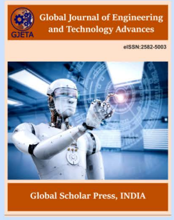
Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/



(RESEARCH ARTICLE)

Check for updates

Energy efficient building design with solar passive heating and ventilation systems

Anand Kishorbhai Patel *

Department of Mechanical Engineering, LDRP-ITR, Gandhinagar, Gujarat, India– 382016.

Global Journal of Engineering and Technology Advances, 2024, 20(02), 012–025

Publication history: Received on 24 June 2024; revised on 02 August 2024; accepted on 05 August 2024

Article DOI: https://doi.org/10.30574/gjeta.2024.20.2.0144

Abstract

This paper aims at evaluating the usability of solar passive heating and ventilation systems to promote energy efficiency and comfort in buildings. The solar passive concepts such as direct, indirect or isolated gain really minimize the usage of mechanical systems of heating and cooling. To achieve these objectives, the current study used a critical thematic analysis of research questions and evidential case studies to examine design strategies, technological developments, implementation issues, and outcomes.

To achieve this, a secondary qualitative research approach was utilized whereby data was gathered from literature, cases and technical reports. Specifically, direct gain methods, Trombe walls, and sunspaces showed promising results, capturing heat in great amounts and using less energy. Additional modern features like high-performance glazing, advanced thermal mass materials, and improved insulation techniques also contribute positively to these systems. Nevertheless, fine-tuning of design and the adaptation of each built structure from the climate context often poses some problems that are linked to the initial costs of construction and development of complex design ideas.

Indeed, the findings of this study have significant ramifications for future building designs. The use of solar passive elements, advanced materials, and mechanical systems is recommended in construction and design, consistent with climate conditions in the specific region. These measures not only address energy conservation but also comfort and environmental impact goals with a systems-based approach. Thus, the findings of this study contribute to the existing knowledge on solar passive building designs contributing to embracing sustainable building practices leading to an energy-efficient built environment.

Keywords: Passive solar design; Insulation; Solar absorption; Ventilation; Thermal capacitance; Glazing; Renewable materials; Responsive architecture

1. Introduction

Energy conservation in construction has become the subject of discussion as the world seeks to address global warming and conserving energy. Since buildings consume a major portion of energy world over, energy conservation plays a critical role in sustainable development. Passive solar heating and ventilation seems to offer a viable and sustainable strategy for moderating internal climate of buildings to reduce dependency of conventional active systems. Solar passive design techniques get the building elements to effectively capture, store and distribute the solar energy. This involves the positioning of windows, walls, and floors to admit light and heat in the winter months and exclude the same in the summer. Some of them are thermal mass, natural ventilation and insulation all of which helps to regulate the thermal performance of the building. These elements if incorporated can help to significantly cut on the energy consumed, greenhouse emissions and improve the comfort of the occupants.

* Corresponding author: Anand Kishorbhai Patel

However, there are some research gaps that are obviously apparent in the current literature. Previous research mostly investigated the theoretical aspect of solar passive design or case-analysis with relatively less study on comprehensive performance appraisal and economic feasibility in long term. Further, the integration of multiple passive design measures and synergy effects of the overall passive design concept are not well discussed. Therefore, the objectives of this research are as follows: to fill these gaps by presenting a comprehensive study on the application of solar passive heating and ventilation in energy efficient buildings. This study will incorporate a secondary qualitative research approach to combine findings from case studies and research papers to assess the efficacy of these systems and highlight their real-life application. The evaluation entails analyzing design strategies, performance indicators as well as the consequences for sustainable buildings.

2. Literature Review

It is critical to discover the current literature during the investigation of solar passive heating and ventilation systems for energy efficient buildings [1]. This review serves a dual purpose: It gives an essential background of the current condition of technology and where its effective applications are used, and where more advancement and exploration is required [2]. Consequently, the literature review presented in this paper should identify key areas of both theoretical and practical interest, as well as important trends, including technology trends, the effectiveness of existing frameworks, and case studies. These themes not only substantiate the advancements in the field but also reveal the existing limitations and research opportunities, significantly contributing to the advancement of sustainable architectural practices by standing on the breadth of existing knowledge and theories [3].

2.1. Historical Context and Evolution of Solar Passive Designs

The concepts that help to regulate the internal temperature of the building using energy from sun are known as the solar passive design principles that originated from ancient practices but were provided with a scientific structure in the twentieth century [4]. Nature-inspired adaptations are evident in native and ancient built forms: the Anasazi house and Greek urban design where construction positioned structures in harmony with the sun to capture heat in winter but exclude it in summer [5].

Modern passive solar design based on scientific principles started during the energy crisis of the 1970s, thus representing a drastic shift from the traditional practices [6]. This period saw the publication of texts as "The Passive Solar Energy Book" by Edward Mazria, which offered a systematic way in which solar design could be accomplished through quantified data and set standards. Another important event that contributed to the advancement of research and development in this field was the establishment of the Solar Energy Research Institute (now known as NREL) in 1977 in the United States [7].

2.2. Overview of Existing Studies on Solar Passive Designs

Solar passive designs have been researched widely with a goal of enhancing the natural light and air flow to the building [8]. Research predominantly focuses on three primary methods: Solar heat gains might be direct, indirect, or via sunspaces. Research has used actual measurements, simulations, and comparative case studies on the indicated approaches.

- Direct Gain: Researches in direct gain focus on the capability of south-facing glazing to admit light that falls on masonry slab or wall to be used as a heat reservoir [9]. These materials regulate interior temperatures by releasing cold-accumulated heat, according to studies. Most studies have examined the raw thermal mass of different materials and found that certain kinds of masonry are better than water for residential applications owing to flexibility and dual usage [10].
- Indirect Gain: The most reported indirect gain approach is the Trombe wall. Studies here have explained how this wall traps heat obtained from the sun by sliding behind glass boards and then gradually diffusing it in the living spaces [11].

