transmittance factor. The interrelation of all these elements is fundamental, as it is essential for everything to work in conjunction as one cohesive approach rather than in isolation. Without properly considering the whole system, one element could negatively impact the overall performance, so it is imperative to look at each in relation to the whole building design. Finally, the need for built examples is stressed, as each strategy is often best understood with practical application [18].

4.1 Insulation Materials

In the context of passive building design, insulation materials play an essential role. Insulation's aim is to minimize all forms of heat transfer, greatly increasing energy efficiency during all seasons . With the introduction of passive solar design, the need for insulation increased dramatically. It became vital to keep the heat within the building during winter and to prevent excessive heat accumulation during summer. A well-insulated building shell has limited heat fluctuations, creating a constant inside climate. The greater the difference between inside and outside temperature, the thicker the insulation layer typically is. However, oversized insulation can lead to undesired effects, such as moisture issues. There are numerous insulation materials, both conventional and ecological, with various thermal protection characteristics. Conventional insulation materials, like fiberglass or foam, offer high protection but have negative ecological impacts and end-of-life issues. However, innovative ecological insulation materials can provide sufficient insulation levels with a minimal environmental footprint. Other characteristics, such as R-value, environmental impact, and durability, play a pivotal role in the material selection . Some designers emphasize usability and resource management, choosing materials with a natural life cycle. In contrast, others prefer technical precision and select unconventional materials that experiment with new forms and compositions. In any case, installation practices are crucial for maximizing insulation performance because oversights during installation can nullify the material's advantages. Therefore, skilled craftsmanship is essential when working with unconventional materials. New trends in the building industry observe a search for sustainable options within insulation. Advances in the use of bio-based and recycled materials replace plastics and minerals. Some of these materials have been used for centuries, only to be forgotten during the modern material boom. Today, these materials are rediscovered, often with mixed results. In contrast, new materials are developed in laboratories. Practical applications and case studies complement the research, demonstrating the significance of insulation in passive design [19].

4.2 Thermal Bridges

Thermal bridges represent localized critical points through which heat transfer takes place more easily than in the surrounding area. Their presence in a structure affects the overall thermal performance and can compromise its design’s energy efficiency. The ideal state of an envelope would be to maintain the same thermal transmittance (U-value) throughout, avoiding any sort of thermal bridging. However, in practice, thermal bridges are often found in buildings, whether intentionally or unintentionally designed. Thermal bridging can occur due to the following reasons: 1) Poor detailing of junctions between elements; 2) Change in materials with different heat transmittance values. Construction practices may also compromise a originally well-designed building envelope, such as non-conformity to building plans and details, enactment of unforeseen construction practices or the use of non-conform material. Thermal bridges can be dealt with at the design level by either avoiding or minimising them. The former is usually performed by using continuous insulation, which is insulating material covering the building envelope without any interruptions, hence, no thermal bridges are introduced. When thermal bridges cannot be avoided, the next best solution is to minimise them. This can be done by optimally detailing junctions so that thermal bridging effects are reduced as much as possible. Awareness to thermal bridging is critical to avoid problems rather than being reactive to them. Even though a good building design may consider thermal bridging effects ahead of time, poor detailing practices may render those designs ineffective. Similarly, long theoretical understanding of thermal bridges may be disregarded in practice if construction activities are done without conforming to details or if cheap solutions are favoured over effective ones. The exterior thermal envelope in most case studies is well thought out and constructed in compliance with the plans. Instead, attention has been dedicated to interior thermal bridges as they were found to have the most significant impact on the energy problems these buildings were facing. Since the 1970s, most EU countries have enforced national building codes and standards which, among other things, aim at minimising the effect of thermal bridging [20].

