A Study of Passive and Active Strategies through Case Studies for the Composite Climate Zone of India

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Abstract There are only 4500 buildings and about 4.17 billion square feet of the area under green buildings till 2016. It is only around 5% of India's total construction, and there is considerable potential for sustainable design in the Indian market. Sustainable building design requires passive and active techniques. It is vital to design a sustainable building that uses passive strategies to its fullest because they are cheaper and more efficient than active strategies. The designer emphasizes active features and neglects passive features to obtain sustainable building ratings in the current context. The whole purpose of sustainable design has been defeated. To achieve a sustainable design in a real sense, passive strategies should be formed in response to the local climate and given primary importance. Active strategies are only bound to complement passive strategies. This study focuses on understanding the passive design strategies for India's composite climate in response to the local climate through case studies of buildings. This paper deals with passive design strategies such as orientation, fenestration, shading devices, earth touch, roof garden, water, landscaping, and active strategies, often include solar panels, solar water heaters and wind towers. The two studies, i.e., the American Institute of Indian Studies and the Solar Energy Center, use the sunken courtyard, orientation, shading devices, water bodies, a verandah inspired by traditional passive features, and another study, the PEDDA Complex, use the southern dome structure, shading devices, water bodies as modern passive features. All studies use active

strategies to complement passive strategies. The study concludes that all three case studies use passive strategies as primary ones, either influenced by traditional architecture or modern perception and that active strategies complement passive strategies.

Keywords PEDDA Complex, American Institute of Indian Studies, Solar Energy Center, Passive Strategies, Active Strategies, Sustainable Design

1. Introduction

Sustainable development is a multidimensional concept, and the primary objective is to bring the environment and development together. The concept of sustainable development was first discussed in the Stockholm Declaration of 1972, and then in the Brundtland Commission report in 1987. This report became a benchmark for efforts to align economic development and environmental protection. The definition of sustainable development in this report indicate, "Development meets the needs of the present without compromising the ability of the future generations to meet their own needs." [1]

1.1. Sustainable Design in the Indian Context

Sustainable development in architecture refers to three

domains: environmental, social-cultural, and economic related to the built environment. This paper will address only the environmental domain of sustainable development. The environmental domain tackles concern such as waste effluent production, solid waste, carbon dioxide emissions, land use, inadequate use of water, raw materials, and energy consumption in the built environment. [2]

Sustainable architecture design focuses on reducing footprint, using passive and active energy-saving techniques, using local and sustainable materials to reduce the load on natural resources of materials, integrating multiple effective mechanical systems, and eventually minimizing the overall effect on the environment and natural resources. The sustainable approach also leads to the health and well-being of users. [3] A sustainable design approach will resolve India's future potential environmental pollution, energy, and natural resource crisis.

The energy crisis is a significant issue in India, and buildings consume 30-40 percent of India's overall energy consumption. [2] The building sector is proliferating and is projected to expand five times in India from 2005 to 2030. [4] The energy demand for this rapid growth in the building sector is severe. Hence, the design of the building should be in such a way that it consumes less energy. It should also generate energy by renewable energy sources such as solar panels, wind towers so that net-zero energy in buildings can be achieved in the future.

1.1.1. Sustainable Design in Ancient Indian Architecture

The concept of sustainable development lies in the balanced use of the elements of nature. During the Vedic era, methods such as the Panch Mahabhuta or the five basic elements of nature were used, i.e., Jal (water), Agni (fire), Prithvi (earth), Vayu (wind), and Akash (space) for the design of the building. This science was called Vastushashtra. The basic principle of Vastu Shastras is to make the best of nature without harming nature. The use of Vastu Purusha Mandala was for the allocation of different parts of buildings according to climatic principles, such as the kitchen in the south or south-east, etc. [12]. This traditional wisdom and sustainable design principles have been lost in India for nearly 500 years due to Mughal and British Raj.

Traditional buildings in India have used passive strategies to establish comfortable conditions inside buildings. These buildings have performed very well, but in the present context, these traditional buildings often require active strategies to establish comfortable conditions due to climate change. Modern conventional buildings need more active strategies than traditional buildings because they were not based on passive strategies. It is concluded that passive design strategies are the first to be designed and that active strategies can only supplement passive design strategies as they do in traditional buildings. It is essential

to know traditional buildings' passive features, incorporating a modern building with slight modifications. The two studies chosen in this paper use the passive features of traditional Indian architecture.