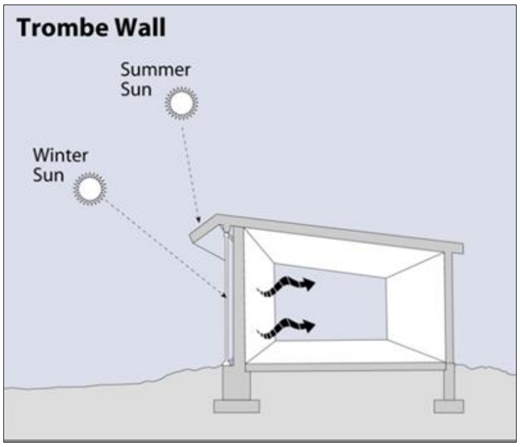


Figure 1 Trombe walls (Indirect gain) [13]

Trombe walls need thickness and thermal conductivity, and heat migrates at one inch per hour through brickwork. They store solar heat throughout the day and provide evening comfort [12].

- Isolated Gain: Sunspaces or solariums are the other area of interest as they provide separation between internal living areas and exterior conditions. Such works emphasize sunspaces' adaptability as heat sources, plant growth zones, and leisure places [13].

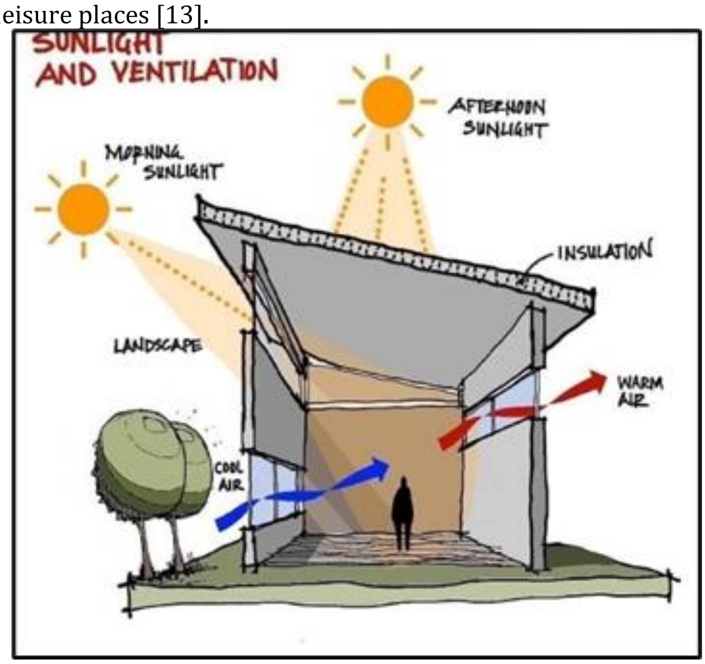


Figure 2 Sunspaces (Isolated gain) [13]

Performance is frequently measured by the ability to close areas to main building temperatures in bad weather.

Studies have also demonstrated that these technologies' success and deployment vary by region. Direct gain and Trombe walls are utilized more in cold climate zones where heating is needed, whereas isolated gain via sun spaces is employed in hot climate zones where cooling is needed in addition to passive heating [14].

2.3. Technological Advancements and Their Effectiveness

Modern trends in material and construction technologies as well as integration of systems into buildings have greatly augmented the efficiency of passive solar concepts. Landscapes for natural shading and thermal mass materials are important breakthroughs [15]. High-specific heat-coefficient concrete blocks and stone slabs have been constructed for passive solar systems. These materials are designed to store heat in the winter and utilize it at night to manage home temperature without using the heating system.

There has also been significant contribution from architectural improvements as well. Shading devices including overhangs, awnings, shutters, and trellises forms part of building aesthetics, which help minimize solar heat gain during the summer thereby reducing cooling costs [16]. Window orientation and proportions are modified to maximize heat intake in the cold season and minimize gain in the warm season. High-performance glass, which lets light in but blocks heat, has reduced cooling loads.

Integrated systems have led to the use of combined heating systems which involve passive solar heating and mechanical devices like fans or blowers to circulate the heat collected within the building. This technology promotes natural convection and provides a comfortable interior atmosphere in bad weather. Climate also affects passive solar design aspects like thermal mass location and glass [17]. These devices have high thermal capacitance for heat gains and are located for best sun exposure in colder areas. Warm-climate designs use shade and ventilation to reduce heat intrusion.

Figure 3 A vine-covered trellis shades the home and promotes air movement [18]

Studies conducted so far with respect to quantitative measures of performance have shown marked improvements in efficiency and economy. Passive solar solutions in buildings save heating and cooling expenses by adapting to the local environment. Environmental concerns are also addressed since these designs reduce fossil fuel consumption and greenhouse gas emissions [18]. Such technical advancements save energy and promote environmentally friendly building techniques.

2.4. Case Studies Showcasing Successful Implementations

Of an exemplary solar passive design is the Maths, Statistics and Computer Science (MSCS) Building at the University of Canterbury. This 11,500m^2 building was designed with passive heating, cooling and natural ventilation systems to achieve the energy targets co [19].

Figure 4 MSCS Building [20]

Integrated features work in multiple ways to provide natural ventilation and daylight and reduce material usage for better implication of design interrelation.

2.4.1. Design Approach

The building proper provides two main accommodation wings which are either side of a five-storey high atrium. The northern block is used for the accommodation of staff and postgraduate offices while the southern block hosts most of the undergraduate teaching [20]. The basement beneath the atrium has educational and service amenities. Using computer modelling for thermal performance and comfort indices, the building design was orientated north-west to south-east for optimal solar heat gains. Thermal mass, which allows solar heat gain through concrete shear walls with restricted aperture, improves building temperature management.