4.3 Shading Devices

Buildings are viewed as closed systems with defined boundaries separating indoor spaces from the external environment. Passive techniques are employed to create environments that ensure control of heat transfer and energy usage. There is a set of components that have become crucial to modern architecture. In the realm of passive architecture, shading devices are probably the most important components. Simple shading elements can greatly extend the life of a building while ensuring comfort for its inhabitants. On the other hand, complex systems, such as automated brise-soleil, require careful design and analysis to ensure they really enhance the efficiency of a system and are not merely an architectural ornament . Shading is the first step in solar gain control and, for that matter, the most widely applied. Shading solutions can generally be classified as static or dynamic. Static devices include overhangs, louvers, fins, screens, perforated walls, cloths, etc. Dynamic devices can be either controlled mechanically or automatically according to building management systems. Shutters and blinds are the most common interior shading options. The effectiveness and choice of shading devices highly depend on the building's climate, orientation, and architectural design. Given that passive shading devices are integrative architectural elements, their influence extends beyond energy savings and indoor conditions to aspects that include aesthetics, maintenance, and building envelope materials [21].

Shading is shown to be the most advantageous measure, justifying its application both in the design stage and for existing populations. Examples of appropriate shading installations are presented for need-based solutions and for building post-occupancy audits. Results show that shading measures can save as much as 90% of cooling energy. For academic institutions in warm regions, shading becomes crucial, as it is typical for larger east-west orientations, which may increase the demand for artificial lighting. It should be noted that passive remedies account not only for architectural features but also for landscaping initiatives against overexposure. Shading devices are viewed strictly as architectural elements in the realm of passive architecture. Options to use vegetation as a passive shading initiative are briefly presented [22].

5. PASSIVE TECHNIQUES IN HVAC SYSTEMS

Passive techniques in HVAC systems aim to enhance energy efficiency while ensuring occupant comfort through controlled indoor climate and air quality. These principles minimize reliance on mechanical systems for heating, cooling, or ventilation, employing building design or environmental elements to create a livable space [10]. Several architectural passive systems have been used for centuries, but as building technology advanced, there was increased focus on active systems. In recent decades, due to rising energy costs and environmental concerns, there has been renewed interest in passive systems [23].

Most passive HVAC techniques fall into two main categories: those using air as the distribution medium and those using water or other fluids. Each category can utilize various strategies, either integrated into the building or applied separately. Active systems apply energy to the indoor environment through pure mechanical or electrical means, while passive systems use natural means for control, such as temperature or phase changes. The efficiency of passive techniques increases in well-designed buildings, as energy or maintenance costs decrease. Significant attention should be given to minimize requirements for active systems through integrating and combining passive techniques. The following are some commonly used passive techniques in HVAC systems.

Radiant Heating and Cooling Radiant heating and cooling employ selective materials with good radiant properties to transfer heat effectively. Floor surfaces are heated in radiant systems, where low-temperature hot water is circulated through pipes embedded in floor slabs. The room air temperature is kept low, and the floor surface temperature is kept higher than that of the air, creating a downward heat transfer from the floor. In the case of radiant cooling, the rooms are cooled with chilled water, which can condense water vapor in the air; thus, condensation must be avoided. A similar principle can be applied on walls or ceiling surfaces, with flooring being the most common.

Earth Tubes Earth tubes, also known as earth air heat exchangers, are duct systems buried underground that use the earth's relatively constant temperature to preheat or precool fresh air for the building. Outside air is drawn into the tubes, where it is cooled or heated by conduction with the earth, depending on the outside temperature. With earth tubes, ventilation air is conveyed through underground tubes before it enters the building, which is a relatively inexpensive and effective method for passive cooling system design. The ideal earth tube length is determined by the required mean coil temperature. Integration of earth tubes with other HVAC systems such as direct evaporative cooling and hybrid ventilation reduces overall energy consumption and operational costs. It is crucial to ensure proper design and integration of the earth tube system with the building to avoid possible condensation.