1.1.2. Sustainable design in the Present Context of India

The new concept of sustainable design based on the western model started in 2003 through a pioneer LEED rated Platinum building CII-Sohrabji Godrej Green Business Centre at Hyderabad. Many other rating systems have been induced in India, such as GRIHA, BEE, and many more. [12]

Many architects/architecture firms have made a significant contribution to the field of sustainable design, such as Ashok B Lal, Sanjay Prakash, Yatin Pandya, Didi contractor, Vinod Gupta, Benny Kuriakose Made in Earth, Hunnarshala Foundation, Trupti Doshi architects, Thannal Hand Sculpted Homes, Studio Eugene Pandala, Mozaic, Kamath Design Studio, Biome Environmental Studio. There may be many more architects and architectural firms working in the field of sustainable design. [13]

LEED- India has completed around 2,230 building with approx. 900 million (908,000,000) square feet per the LEED report in motion: India published in 2017. [12] GRIHA has accredited only 80 buildings around the country until 2018. [13] There are just 4500 buildings and about 4.17 billion square feet of the area built under green buildings until 2016. This is just about 5% of India's total construction, and there is a tremendous opportunity for India's sustainable design market. [16]

1.1.3. Sustainable design in Future Scenario of India

The present scenario data indicate that there is so much potential for sustainable buildings in India. There is a requirement of highly professional trained architect / architectural firms to design these sustainable buildings in the Indian context. Architects / architectural firms need to explore India's traditional architecture and incorporate a few ideas from these buildings. The two case studies in this paper are inspired by traditional Indian Architecture.

1.2. Passive and Active Strategies: Need and Importance

The sustainable design of buildings consists of two types of strategies, i.e., passive and active strategies, to achieve the project's environmental sustainability. Passive Design strategies do not use mechanical means and electrical power and refer to the direct use of natural energy sources such as the Sun and wind. [5] The strategies could include building orientation, building shape, selecting the appropriate building material for building envelop, the size and shading of the fenestration device, and the water used for evaporative cooling without electrical power. The architect's role in passive design strategies is significant because it anticipates the design

response to create a comfortable environment for users both in and out of buildings without using mechanical means.

Active strategies use mechanical means and electrical power to create comfort for occupants. Almost all utility systems in buildings can use active strategies such as air conditioning systems, fire protection systems, plumbing systems, audio systems, cleaning systems, and renewable energy sources such as solar panels and wind towers to generate electricity. This means that the active strategies involved initial costs and maintenance costs for the entire system's life.

1.3. Literature Review: Need and Significance of Study

The sustainable buildings are rated by two agencies, i.e., the Indian Green Building Council (IGBC) and Green Rating for Integrated Habitat Assessment (GRIHA) to assess sustainability performance on different parameters such as energy consumption, site planning, passive and active strategies, water conservation, and waste management. There is an observation that these rating systems do not have the methods to verify that buildings have implemented passive strategies to their fullest extent. The rating system's result is often very dangerous; the buildings that have been rated use active strategies to meet the rating system's needs. The purpose of sustainable design has been defeated.

Fabrice Mwizerwa, and Mukesh Kr Gupta, in their research paper titled "Establishing Climate Responsive Building Design Strategies using Climate Consultant," discussed various innovative and sophisticated-cutting-edge technologies in sustainable building design irrespective of their requirement as per the local climate. The study has been conducted using climate consultant software (an energy tool) for Guseyni. It concludes that passive design strategies are sufficient to achieve occupants' thermal comfort; there is no need for active or mechanical strategies.[6]

Sachin Vyas Gayatri, and K. N. Jha, in their research paper titled "Comparative Study of Rating Systems for Green Building in Developing and Developed Countries," discussed the comparative analysis of the rating system in developing and developed countries. The study advises that there are so many topography variations and climate in India from the north to the south. The rating system should address the topographic and climate factor from east to west.[7]

Kang Ji-Eun Kang, Ki-Uhn Ahn, Cheol-Soo Park, and Thorsten Schuetze, in their research paper titled "A Case Study on Passive vs. Active Strategies for an Energy-Efficient School Building Design," discussed the cross-comparison of the passive versus active approaches on energy-saving using Energy Plus simulation. The study concludes that there are more benefits of using passive design strategies than active design strategies and that

there is less energy demand by passive design strategies.[8]