2.4.2. Implementation Challenges

The first major difficulty was that of adequately providing natural ventilation with confined sound levels. This was achieved through a 6. Large central 8-meter-wide atrium which enhances air flow across the building. Occupants may control the building's temperature via flexible interior windows, vents, opening windows, louvres, and shutters. The addition of a new artesian borehole for cooling was logistically difficult but made the building more energy-efficient [21].

2.4.3. Outcomes

A post occupancy evaluation in 2001 showed that students and staff had high satisfaction rates based on comfort, noise, lighting, and temperature, all of which were higher than the fifth percentile of benchmark data [22]. The natural ventilation system was lauded for adequate air quality and noise. The building's thermal bulk and orientation helped sustain indoor temperature in Canterbury's changing environment.

2.4.4. Unique Features

Some features specific to the MSCS building include the thermal massing, natural ventilation, and multifunctional design approaches integrated in the building design. Artesian borehole cooling employed with the Future Sciences Library construction is another example of resource efficiency. This case study illustrates that passive design may reduce energy use and improve occupant comfort at little cost [23].

2.5. Identification of Common Themes and Gaps in Previous Research

A review of research literature on solar passive designs brings out many similarities: natural ventilation takes the central stage, thermal mass and orientation are other important factors determining efficiency of designs. These features must match the local climate and other architectural structures. Resolving aesthetic and structural issues while providing a suitable indoor atmosphere without overusing conditioning equipment is common [24].

Large gaps still exist in the literature for empirical assessment of long-term effectiveness and lifecycle cost of these systems for different climates. There is also a research need in applying upgraded concepts to newer materials or introducing new technologies like phase change materials or sophisticated glazing. Therefore, further local or building type-specific research is needed to refine passive solar approaches [25].

2.6. Summary

From the reviewed literature, one can learn about the basic concept of solar passive designs, their possible benefits, and possible drawbacks. As a result, this review calls for the continual effort and empirical study to fill the gaps in these areas highlighted, especially the material science and climatic adaptability.

3. Methodology

This study employs a secondary qualitative research technique since the data would be collected from other sources to analyze the applicability of solar passive designs in building design. The process involves systematically reviewing passive solar energy system academic publications, cases, and technical materials [26]. This method enables for data analysis to identify patterns and gaps and draw conclusions about passive solar design's present and future status.

3.1. Criteria for Selecting Sources

The selection of sources is guided by several criteria to ensure relevance, credibility, and comprehensiveness:

- Relevance: Only sources that cover aspects of solar passive design principles, uses and impacts are considered for sourcing. Discussed here are only those materials that are strictly relevant to considerations of passive solar technology in residential or commercial constructions [27].
- Authority: Primary sources are preferred, including scientific journals, reputable journals from renowned publishers, and official documents from the government. These sources can be considered reliable for their thorough reviewing and industry accolades [28].

- Timeliness: To achieve this, the research focuses on papers published within the last decade in order to capture the most recent technologies and standards. Benchmark works are included regardless of publication year since they establish the topic.
- Geographical Diversity: To address a weakness in the present literature analysis, sources from diverse locations are utilized to assess how regional climate and building approaches affect passive solar designs.
- Methodological Diversity: Data sources which use different research methods are included so as to get a wide outlook on the issue under study. This includes quantitative studies, simulation, and comparative research studies [29].

3.2. Methods of Data Extraction and Synthesis

The approach employed in the extraction and synthesis of data in this research involves the following coordinated steps that aim at providing a coherent review of the literature on solar passive designs. First, on the selected sources, the relevant data are collected using a structured form of data extraction. The author may outline the research's aims, methodology, results, and suggestions, as well as study type, sample size, important factors, and solar passive design findings, in this manner [30].

After data extraction, a thematic analysis is then performed and the data is then coded and categorized as per recurring themes such as design strategies, effectiveness, implementation issues, technological trends etc. It's crucial to find and compare study trends and patterns to organize the field. Comparative investigation follows to determine how environmental and architectural factors affect solar passive design performance [31]. This method shows study similarities and contrasts to offer a complete understanding of solar passive design applications.

The synthesis phase then combines all extracted and analyzed data to present the current state of research with respect to solar passive designs. Not only does this synthesis describe what is currently known also what is still unknown, thus providing a clear research agenda for future work. Finally, all selected studies are quality assessed to establish their dependability in the synthesis. This examination examines each work's methodological and bias concerns to see how they affect study findings. These procedures provide a solid methodological framework that roots the study and assures its relevance to solar passive design concerns [32].

3.3. Analysis

The collected data were then reviewed and analyzed to identify key themes for defining the potential of solar passive systems in building design. These are strategies in design, technologies, and its application, and the findings regarding energy utilization and comfort level.

3.3.1. Design Strategies

The most important concepts concerning solar passive systems are direct gain, indirect gain or Trombe walls, and isolated gain or sunspaces. All depend on certain architectural features for efficiency in the harvesting and use of solar energy [33].