Drawing from a historical perspective, a few passive HVAC techniques are discussed here. Today, passive techniques to control building HVAC systems actively are increasingly being implemented. However, most passive techniques still remain in the domain of "simple" approaches. Even so, addressing simple techniques may provide an entry point for more complex applications or address situations where complexity is unwarranted or beyond the building owner's capability. Simple passive techniques available for use in newer buildings or to retrofit existing buildings include assessing how a building is sited and designed, focused on building envelope strategies and systems that use outside air to meet temperature needs within the building [24].

5.1 Radiant Cooling and Heating

Radiant cooling and heating systems are passive techniques based on thermal radiation. Indoor comfort is maintained with a combination of energy gain/loss by convection, conduction, and thermal radiation processes. Changes in this energy balance modify the mass, airflow, and temperature of the indoor environment, creating an operative temperature. During summer, solar inflooding and internal heat gains from people and appliances increase the energy balance, requiring energy losses to maintain comfort. Evaporation, ventilation, and radiation are the three ways to fulfill these losses. Ventilation systems cool air, but radiative systems transfer energy balance through surfaces, either absorbing or emitting thermal radiation, converging temperatures near improvement. A conductive transfer medium brings hollo pipes to a chiller, inducing energy losses to water flow. Otherwise, surfaces warm up surrounding air, inducing natural convection movement to warm up spaces [25]. The passive or active character of radiant systems depends on the design. Either way, these principles are combinational design solutions by material characteristics and forms to achieve desired temperature regulation. Generally, four approaches in thermal control combinations of reliance on design and materials choose desired temperature adjustment results. Quantification results from simple to complex models approach each theory application. Avoiding any heat transfer is passive control, usually an unwanted effect. The other approaches are on the physic nature of materials explanations. The plan to apply models and examples limits results to built structures, considering computational experiments and laboratory prototypes. Radiant systems are widely applied in modern architecture. Since its revival, in the mid-20th century, it's been popularly implemented and researched in designs of individual houses to public buildings, exhibiting huge versatility to be suitable for various building types. Combining the principles prevents cold draughts and overheating zones. Usually, forced air systems bring comfort with energy expenditure and maintenance costs. Radiant systems significantly reduce these energies demands. Four different system categories operation modes aggregate applied techniques principles under similar aggregate characters. The task is to keep temperature differences below comfort criteria. The advantage of a radiant system is better comfort and air quality because draughts are avoided by minimizing airflow movement, and radiant systems are often designed for cooling to sun exposed surfaces. Construction costs rise at the beginning, but implementation rarely entails new expenditures, just calculated needs for other techniques. Considering awareness, building designers often rely on replicated successful examples, preventing innovation. Simplicity in design necessitates more complicated control systems, and improper use often requires complex design and installation alternatives. Roof-over, open form, passive design houses in alpine conditions, for instance, required careful solar-fitted shaping operative temperature zones enacted by free convection and materials thermal storage properties. They can cool afternoon sun-heated spaces only with opening cycles during the night. Free cooling principles are applied to temper air before it enters the interior, selecting draught-sensitive systems to flow fast through insulated ducts buried in the cold soil or taking advantage of a natural thermal gradient stack effect. Each designed system controls one space with air temperature, often disregarding other temperature-adjusted control possibilities, but cumulative experience ratified time-tested results and general outlines. Applied in public and exhibition halls, libraries, even entirety institutional auditoriums, usually forced ventilation with energy expenditure simplicity is avoided, taking advantage of size imposing great thermal inertia and depth stratification. Carefully designed combined systems can cool sun-exposed high ceilings with great water conduction pipes in parabolic surfaces, combining radiant cooling and free convection draughts, adjusting stratification with many small jets at lower floors. Spaces require periodic adjustments to maintain comfort due to heating change rates, involving complex control systems adjusting many devices. Flat plate collectors can bring thermal energy for heating or other needs. Indirect experiences with temporally fixed draught-free cooling showed time-consuming gradual interior water temperature adjustment to outside being often lower and long uncertain adjustment to interior temperature gradients demise comfort throughout, and at worst outside was heated above desired limits. Detailed models describe heat exchanges in simple elements, but complexity rises with many coupled equations needing heavy computations, high efforts often disregarding free technologies propagating simple conduction and strength net approximation models [26].