Kang Ji-Eun Kang, Ki-Uhn Ahn, Cheol-Soo Park, and Thorsten Schuetze, in their research paper titled "Assessment of Passive vs. Active Strategies for a School Building Design," discussed the impact of passive vs. active approaches on energy savings in buildings using Energy Plus simulation. The study concludes that passive design strategies should be addressed mainly because they are more energy-saving than active strategies. The result also confirms that the excessive use of active strategies can be unproductive. [9]

Aniza Abdul Aziz and Yasmin Mohd Adnan, in their research paper titled "Incorporation of innovative passive architectural features in office building design towards achieving operational cost saving-the move to enhance sustainable development," discussed saving in operating cost of an office building by incorporating the passive features. The study concludes that the cost of energy reduction is a significant component of the operation cost, thus saving energy through passive features reduces the cost of operation of buildings. [10]

Sahid ST., Ir. Surjamanto W, and Ir. Sugeng Triyadi, in their research paper titled "Role of Passive and Active Strategy in Green Building Context," discussed the comparison of passive and active strategies, the role of each strategies in designing a green building. The study discussed various options, such as optimizing passive strategies, optimizing active strategies, and optimizing passive and active strategists. The combination of passive and active strategies works best. Passive strategies should also be optimized before switching to active strategies to achieve thermal comfort without consuming excess energy. [11]

It can be concluded that passive design strategies are not costly and very effective. The passive strategies in traditional buildings were to the fullest because there was less scope for active strategies. The sustainable rating system does not guarantee the optimum implementation of passive strategies. As per the Literature Review, passive and active strategies have been studied through energy simulation software and literature review. These studies may be adequate theoretically but do not represent the realistic implementation of passive and active strategies to projects. There are only a few studies available that have been performed through a case study, and hardly any such study is available in the Context of India. It clearly shows a need to explore passive and active strategies through case studies in India's climate zones.

This study will create a ready reference for architects, architecture students, and civil engineers to understand the composite climate zone's passive and active design strategies. The rating agency can also refer to it for a more detailed understanding of integrating passive features in their manuals.

2. Aim, Objectives, Scope, and Limitations

2.1. Aim

To understand passive and active design strategies for India's Composite climatic zone and its applications in buildings.

2.2. Objectives

- To study sustainable design in the Indian context
- To analyze the composite climatic zone of India
- To analyze the passive and active design strategies in the composite climatic zone.
- To analyze the applications of passive and active design strategies in buildings situated in the composite climate zone.

2.3. Scope and Limitation

Macro variations occur in the composite climate zone of India. This study only studies the climate of Chandigarh. This may be conceptually relevant to the entire composite climate region, but macro variations must be considered in the specific city or location. This research only covers institutional / office buildings. It deals only with two components of sustainable strategies, i.e., climate responsive design and energy conservation, at the level of case studies.

3. Methodology

It is important to know the past, current, and future sustainable design scenarios in India. The past scenario of sustainable design has been discussed based on the principles of the design of Vastushastra in ancient India. The present scenarios have been discussed through different rating systems, Indian Architects working in sustainability, rated building in India, and sustainable design. The future scenario has been discussed to highlight the scope of sustainable design and learning lessons of sustainability from traditional Indian architecture.

The paper involves studying passive and active design features in India's composite climate, and the area of India under the same is vast. It is not possible to study the climate analysis of all cities of the composite climate of India. This study only deals with the climate analysis of Chandigarh City as a representative of the Composite Climate to highlight the various objectives of climate-based building design. It is important to understand all the focus areas of sustainable design for passive and active strategies. This was addressed under India's Passive and Active Design

Strategy for Composite Climate Zones. Later on, only two focused areas have been chosen for this study.

The study deals with passive and active methods by case studies, and the chosen cases should be considered the best practices to illustrate sustainable design principles. There are many cases available on the composite climate of India related to sustainable design. However, due to the rating system, the current designs had lost the focus from passive strategies. These modern buildings hardly integrate the Indian architecture's traditional passive features such as the courtyard, verandah, and water bodies. The two cases aid in this research, the American Institute of Indian Studies and the Solar Energy Center is based on traditional Indian architecture, and another case is one building of the PEDDA complex since it represents modern passive designs that are unique. In 2001, all three studies were listed in the most authentic book entitled 'Energy Efficient Buildings in India', edited by Mili Majumdar, published by the Ministry of Non-Conventional Energy Sources. This book has presented the best practices of sustainable design in India.