- Direct Gain: This strategy is used to place windows on the southern side to allow heat during winter and to exclude heat during summer. This approach is easy and inexpensive because sunlight directly penetrates the living area, strikes interior surfaces, and accumulating heat [34]. Direct gain requires appropriate window placement, high performance glazing for insulation, and adequate size to store and release heat over time. Prior studies have indicated that direct gain can reduce energy consumption substantially depending on the amount of solar radiation in houses.
- Indirect Gain (Trombe Walls): Trombe walls are an enhancement of the indirect gain construction. They are a large concrete wall that is affixed to the glass, preferably on the south side of the building. This wall harnesses solar energy and then emits it within the building, keeping interior temperatures stable by emitting daytime heat at night [35]. Trombe walls are most beneficial in areas with a large difference in the temperatures during the day. Their efficiency is calculated and depends on factors like the thickness of the wall and the material used, and the available ventilation.
- Isolated Gain (Sunspaces): Sunspaces or solariums are buffer spaces which accumulate heat from the sun and distribute it to the living spaces. Spaces should be easily isolatable from the main building using doors or windows in order to regulate the heat exchange [36]. The sunspace gathers solar heat in the course of the day but can transfer it to the rest of the structure if necessary. To reduce heat loss, the sunspace is shut during the night and on any cloudy day as well. Sunspaces offer extra living area and warmth, therefore being useful and increasing value.

3.3.2. Technological Advancements

Modern technological developments have enhanced the efficiency and effectiveness of solar passive systems. Some of the advancements made are high-performance glazing, advanced thermal mass materials, and insulation.

- High-Performance Glazing: Some of improvements include low-emissivity (low-E) coatings which have revolutionized windows through increasing its energy efficiency and solar heat gain. These coatings reflect the heat from the infrared rays back to the building while at the same time being transparent to the visible light. Other alternative such as double and triple glazing have also been commonly used as they also help to improve thermal efficiency by putting air gaps between the layers of glass.
- Advanced Thermal Mass Materials: The use of phase change materials (PCMs) in buildings has improved their thermal storage performances. PCMs possess high heat capacities to change phase (for instance, from solid to liquid) for better thermal management than concrete or stone [37]. Specifically, these materials can hold large quantities of heat and gradually release them for controlling inner temperatures [38].
- Improved Insulation Techniques: Improvement in insulation materials and methods have decreased heat transfer to a great extent thus reducing heat loss and heat gain. These are VIPs, aerogel and reflective insulation have high thermal resistance and therefore no mechanical heating and cooling is required.

Solar passive designs show that the efficiency of each plan depends on the specific use and environment. Direct gain designs are especially suitable for residential buildings with substantial sunlight exposure as they use less energy and provide comfort to the users [39]. Trombe walls are slightly more complicated but maintain steady interior temperatures in areas with extreme temperature differences. The versatility makes sunspaces give effective solutions that help in both energy conservation and living area gain. Progress in glazing and thermal mass materials are among the main factors contributing to increased efficiency of the solar passive systems. High-performance glazing and PCMs help to store and circulate heat, thus maximizing energy conservation.

3.3.3. Implementation Challenges

There are certain barriers in the use of solar passive designs despite the numerous advantages associated with them. These are the need to embrace climate in the design of structures, integration of new structures with the existing ones, and first costs in utilizing the new materials and methods of construction.

- Climate-Responsive Design: These designs have to address specific climatic conditions and should be optimized which is complex in nature. This includes the study of orientation with respect to the weather and climatic conditions, the amount of solar heat received by the structure and the change of seasons.
- Integration with Existing Structures: Integrating solar passive system in a building is a daunting task because of constraints such as space, structure and appearance [40]. The objective of the architects and builders is always to strike a balance of conserving energy while at the same time maintaining the original structure and practicality of the building.
- Initial Costs: Installation cost of solar passive system is relatively high compared to the general construction costs because it entails the use of enhanced materials and unique construction practices [41]. Nevertheless, such costs are mostly recovered by the energy consumption saving in the long run and the increased property value.
- Aesthetic Considerations: One of the challenges of providing architectural forms and construction is the integration of aesthetics and functions and applications. In contrast, contemporary architectural ensembles can easily implement solar passive elements; however, it is here that it is critical to consider that these should not detract from the appearance of the building.

3.3.4. Outcomes in Terms of Energy Efficiency and Occupant Comfort

Studies have shown that constructions realized as far as the idea of solar passive is concerned are capable of saving energy and provide better comfort to the users of the building. Fewer mechanical means of heating and cooling obviously translate to less electricity usage and associated greenhouse gas emissions. These buildings also have less internal temperature and air quality variations, making residents happier.

- Energy Savings: Solar passive designs only require minimal external inputs of energy since they depend on natural solar energy for both heating and cooling. This results in great savings on electricity expenses and plays a part in conserving the environment by reducing carbon emissions.
- Occupant Comfort: Solar passive buildings have more stable internal temperatures, which improve comfort for the persons within them. As it has been highlighted by thermal mass and effective shading devices the indoor

climate can remain comfortable all year round.
- Air Quality: Cross-ventilation systems enhanced in solar passive structures enhance indoor air flow and limit the use of mechanical systems. This leads to improvement of living standards and occupants' health.

3.4. Discussion on How Solar Passive Systems Contribute to Energy Efficiency

Solar passive systems contribute to energy efficiency through several mechanisms:

- Maximizing Solar Heat Gain: This is achieved by being smart in the placement of windows and using materials that are capable of trapping heat during the day and releasing them at night [42]. This decreases reliance on traditional heating systems, particularly in regions with harsh winter conditions.
- Natural Ventilation: Most of the solar passive designs have natural ventilation that helps in the circulation of air in the building. This decreases the reliance on mechanical cooling devices during the warmer seasons of the year. Integral parts such as windows, vents, and atria facilitate natural convection of heat and control of indoor air quality.
- Thermal Mass: These include materials such as concrete, brick and stone which have the tendency of storing heat in the building structure. By day, they absorb heat from sunlight, while during the night, they gradually release the heat to maintain a stable indoor temperature without the need for additional heating.
- Shading Devices: Overhangs, trellises, and awnings which are well positioned, for instance on the south side, effectively exclude direct summer sun thus minimizing the need for cooling. These devices play an important role of maintaining cool temperature inside the buildings during summer while at the same time being capable of providing warm temperature during winter.
- Insulation: Ventilation techniques work in conjunction with solar passive designs by reducing heat loss in winters and heat addition in summers. Proper insulation also helps in preventing heat that has been retained by thermal mass or generated from solar heat collectors from being dissipated.