5.2 Earth Tubes

As climate change continues to challenge human civilization, architecture and the built environment have a critical role to play in climate change mitigation and adaptation. Building design can significantly reduce energy demand while improving human adaptation to the changing climate. This paper focuses on passive strategies that naturally regulate building microclimates using local natural resources, particularly in the context of the contemporary urban environment. Passive techniques are building strategies that utilize natural elements to maintain comfort without or with minimal reliance on active mechanical means [27].

Earth tubes are a passive technique that involves buried pipes or ducts that bring air into or out of the building using natural ventilation induced by wind pressure or buoyancy force. Recently, there has been renewed interest in earth tube systems as a method of natural ventilation and climate regulation. Basically, an earth tube system consists of a buried pipe or duct that preconditions the incoming air by taking advantage of the ground's stable temperature. Research indicates that earthen tubes help to significantly reduce energy consumption in buildings and improve indoor air quality, thereby creating a healthier indoor environment [28].

To ensure the proper effectiveness of earth tube systems, the design and installation requirements must necessarily be considered. This includes factors such as the considerations of climate, site, soil, and system orientation. In addition to the design needs, the benefits and challenges of putting these earth tube systems into practice are also explored. Though earth tubes could potentially cause many moisture control-related problems, which often lead to mold growth, system failures, and unpleasant smells, practical examples demonstrate that if properly designed, earth tubes can be elegantly and robustly integrated into buildings. Three different case studies assess how earth tube systems provide important passive strategies. The first two case studies represent successful applications of earth tube systems in Europe, while the last case examines an earth tube strategy applied to a student design project in Bangladesh. In addition, the integration of earth tube systems with other passive strategies further enhances the overall building performance. Overall, earth tubes represent a straightforward and practical solution in the context of sustainable architecture.

6. PASSIVE TECHNIQUES IN WATER CONSERVATION

Sustainable water management in buildings requires a holistic approach, focusing not only on mechanical solutions but also on passive techniques that minimize water usage while optimizing efficiency. While most modern buildings in Ireland emphasize energy efficiency, this often overlooks the importance of innovative passive water conservation strategies. Water is a resource that is often taken for granted, despite the fact that freshwater accounts for only 2.5% of the planet's total water supply. Of this small volume, around 70% is consumed by agriculture, while buildings account for more than 20% of global freshwater use. Therefore, the adoption of passive techniques in water demand management is crucial [29].

Passive water conservation techniques are primarily characterized by their low-tech and low-maintenance nature. These practices traditionally rely on local climate, materials, and culture, resulting in built environments that are well adapted to their surroundings. Rainwater harvesting, for example, is a passive method of water conservation that involves the collection and utilization of natural precipitation. While often regarded as a high-tech solution, this practice can be implemented in a low-tech manner by using simple collection systems and storage tanks. Rainwater is most commonly used for non-potable purposes such as toilet flushing, laundry, and irrigation. In addition to reducing demand on municipal water systems by up to 80%, this technique minimizes the environmental impact of buildings. Greywater is defined as wastewater from sinks, showers, laundry, and other sources that do not contain human waste. While building codes in Ireland have yet to recognize greywater recycling as a viable option for new constructions, it is an important passive technique in water conservation. Reusing greywater for irrigation, toilet flushing, or other non-potable purposes is a low-tech solution that can be implemented without complicated proprietary systems. Typically, highly water-consuming fixtures such as showers result in significant volumes of greywater that can be treated with simple filtration systems. Similar to rainwater harvesting, this strategy is most effective when implemented at the building or community scale [30].