The basis of the analysis of the cases mentioned above is mainly on two parameters, i.e., the aspect of climate-responsive design and energy and other aspects such as water conservation, waste management, and many more, are not included in this study. Climate responsive design includes orientation parameters, fenestration, shading devices, natural light, ventilation, courtyard or atrium, and sustainable building materials. The energy aspect includes the cooling parameter, earth contact, roof garden, water bodies, solar plant, or panels. These three studies' results were elaborated after the analysis and discussion of these parameters in each study.

The conclusion and recommendation were made based on analysis and review and based on the findings. The three case studies' study areas are shown by the location map in Fig 1, Fig 2, and Fig 3.

Source: Google Earth

Figure 1. Location Map of American Institute of Indian Studies, Gurugram

Source: Google Earth

Figure 2. Location Map of Solar Energy Center, Gurugram

Source: Google Earth

Figure 3. Location Map of PEDA Complex, Chandigarh

4. Analysis and Discussion

There is a division of Analysis and Discussion into three parts: the first part consists of the composite climate of India; the second part consists of the passive and active strategies in the composite climate zone of India, and the third part consists of the implementation of the passive and active strategies in the case studies.

4.1. Composite Climate of India

4.1.1. Climatic Zones in India

According to the National Building Code of India, India is divided into five climatic zones: hot and dry, warm and humid, temperate, cold, and composite. Bansal and Minke, 1988, carried out a detailed study and categorized Indian climate, as shown in Table-1. [17]

The climate classification is beneficial in determining the building to occur in a particular climatic zone. There are also variations in climatic data for a particular area in a single climate zone. It is essential to study in-depth climate data where the building is situated to learn about sustainable design strategies. The climate data element should evaluate the data of the latitude and longitude, temperature, humidity, rainfall, wind, and solar radiation. [18]

4.1.2. Analysis of Climatic data

Data from Chandigarh are dropping in the composite climate. There will be an analysis of climate data to understand the characteristics of the composite climate. There will be slight variations for different locations; however, the generic characteristics will remain the same.

Table 1. Climatic Criteria's of Bansal and Minke

Climate Zones	Mean Monthly Temperature ($^{\circ}\text{C}$)	Relative humidity (%)	Precipitation (mm)	Number of Clear Days
Hot & Dry	>30	< 55	<5	>20
Warm & Humid	>30	> 55	>5	<20
Moderate	25-30	<75	<5	>20
Cold & Cloudy	<25	>55	>5	<20
Cold & Sunny	< 25	< 55	< 5	>20
Composite	When Six months or more do not fall within any of the above categories			

4.1.2.1. Climatic Data of Chandigarh

Source: Meteoblue

Figure 4. Temperature, Rainfall graph of Chandigarh

Wind Direction in Winter – NE to SW

Wind direction in Summer and Monsoon – SW to NE

Source: Meteoblue

Figure 5. Wind graph of Chandigarh

Source: <https://weatherspark.com/>

Figure 6. Humidity graph of Chandigarh

Latitude and Longitude: The exact cartographic co-ordinates of Chandigarh are $30^{\circ} 44' 14\text{N}$, $76^{\circ} 47' 14\text{E}$. It has an average elevation of 321 meters (1053 ft). [19]

4.1.2.2. Climatic Analysis of Chandigarh

A. Critical Seasonal Analysis

There are five seasons in Chandigarh: summer, winter, monsoon, autumn, and spring. Three seasons are vital, and two seasons (autumn and spring) are temperate. The analysis of the three essential seasons and the inferences drawn from the analysis are as follow:

i) Summer (April -June)

This period is the most critical; the mean maximum temperature ranges from 27°C in March to 41°C in June, as shown in Fig 4. The relative humidity for this time is 30-45 percent, as shown in Fig 3. The solar chart also shows that the sun's hours are the highest during this time, so the heat gain is the maximum, as shown in Fig 7. During this time, the wind direction is SW to NE [19], as shown in Fig 5, and the wind contains heat.