3.5. Comparative Analysis of Different Design Approaches and Their Outcomes

The comparison of different design strategies identifies various strengths and weakness of each approach. Each of the three primary design strategies has its advantages and can be used in various climates and for different buildings.

3.5.1. Direct Gain

- Advantages: Direct gain designs are easy to execute and inexpensive. They allow solar heat gain through south facing windows for considerable heating advantages in winter period.
- Challenges: It can be a challenge during summer to regulate the amounts of heat by regulating the shading devices. They also face a danger of glaring and fading of the interior furnishings due to direct sunlight.
- Outcomes: Common features of direct gain designs include significant reduction in heating costs and enhanced thermal comfort in winter.

3.5.2. Indirect Gain (Trombe Walls)

- Advantages: Trombe walls give a slower discharge of heat and this go a long way in helping to regulate temperatures hence improving comfort. They are most suitable for areas with large daily temperature fluctuations.
- Challenges: There is the initial high cost of constructing Trombe walls since they call for certain materials and reinforcement structures. There is, however, need to pay attention to position and thickness to get the best out of it.
- Outcomes: According to the findings, structures that use Trombe walls have steady indoor temperatures and uniform energy conservation regardless of the season.

3.5.3. Isolated Gain (Sunspaces)

- Advantages: Additional, sunspaces have other purposes such as providing extra space and other means of heating. They can be retrofit into existing structures, or can be designed into new structures.
- Challenges: Minimizing the risk of overheating in the rooms near the sunspaces is a challenging task in design. Sunspaces can prove to be very efficient depending on the climate and the degree of utilization.
- Outcomes: Sunspaces contribute to general building effectiveness and offer various utility rooms that help occupants to be happier and more comfortable.
-

3.6. Technological Enhancements

- Advanced Glazing: This way, high-performance glazing materials enable a reduction of heat loss and gain and, therefore, enhance the general performance. These materials are most advantageous in direct gain designs where large windows are incorporated.
- Phase Change Materials (PCMs): PCMs have higher thermal storage capacity than most conventional materials because they can store and release heat effectively. The use of PCMs in thermal mass elements improves the efficiency of both direct and indirect gain systems.
- Hybrid Systems: Passive solar techniques can be integrated with other mechanical systems like the fan and blower in order to maximize energy conservation and occupant comfort. Hybrid systems are specifically suitable for areas that experience wide fluctuations in temperature.

3.7. Case Study Comparisons

The Maths, Statistics, and Computer Science (MSCS) Building at the University of Canterbury provides a good example of how architects and engineers incorporate passive solar systems such as natural ventilation and thermal mass in their designs while keeping client comfort and architectural appeal in mind. On the other hand, other case studies from other countries demonstrate that the effectiveness of passive solar designs depends on the climatic conditions and the particular characteristics of the structures. Direct gain technologies and Trombe walls are better for thermally demanding structures like those in Northern Europe. Hot climate buildings, like Mediterranean ones, emphasis on sun protection and ventilation to reduce heat gains. Such comparisons demonstrate the need to tailor passive solar techniques to the local environment for optimal

4. Results

From the thematic analysis of the data collected on solar passive designs the investigation identified several important observations as follows; It was possible to recognize the following primary themes: design strategies, technologies, implementation issues and results in terms of energy savings and occupants' comfort.

Direct gain, indirect gain (Trombe walls), and isolated gain (sunspaces) were the main strategies that characterized the solar passive systems. Direct gain which entails the positioning of south-facing windows was discovered to be the simplest and most common method. Indirect gain, Trombe walls helped maintain constant indoor temperatures since they released heat slowly after absorbing it. Used as isolated gain areas, sunspaces provided a variety of spaces for heat collection and distribution which gave both utility and beauty.

Modern technological advancements have enhanced the efficiencies of solar passive designs to a great extent. Some advancements found were in high-performance glazing, advanced thermal mass materials such as phase change materials and better ways of insulating. These technologies improve heat storage and circulation which in turn improves the efficiency of the solar passive systems. Another factor was the optimization of energy use through the incorporation of both passive solar design features and active mechanical means such as fans and blowers.

However, several barriers were mentioned time and again. It remains crucial to develop and adjust the design depending on the climatic conditions as precisely as possible to achieve the best performance. Implementing passive strategies into buildings proved to be problematic due to the problems of design integration and aesthetics versus performance. Some of the disadvantages mentioned included increased initial costs on account of using hi-tech materials and construction methods.

All the reviewed studies revealed that solar passive principles were effective in reducing energy consumption and improving occupants' comfort. Less use of mechanical systems for heating and cooling also reduced the energy demand and emissions of greenhouse gases. This showed that solar passive designs provided more than just lighting as occupants recorded higher satisfaction due to better controlled indoor temperatures and improved air quality.

4.1. Integration of Case Studies with Broader Thematic Findings

This means that the findings of the case studies when used in conjunction with the thematic analysis offer a rich and detailed picture of the application of solar passive designs and their performance.

University of Canterbury's MSCS Building: It is demonstrated here that passive solar techniques, such as natural ventilation and thermal mass, can be integrated successfully into a building and design for comfort, form, and function without compromising occupant satisfaction or energy efficiency. In regards to the elements stressed in this design, it is crucial to note that the MSCS Building employs thermal mass to maintain indoor temperatures stable and the unique natural ventilation system.