6.1 Rainwater Harvesting

Rainwater harvesting is a key passive water conservation technique, concerned with the collection and use of rainfall. This practice has traditionally been common in rural areas, but its systematic use has been neglected in modern architecture. Private and community rainwater harvesting systems began to be implemented again from the 1990s in response to dwindling water supplies, new environmental policies, and rising environmental awareness. For successful designs, an understanding of site context, hydrology, and the key components of the systems is crucial. A summary is provided of both the issues that need to be considered and examples of successful implementation of rainwater harvesting in design.

A rainwater harvesting system essentially consists of three components: collection, storage, and distribution. Collected rainwater can be used directly on site or be connected to a larger system that treats and distributes it. Harvested rainwater is generally used for irrigation and other non-potable applications since direct household use requires thorough filtration treatment. Although treatment kills harmful bacteria, it alters the water's essential characteristics, adding chemicals that may burden both the environment and health. On the other hand, untreated runoff can flood urban surfaces and harm local watercourses. Vegetated surfaces treated with the right plants and materials can retain and naturally filter water, maximizing its use while reducing runoff [31].

The most obvious advantage of using harvested rainwater on site is a reduction in the need for mains supply water, lowering costs and preparing for water shortages. Also, an independent supply for irrigation reduces the chance of overheating and drought damage in green areas during summer. In addition, when used in toilets, it reduces the need for energy-consuming treatment of drinking water. On an environmental level, it reduces runoff from paved surfaces, minimizing silt and pollutant transport to drains and local water sources. Finally, it protects local water sources from over-extraction by considering the groundwater level and the controlling water basin when distributing underground. Excess water can be directed to a natural watercourse by sensitive filtering treatment.

Although a rainwater harvesting system can be as simple as a barrel under a drainpipe, the basic principles require consideration of several issues and general problems. For instance, collected water needs to be filtered before storage to prevent sediment accumulation, since it becomes a nutrient-rich habitat for bacteria. Fine mesh grates can block leaves and soiled particles but need to be regularly checked to avoid overflow. Another problem is maintenance access to the system components, mostly the underground parts, where unchecked sediment accumulation can stop the entire system's function. Local laws and regulations should also be considered, and some restrictions might apply.

The success of any passive technique, such as rainwater harvesting, largely depends on site selection. In planning, the area and orientation of surfaces used to collect water should be considered first, as well as the surrounding structures affecting water flow direction. Also, how exactly and for which surfaces the system will be designed impacts the building design. For instance, runoff from a roof structure is the best control possible since the most effective filtering happens when water flows over natural surfaces. If not integrated from the beginning, open-air systems are often paved surfaces that tend to accumulate sediment and are prone to flooding. Finally, the most efficient systems are those fully integrated into the design from the start, not added as an afterthought.

A system should be as simple as possible, removing any unnecessary components. For instance, complex underground systems might require extensive maintenance and could be more problematic than open-air solutions. However, if underground systems are used, maintenance access should be considered in the design. Finally, it's important to remember that natural systems take time to establish. For example, when a system relies on vegetation, appropriate plants should be carefully selected, and adaptability to changing conditions needs to be considered.

Two contrasting examples of successful water conservation systems are presented. The first is a nearly completely passive system integrated into the landscape of a public day-care center in Lund, Sweden, using only natural filtering and flow control. The second is a more complicated underground system using several treatment stages to thoroughly filter the water before it is distributed underground in a large private house in Vienna, Austria. While successful, the second system might require more consistent maintenance. The goal of these case studies is to show implementation diversity and consider several factors [32].