Inference: The buildings should be designed to reduce the heat gain in summer. They should allow the wind after due care of the reduction of heat in the wind.

ii) Winter (Dec –Feb)

This time is not as important as summer; the average min temperature ranges from 7.3°C in Dec to 8.9°C in Feb, as in Fig 4. The relative humidity is almost zero, as

shown in Fig 6, and is a dry time. The solar chart shows that the sun's hours are a minimum during this time. Solar radiations are also minimal, as shown in Fig 7. The wind direction is NE to SW in the winter [19], and the wind is cold.

Inference: The buildings should be designed to optimize heat gain during the winter, preferably direct sunlight. After due consideration, the building should allow the wind to increase the heat in the wind.

iii) Monsoon (July to September)

This time, the mean maximum temperature is 36°C in July to 33°C in Sept, as shown in Fig 4. The relative humidity level in these months ranges from 60% to 95%, as shown in Fig 6. The rainfall during this time is very high, as shown in Fig 4. The average rainfall for the year 2017 was approximately 974 mm.

Inference: The buildings should be constructed to minimize heat gain and allow sufficient wind flow inside the building to reduce relative humidity. It is better to extract extra moisture from the wind before entering. The amount of water obtained by rainfall is sufficient to be used for various purposes.

B. Solar Path Analysis

Solar path charts are available for a difference of 1-degree latitude. Latitude of Chandigarh is $30^{\circ} 44' 14\text{N}$, which is very close to 31°N , so this chart will be used for analysis, as shown in Fig 7.

Source: Climatology and solar data for India: T.N. Seshadri

Figure 7. Solar Chart of Latitude 31degree North of Chandigarh

This Solar Chart, as shown in Fig 4, clearly shows that in the summer of June 21, the Sunrise at 30° from E to North and the Sunset at 30° from W to North. This is the longest exposure period of the Sun. Likewise, in the winter, on the 22nd of December, Sunrise at 300 from E to South and Sunset at 300 from W to South. This is the shortest period of sun exposure.

In the summer, Sun's vertical movement, June 21, reaches 8 am at 40° altitudes, 12 pm at 83° and 4 pm at 40°, meaning that the Sun is at higher altitudes. Likewise, in the winter of December 22, the Sun hits 8 am at 10°, 12 pm at 35°, and 4 pm at 1°, meaning that the Sun is at a lower altitude during the winter.

Inferences:

The sun in the summer morning is not as critical as indirect radiations are slightly lower, and the design criterion should be to prevent direct sunlight. The noon sun has substantially more direct and indirect radiation; thus, all forms of radiation should avoid. It is easy to avoid direct sunlight to the south by horizontal shading. The afternoon

sun and the evening sun are critical in the summer; thus, the indirect radiations and the direct radiations are very high. Therefore, both forms of radiation should be avoided. It is not easy to avoid direct sunlight in SW, W, and NW. The sun is not so critical in the winter, and it should be allowed inside the buildings during the day.

4.2. Passive and Active Design Strategies for Composite Climate Zone of India

As discussed in the previous section, it is essential to understand that sustainable design strategies are based on climate analysis. The building design is more challenging in composite climates than other climatic regions, as it should be designed for hot-dry in summer, warm-humid in monsoon, and cold-sunny in winter. Summers are the main focus of the composite climate, so buildings should minimize heat gain in summer and increase heat losses. Winters are also vital to the second priority; buildings are

supposed to maximize heat gain and minimize heat losses in winter. The monsoon is the third priority; the buildings should allow for natural ventilation and reduce heat gain.

The author classified the following passive and active strategies in different focused areas in his M. Arch Thesis in 2013 based on the rating system. [20]

4.2.1. Mitigating Heat Island Effect (Passive Design Strategies)

Objective:

Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to mitigate microclimate impacts.

Strategies:

- a). Shading to non-roof areas
- b). Previous paving /open grid pavement /grass pavers
- c). Use water bodies as evaporating cooling
- d). High reflectance material for paving
- e). High reflectance material on roofs

4.2.2. Climatic Responsive Design (Passive Design Strategies)

Objective:

To apply climate-responsive building design measures, including daylighting and efficient artificial lighting design, to reduce conventional energy demand.