Comparative Analysis with Other Global Case Studies: Other examples of the case studies worldwide show that passive solar building designs are only effective based on regional climates and specific needs of the building. For example, structures located in regions experiencing severe winter, like Northern Europe, are likely to experience higher gains from direct gain methods and Trombe walls since they require a lot of heating. On the other hand, buildings in hot areas, such as the Mediterranean region, focus more on protecting from direct sunlight and using natural convection. These comparisons bring into the fore the importance of integrating passive solar strategies well with the local environment for efficiency.

5. Discussion

The evidence provided by the thematic analysis and case studies clearly substantiate the advantages of solar passive designs for improving energy efficiency and comfort. The design strategies such as direct gain, indirect gain or Trombe wall, and isolated gain or sunspaces were found to be highly variable in their efficiency depending on the climatic conditions and the needs of the building [43]. The direct gain designs which are quite easy and economical in terms of application helped in the effective absorption and storage of the heat collected through south facing glazing. Trombe walls, which gently store and release heat, kept rooms stable in places with considerable temperature variations. Thus, sunspaces enhanced living space, flexibility, and solar heat collection and distribution.

High-performance glazing, enhanced thermal mass materials like phase change materials and insulation experts have greatly boosted the effectiveness of solar passive systems. They enhance heat accumulation and circulation thus improving on the utilization of energy. However, these systems depend on accurate climate-responsive design, which in the case of this study would mean the ability to understand the local climate and variations in the seasons.

5.1. Implications for Design Practices

The contribution of the research to current states of design practices in architecture and construction industries is extensive. First, there is the very significant need for the incorporation of climate responsiveness in to building projects. The principles of solar passive design must be incorporated to the building by the architects and builders to correspond to the climate of the region [44]. For instance, it recommends that in regions of cold climates, direct gain methods and Trombe walls should be utilized since they have the capacity to heat. But it should be noted that warmer climates have to employ mechanisms like shading and natural airflow to avoid heat entrapment.

5.2. Recommendations for Practitioners and Policymakers

For practitioners, the following recommendations can help enhance the adoption and effectiveness of solar passive designs:

- Embrace Climate-Responsive Design: Incorporate passive solar strategies depending on the climatic conditions of the regions in which the construction will be implemented. Include climate analysis to the tactical design elements [45].
- Integrate Advanced Materials: Encourage the adoption of high-performance glazing, advanced thermal mass materials and improving insulation in buildings [46]. These materials greatly improve heat storage and transfer capabilities, making them better suited for energy management.
- Adopt a Holistic Approach: Remember that they are a part of integrated solar passive building design which involves architectural, material and mechanical considerations. This approach optimizes the global performance of the energy of the building.
- Focus on User Comfort: Internal spaces by designing products for thermal stability and enhancing indoor climate control by using natural means of ventilation.

Policymakers should consider the following measures to support the widespread adoption of solar passive designs:

- Incentivize Green Building Practices: Establish tax credits and grants for efficient passive solar designs and other energy-efficient designs for projects.
- Update Building Codes: Update the building codes to require or recommend the integration of solar passive techniques in new constructions as well as large-scale refurbishments. These elements should contain guidelines on how to incorporate materials of high-performance and climate-sensitive designs.

- Promote Education and Training: Promote awareness and facilitate coursework and skill development for architects, builders, and engineers on the concepts and application of solar passive designs [47].
- Facilitate Research and Development: Invest in research studies that identify new materials, technologies and approaches to improving the performance of solar passive systems. Promote partnerships between institutions of higher learning, industries, and government organizations [48].

5.3. Limitations of the Current Study and Areas for Further Research

Some limitations of the current study, which has offered information regarding the solar passive designs, should be noted: This limits the generalization of the findings across various contexts due to depending on the secondary qualitative data. Furthermore, the reliance on case studies of building projects located mostly in certain geographical areas reduces the range of climate and construction contexts considered in the study [49].

To overcome these limitations, future studies should go for empirical studies with more diverse geographical locations and structural types. Further research that measures the evaluation of solar passive designs many years after their implementation would give more detailed and concrete empirical evidence about their efficiency and the related cost advantages. In addition, it is possible to consider the incorporation with other modern technologies, like smart home systems and renewable energy, with the principles of solar passive buildings as an opportunity for further research [50].

6. Conclusion

6.1. Recap of the Research Objectives and Findings

This research aimed at establishing the use of solar passive designs in building architectural designs to efficiency and comfort of the occupants. The objectives of the survey were as follows: to determine specific design solutions, to analyze the state of technological developments, to determine the main problems in implementation, as well as to assess the results using the methods of thematic analysis and case descriptions. The study showed that direct gain, indirect gain or Trombe walls, and isolated gain or sunspaces are the basic concepts employed in solar passive designs. The stated solutions reduce energy usage and increase room comfort when appropriately implemented. High-performance glass, better thermal mass materials, and improved insulation boost these systems' potential. However, good solar passive architecture requires extensive climate-sensitive planning and interaction and modification of existing buildings for use, which may be costly and difficult.

6.2. Impact of the Research on Future Building Designs

The findings of this research, therefore, have extremely seminal implications for future building designs. Firstly, it stresses the need to make climate-adaptive constructions without which architects and builders should make solar passive strategies oriented to particular climate conditions for the best result. This implies that, architects and developers will more and more have to factor in sophisticated climate analysis to be able to determine where to place the windows, what material to use among other things to do with building designs. High-performance glazing and advanced thermal mass materials are likely to remain regular features in sustainable building projects because of the benefits accrued from their efficiency in energy use and comfort levels of building occupants.