6.2 Greywater Recycling

Part of passive water conservation in the modern world and buildings is greywater recycling. Greywater is defined as the wastewater generated from all of the general non-toilet functions in a building. This includes activities such as bathing, washing, or cleaning in sinks, dishes, or laundry. Greywater is often mischaracterized as “soapy” water, but this is inaccurate as a simple definition. Greywater is most commonly defined as any wastewater not classified as blackwater (wastewater containing human excrement). Blackwater is considered to be a more hazardous pollutant, as it contains pathogenic bacteria and viruses. Because of this, states and local governments impose strict regulations on the treatment and disposal of blackwater in buildings. Greywater, although still a pollutant, is classified as a much less hazardous pollutant and can be treated and filtered for reuse at a single building site with fewer regulations. Furthermore, not all fixtures in a building contribute to greywater; some fixtures should never be plumbed to the greywater system. These fixtures include any drains that pass water directly or indirectly from toilets, bidets, or urinals. These fixtures, along with kitchen sinks, should be plumbed to the blackwater system in order to prevent contamination of the greywater supply.

There are five general processes in a greywater system; collection, treatment, filtration, storage. Collection refers to the plumbing of specified fixtures in a building to a separate greywater system. Collection generally consists of a simple network of drains and pipes plumbed from specified fixtures to a greywater holding tank or reservoir. Treatment and filtration refer to the processes where greywater is cleaned, having pollutants removed to ensure the water quality is safe for reuse. Treatment processes involve methods to remove contaminants (pollutants) that biodegrade or cannot be filtered out. For example, enzymes and nutrients are contaminants that cannot be filtered out and must be treated. There are many different options for treatment including chemical, physical, or biological methods. Filtration processes remove contaminates that can be seen and measured, such as hair, food solids, and soaps. These contaminants are usually undesirable to the treatment processes, so filtering is generally done prior to treatment. Storage refers to holding treated greywater prior to reuse. Once treated, greywater can generally be reused for any function that greywater is normally generated from. Fixed non-potable reuse systems used in buildings commonly reuse greywater for toilet flushing and irrigation. While there is currently a shortage of long-term studies on the biological impacts of greywater reuse on plants and soils, there are many potential benefits to the environment. Recycling greywater and reusing it for irrigation limits the needs for potable freshwater, drastically lowering the overall building water footprint. Furthermore, greywater recycling systems can greatly diminish potential effects on local waterways from building effluent. There are also many potential benefits to urban runoff quality, quantity, and timing. Runoff from rainfall events is directly correlated to the amount of impervious surfaces in an area. In urban settings, where greywater recycling is absent, most impervious surfaces are maintained with potable water, creating an artificial signal of runoff. Without greywater recycling, there is a tendency for runoff events from impervious surfaces to coincide with large amounts of rainfall, further degrading urban water quality [33].

7. CASE STUDIES OF BUILDINGS WITH SUCCESSFUL PASSIVE DESIGN

This collection of case studies presents a selection of buildings that have successfully integrated various passive design principles. Some projects utilize only a few basic techniques while still achieving impressive results. Others display more complex design and construction aspects that contribute to their sustainability. Though each case study is unique regarding building type and context, the principles applied can be universally adapted. Detailed analyses of each building include environmental performance data, occupant comfort reports, and energy use comparisons to similar, non-passively designed buildings. The aim is not to provide a definitive list of "successful" passive buildings but to present a range of approaches for consideration in future designs [1].

The buildings are grouped by type: a screening facility for the U.S. Forest Service, a school in Spain, interlocking apartments in Vienna, and a community house in Denmark. The screening facility is a low-tech building whose success relies on proper orientation and the clever use of natural materials. The school is a simple structure utilizing a passive solar envelope design to reduce heating needs. The apartments utilize a more complex design solution, employing a double facade to control temperature and energy use variations while enhancing acoustical comfort. The community house combines basic techniques in a design that emphasizes space and light. Each case study closes with a summary of important lessons learned through the design process. Finally, a few words on what these successful applications might mean for the future of community and sustainability awareness are offered [34].