Furthermore, the findings of the study emphasize the necessity of the design process, which involves architectural decisions, the choice of materials, and the mechanical systems incorporated into the building. From this integrated approach, future building designs will incorporate all these parts so that they will provide better energy solutions for the building. As those of the long term advantages of the use of solar passive designs become common knowledge the initial costs shall be perceived as costs which will be recouped by the energy savings and increase in property value. This change of mind set will foster the adaptation of sustainable construction measure by many.

6.3. Final Thoughts on the Advancement of Solar Passive Heating and Ventilation Systems

The incorporation of solar passive heating and ventilation systems should be applauded as it is a major achievement in sustainable building design. Some of these systems rely on natural energy currents for heating and cooling thus little mechanical intervention is needed. Even as new technologies are developed and refined, solar passive designs will become even more improved in terms of efficiency and versatility. They aren’t just high-performance glass, phase change materials, and advanced insulation strategies. Future developments could be the incorporation of smart home technology to control passive technologies with respect to real-time weather conditions, thus improving energy and comfort levels in buildings. The current research shows the importance of continued IFD innovation and empirical studies to address the remaining issues of solar passive design. In future work, extending the geographical coverage and including a range of buildings other than commercial and residential, could offer more comprehensive information regarding the efficiency of these systems.

References

[1] Abou-El-Sood H. Integrating QuickBooks® in financial accounting classrooms: evidence from the UAE. Accounting Education. 2024;

[2] Al-Rukaibawi LS, Szalay Z, Károlyi G. Numerical simulation of the effect of bamboo composite building envelope on summer overheating problem. Case Studies in Thermal Engineering. 2021;28.

[3] Azzam MEAY, Alsayed MSH, Alsultan A, Hassanein A. How big data features drive financial accounting and firm sustainability in the energy industry. Journal of Financial Reporting and Accounting. 2024;22(1).

[4] Song J, Huang X, Shi D, Lin WE, Fan S, Linden PF. Natural ventilation in London: Towards energy-efficient and healthy buildings. Build Environ. 2021;195.

[5] Bauer A, Möller S, Gill B, Schröder F. When energy efficiency goes out the window: How highly insulated buildings contribute to energy-intensive ventilation practices in Germany. Energy Res Soc Sci. 2021;72.

[6] Blocken B, van Druenen T, Ricci A, Kang L, van Hooff T, Qin P, et al. Ventilation and air cleaning to limit aerosol particle concentrations in a gym during the COVID-19 pandemic. Build Environ. 2021;193.

[7] Bouabdallaoui Y, Lafhaj Z, Yim P, Ducoulombier L, Bennadji B. Predictive maintenance in building facilities: A machine learning-based approach. Sensors (Switzerland). 2021;21(4).

[8] Bukalska E, Wawryszuk-Misztal A, Sosnowski T. The chief financial officer and corporate performance: Finance, governance and risk. The Chief Financial Officer and Corporate Performance: Finance, Governance and Risk. 2024.

[9] Carriço de Lima Montenegro Duarte JG, Ramos Zemero B, Dias Barreto de Souza AC, de Lima Tostes ME, Holanda Bezerra U. Building Information Modeling approach to optimize energy efficiency in educational buildings. Journal of Building Engineering. 2021;43.

[10] Cho H, Cabrera D, Sardy S, Kilchherr R, Yilmaz S, Patel MK. Evaluation of performance of energy efficient hybrid ventilation system and analysis of occupants' behavior to control windows. Build Environ. 2021;188.

[11] Ciudad Gómez A. Flipped classroom in financial accounting: analysis of student perception. Journal of Management and Business Education. 2024;7(1).

[12] Elshafei G. Bioclimatic Design Strategies Recommendations for Thermal Comfort Using Mahoney Tables in Hot Desert Bioclimatic Region. Journal of Urban Research. 2021;39(1).

[13] Energy.gov. 2024 Passive Solar Homes Available at: https://www.energy.gov/energysaver/passive-solar-homes#:~:text=Passive%20solar%20design%20takes%20advantage,or%20part%20with%20solar%20energy. [Accessed on 10 June, 2024]

[14] Franco A, Miserocchi L, Testi D. Energy intensity reduction in large-scale non-residential buildings by dynamic control of hvac with heat pumps. Energies (Basel). 2021;14(13).

[15] Hu X. Studying the relationship between financial accounting and mineral wealth management. Resources Policy. 2024;90.

[16] Hwang RL, Huang AW, Chen WA. Considerations on envelope design criteria for hybrid ventilation thermal management of school buildings in hot–humid climates. Energy Reports. 2021;7.

[17] Wbdg.org. 2016 Passive Solar Heating Available at: https://www.wbdg.org/resources/passive-solar-heating[Accessed on 10 June, 2024]

[18] Jiang L. The use of blockchain technology in enterprise financial accounting information sharing. PLoS One. 2024;19(2 February).

[19] Li S. Construction of China's Carbon Financial Accounting System from the Perspective of Sustainable Development. Problemy Ekorozwoju. 2024;19(1).

[20] Environment.govt.nz. 2024 6.1: Mathematics, Statistics and Computer Science Building Available at: https://environment.govt.nz/publications/passive-solar-design-guidance/6-case-studies/ [Accessed on 10 June, 2024]

[21] Li X, Khishe M, Qian L. Evolving deep gated recurrent unit using improved marine predator algorithm for profit prediction based on financial accounting information system. Complex and Intelligent Systems. 2024;10(1).

[22] Liu Y. The use of management accounting and financial accounting in financial management based on multiple linear regression algorithm. Applied Mathematics and Nonlinear Sciences. 2024;9(1).

[23] Mahar AR, Bhatti A, Ashraf MJ, Malik AZ. Financial Reporting for Islamic Financial Institutions: Accounting Standards, Interpretation and Application. Financial Reporting for Islamic Financial Institutions: Accounting Standards, Interpretation and Application. 2024.

[24] Mariati Munte MH, Sijabat J, Panggabean SS. Design of Church Financial Statements Based on Interpretation of Financial Accounting Standards (Isak) 35. Jurnal Indonesia Sosial Teknologi. 2024;5(2).

[25] Singh B, Sharma SK, Syal P. Net Zero Energy Building (NZEB) Design. Journal of The Institution of Engineers (India): Series A. 2021;102(1).

[26] Mi H. Digital Transformation Strategy of Enterprise Financial Accounting Management Based on Blockchain Technology. Applied Mathematics and Nonlinear Sciences. 2024;9(1).

[27] Panel Two: Sarbanes-Oxley Accounting Issues: Cataclysmic Liability Risk Among Big Four Auditors. Panel Two: Sarbanes-Oxley Accounting Issues: Cataclysmic Liability Risk Among Big Four Auditors. 2024.

[28] Parrondo L, Amat O. Research handbook on financial accounting. Research Handbook on Financial Accounting. 2024.

[29] Phuong Hong NT, Tra My PT. Effects of financial characteristics on accounting conservatism of listed companies in Vietnam stock exchange. Cogent Business and Management. 2024;11(1).

[30] Scheuring L, Weller B. Energy-efficient controlled natural ventilation in nonresidential buildings - Experimental investigation of opening durations . Bauphysik. 2021;43(2).

[31] Rashad M, Khordehgah N, Żabnieńska-Góra A, Ahmad L, Jouhara H. The utilisation of useful ambient energy in residential dwellings to improve thermal comfort and reduce energy consumption. International Journal of Thermofluids. 2021;9.

[32] Rieser A, Pfluger R, Troi A, Herrera-Avellanosa D, Thomsen KE, Rose J, et al. Integration of energy-efficient ventilation systems in historic buildings—review and proposal of a systematic intervention approach. Sustainability (Switzerland). 2021;13(4).

[33] Rijal I, Rakhman A, Fatmanah Y, Lailatus Sofia M, Dwi Nafrida S, Rahmawati S L. SIX YEARS OF FINANCIAL ACCOUNTING RESEARCH IN INDONESIA. Jurnal Impresi Indonesia. 2024;2(12).

[34] Riyadi W, Mulyani HS, Hernita N, Ginanjar Y, Lestari AG, Rahmayani MW. The Influence of Attitudes, Motivation, And Perceptions on The Village Financial Accounting System in Kadipaten Subdistrict of Majalengka Regency. Quality - Access to Success. 2024;25(198).

[35] Samuels JA, Snow MC. Analyzing Depreciation: A Financial Accounting Data Analytics and Visualization Case. Issues in Accounting Education. 2024;

[36] Cillari G, Fantozzi F, Franco A. Passive solar solutions for buildings: Criteria and guidelines for a synergistic design. Applied Sciences. 2021 Jan 2;11(1):376.

[37] Prabhakar M, Saffari M, de Gracia A, Cabeza LF. Improving the energy efficiency of passive PCM system using controlled natural ventilation. Energy and buildings. 2020 Dec 1;228:110483.

[38] Sendrayaperumal A, Mahapatra S, Parida SS, Surana K, Balamurugan P, Natrayan L, et al. Energy Auditing for Efficient Planning and Implementation in Commercial and Residential Buildings. Advances in Civil Engineering. 2021;2021.

[39] Ménard R, Souviron J. Passive solar heating through glazing: The limits and potential for climate change mitigation in the European building stock. Energy and Buildings. 2020 Dec 1;228:110400.

[40] Smith JA. Research handbook on accounting and information systems. Research Handbook on Accounting and Information Systems. 2024.

[41] Barone G, Buonomano A, Forzano C, Giuzio GF, Palombo A. Passive and active performance assessment of building integrated hybrid solar photovoltaic/thermal collector prototypes: Energy, comfort, and economic analyses. Energy. 2020 Oct 15;209:118435.

[42] Talei H, Benhaddou D, Gamarra C, Benbrahim H, Essaaidi M. Smart building energy inefficiencies detection through time series analysis and unsupervised machine learning. Energies (Basel). 2021;14(19).

[43] Wang M. Analysis of the innovation path of financial accounting education model from the perspective of integration of industry and education. Applied Mathematics and Nonlinear Sciences. 2024;9(1).

[44] Izati Rasli NB, Ramli NA, Ismail MR, Mohammad Kamaruddin N. Qualitative study of airflow structure across wooden louvred window panels for natural ventilation applications. 3C Tecnología_Glosas de innovación aplicadas a la pyme. 2021;10(3).

[45] Weber I. Interplay of building efficiency and households' ventilation behaviour: Evidence of an inverse U-shaped correlation. Energy Build. 2021;252.

[46] Xue S, Jiang Y, Wei Q. Green financial accounting and transition in the mining sector in emerging economies. Resources Policy. 2024;89.

[47] Yao M. RPA Technology Enables Highly Automated Development of Corporate Financial Accounting Processes. Applied Mathematics and Nonlinear Sciences. 2024;9(1).

[48] Yarmoshenko I, Zhukovsky M, Onishchenko A, Vasilyev A, Malinovsky G. Factors influencing temporal variations of radon concentration in high-rise buildings. J Environ Radioact. 2021;232.

[49] Zhang S, Ai Z, Lin Z. Novel demand-controlled optimization of constant-air-volume mechanical ventilation for indoor air quality, durability and energy saving. Appl Energy. 2021;293.

[50] Zhao J. Study on the Role of Big Data Technology in Promoting the Transformation of Financial Accounting in the Digital Economy Era. Applied Mathematics and Nonlinear Sciences. 2024;9(1).