8. CHALLENGES AND LIMITATIONS OF PASSIVE TECHNIQUES

Four precise concerns regarding passive strategies are outlined: 1) difficulties to implementation, 2) performance depends on climate context, 3) limitations of individual techniques, and 4) outside influence options. To think about simple strategies is to avoid over reliance on them. Avoidance of passive strategy efficiency can be avoided by climate adaptation. Together with strategies, country's culture and climate freely influence building. A rationale is behind the system choice in extreme climates. Different choice paradigms exist, affinity towards passive building usually to temperate climates. To the implementation of passive strategies four key concerns are outlined: to adoption difficulties, performance dependency of climate context, limitations of individual techniques, to outside influence options and regulations .

Passive techniques include a wide variety of systems, from very simple to very complex. Underlining simplicity, such as the natural ventilation might seem simple, yet its successful implementation demands an architect highly informed on design specifics, building effect on flows, local climate conditions, effect of urban context and local winds. Even a small mistake in one parameter could lead to dramatic effect on building performance. So, an initial concern is that passive strategies are difficult to implement properly. Compared to active systems, performance of passive strategies is too much contingent on climate context. For example, while passive strategies have been very successful in temperate regions, they have been failed or even detrimental in some hot climates. Most notable example in the mid 80's in Egypt, where many schools were built with heavily passive designs resulting in high complaints against overheating. The approach failure was too simplistic; it was assumed that one fixed design model would work across country's large climatic gradient. Performance of passive strategies is always too much context dependent. Thus, when looking at strategies outside originally intended context (in this case temperate) caution must be taken [35].

9. INTEGRATION OF PASSIVE AND ACTIVE TECHNIQUES IN SUSTAINABLE ARCHITECTURE

The principles of passive techniques play an increasingly important role for modern architectural and building design, particularly in temperate and extreme climates. It is clear that the goals of "sustainable" architecture and those of so-called "passive" architecture overlap to a considerable extent. Provided that they are correctly designed and utilized, passive methods for heating and cooling buildings are found to be the most energy-efficient. Unfortunately, passive methods usually do not work on their own sufficiently well without some help from active techniques. Passive methods can, however, over-accommodate the need for energy efficiency since they allow for a great diversity of design options ranging from total reliance on outside conditions to total reliance on mechanical systems. Nonetheless, the passive approach is a requirement for sustainability, while an exclusive reliance on passive mechanisms is impractical in a contemporary urban setting [19].

In the view of the author, the role of passive techniques within the wider context of active and hybrid solutions is examined along with some case studies. Generally speaking, passive techniques greatly contribute towards achieving sustainable architecture goals, although they rarely suffice on their own. Passive methods tend to work best in combination with active systems – that is, mechanical and control techniques applied when outside conditions do not satisfy the devised passive strategy. Moreover, this methodology also allows for elegance in design since it limits the ranges for purely passive systems, which can thus be more easily tailored for specific climatic conditions. Of course, one passive strategy could easily suffice or even over-accommodate the need for mechanical systems with which to control the built environment. There are great difficulties, however, in designing purely passive systems, which as a consequence may unintentionally gear themselves for other than the intended climatic conditions. In contrast to this integrative methodology, the use of purely passive systems requires a thorough understanding of all the architectural ramifications of energy transfer and fluid flow between a building and its environment. There is thus a great temptation to over-engineer such systems and attempt to accommodate a wider range of external conditions than they will realistically cope with [36].

10. FUTURE TRENDS IN PASSIVE TECHNIQUES AND SUSTAINABLE ARCHITECTURE

As the understanding of the importance of passive techniques continues to evolve, new practices and innovations are emerging that will enhance their effectiveness within architecture and the built environment. Here are some examples of future trends that will shape passive techniques and their role in sustainable architecture in the years ahead. One innovation in passive strategy practices is the development of new building materials. This may involve materials that are still undergoing refinement and have yet to be introduced to the building market, such as phase-change materials that melt or freeze at a specific temperature to keep buildings within an optimal thermal range. Other examples could include materials that are available but have yet to be widely adopted, such as electrochromic glazing that goes from transparent to opaque based on an electric charge, or phototropic materials that alter their performance based on the presence of sunlight [20]. Some materials, like smart insulation systems that change insulation performance based on climate and occupancy, are already being actively promoted productively for buildings. Considering the passive strategies' inherent avoid reliance on energy input for operation, there has been no ambition to automate them. Still, advances in technology, especially in monitoring and building management systems, offer the potential for passive strategies to be more holistic and therefore more effective. Past approaches have considered passive building systems separately from active, technology-driven systems. Future design approaches could complement this, where data from active systems could continually improve the performance of passive systems [34]. As climate change increasingly stresses built environments globally, the growing focus on resilience within architecture and the built environment sectors will shape how passive techniques are used. Traditionally, sustainable designs seek to enhance performance in local climates; however, extreme weather events are becoming more frequent than atypical conditions in the built environment. This need for adaptability in passive designs means consideration of how built entities may need to change over time rather than just addressing today's climate. While past passive strategy approaches have focused on the building and its systems, there is a need to consider resilience at a community scale that passive strategies can address. This could involve designs that adapt based on changing community needs or leverage local resources, requiring a holistic approach. Currently, most passive strategies are community or context-agnostic, focusing on a single structure. Future strategies could address community-scale passive interventions that incorporate local resources. Finally, a move towards more community-driven designs could shape how resources are employed within passive techniques and strategies. Many current passive strategies adopt a more exclusive approach, where the designer decides how to best employ resources. This could convey the notion that certain resources should be used, such as how exposure to sunlight is considered, with more localised possibilities ignored. Future approaches may look to empower communities to determine how to best use locally available resources in designs. This could consider not just natural resources but also socio-cultural ones, creating designs that reflect vernacular practices often overlooked in contemporary architecture. While passive techniques have played a significant role in sustainable architecture, more research and development will be needed to explore new practices and innovations in using these techniques. Continuing discourse across academia and the architecture and built environment sectors is crucial to foster innovation within passive techniques. Encouraging researchers to seek new practices and architects and designers to explore strategies and techniques currently available for use in architecture and the built environment will be vital. These examples of emerging trends are a starting point in exploring how these trends may shape passive techniques and strategies and the role they play in sustainable architecture. With these curiosity-driven explorations, passive techniques generally approach a more antecedent and essential role within architecture, seen as emerging possibilities that will develop new practices rather than merely adaptations of existing ones [35].

11. CONCLUSION

In conclusion, passive techniques are a set of strategies used in building design to enhance energy efficiency and occupant comfort without relying on active energy input. These techniques are particularly relevant in the context of climate change and the need for more resilient architecture. Passive strategies have been used for centuries, with historical examples such as Roman amphitheaters and the use of thermal mass in traditional Middle Eastern architecture. However, the advent of mechanical systems in the 20th century led to a decline in passive methods. Recently, there has been a revival of interest in passive techniques due to the increased demand for sustainability in the built environment. The fundamental principles of passive design can be applied to most climates, with variations in technique based on contextual factors. During the conceptual phase of a project, it is essential to account for climate conditions and local context to strike the right balance between passive and active methods. While passive techniques can function independently, their integration with active systems is crucial for achieving optimal results. The future of sustainable architecture lies in a holistic combination of both approaches, ensuring that buildings are efficient and comfortable for their inhabitants. As with any architectural technique, passive design strategies face challenges in implementation. These techniques often require deeper awareness and understanding from architects, builders, and clients. In some cases, passive strategies can be hindered by economic or political agendas. For passive design to thrive, education at all levels needs to emphasize the qualities and effectiveness of passive techniques. Implementing passive architecture takes time, research, and perseverance, as convincing clients to embrace methods they may not understand can be challenging. However, it is essential for architects to guide clients toward better design choices. Ultimately, passive architecture should become an unquestioned starting point for all new designs rather than an afterthought. It is crucial to avoid repeating the mistakes of past decades by neglecting the most effective sustainable design practices.

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