Strategies:

- a). Optimum Orientation of Building blocks: Sun as well Wind consideration
- b). Building form: Minimize Surface to volume ratio
- c). Placement of a buffer zone in discomfort orientation
- d). Placement of opening/window opening: Sun and wind consideration
- e). Size of opening/Windows
- f). Shading of opening /Windows: Louvers/Trees or other building blocks
- g). Selection of material for windows: To reduce heat gain in summers, R-value and U value
- h). Material for Walling and Roofing: To reduce heat gain in summers
- i). Shading of Vertical (Walls) and Horizontal (Open ground/piazza) surfaces:
- j). Daylighting and artificial lighting to complement each other: Minimizing the artificial lighting
- k). Use of courtyard, verandah, and all other such techniques relevant to a modern context.
- l). Location and size of water bodies for evaporating cooling

4.2.3. Road, Circulation, and Utility (Passive Design Strategies)

Objective

To reduce site disruption due to laying, maintain utility lines, and minimize energy usage by on-site utilities to reduce transportation corridors on-site, reducing pollution

loads.

Strategies

- a) Design site planning to minimize road length.
- b) Reducing building footprint
- c) Shading of the pedestrian route: already covered above.
- d) Service roads, utility corridors should be aggregate so that minimum disturbance on site.

4.2.4. Energy Conservation (Passive and Active Design Strategies)

Objective

To use renewable energy sources to reduce the use of conventional /fossil fuel-based energy resources and use of earth contact, building materials, roof gardens, etc. to save energy indirectly.

Strategies

- a) Photovoltaic panel
- b) Solar water heating
- c) Earth Contact
- d) Roof Garden

4.2.5. Sustainable Building Materials (Passive Design Strategies)

Objective

To use sustainable building materials to reduce energy demand, to reduce environmental pollution

Strategies

- a) Selection of material having less U value to minimize heat gain
- b) Use material having less impact on global warming
- c) Use materials which have less energy intensity in life cycle assessment

4.2.6. Waste Management (Passive and Active Design Strategies)

Objective:

To use waste generated on-site efficiently to reduce environmental impact and the lowering energy demand for new materials.

Strategies:

1. Using wastewater
2. Using solid waste

4.2.7. Water Conservation (Passive and Active Design Strategies)

Objective:

To use techniques to conserve water and also utilize the natural sources of water effectively.

Strategies:

- a). Rainwater harvesting
- b). Using less water consumption techniques in building.

4.3. Case Studies: Application of Passive and Active Design Strategies

The applications of only two sustainable design strategies, i.e., climate-responsive design and energy conservation, out of seven focused areas addressed in the previous section, will be discussed in three case studies below:

4.3.1. Case Study 1: American Institute of Indian Studies, Gurgaon

This project is located in the composite climate of city Gurugram, formerly known as Gurgaon in Haryana, India, and project statistics are shown in Table 2.

Table 2. Project statistics American Institute of Indian Studies

Type of building	Institutional
Built-up area	1500 sqm
Site Area	-
Completed	1998
Location	Gurgaon
Climate	Composite
Architects	Vinod Gupta, L P Singh, Amrita Sharma, Koheli Banerjee of Space Design Associates, New
Landscape	Kavita Ahuja

Source: Energy Efficient Buildings in India [14]

The American Institute of Indian Studies is a consortium of American universities that allows scholars to promote Indian Art, Architecture, and Music research. This new building is designed to cater to administrative offices, research facilities, archives, a library, and a center for Ethnomusicology. [21]

Concept: The basis of this concept is on the fusion of traditional architecture with modernism. There is an integration of various elements of Traditional Indian Architecture such as Gardens, courtyards, pavilions, and verandahs into the experience of interaction with the outdoor environment. The sunken courtyard, brick on the façade, and other features, such as the arch, the dome reflect the traditional Indian architecture vocabulary. [21, 24]

Source: Energy Efficient Buildings in India [14]

Figure 8. Ground Floor Plan

4.3.1.1. Climate Responsive Design

a). Optimum Orientation

The site area of the project is small. There are two approach roads on the NW and NE sides, the usage of the NW side road is used as the main entrance, and the NE side is the service entrance. The long façade of the building was facing the NE-SW. The building façade is staggered at 45° from the site boundary, as shown in Fig 8, allowing windows in the north-south direction to minimize heat gain. The staggering of the façade serves the function of the best orientation and also adds the aesthetic value of the building façade. [21, 23]

b). Fenestration and Shading Devices, Natural Day Lighting and Ventilation

The main windows face north and south, as shown in Fig 8. There is only a need for horizontal shading in the south to cut direct sunlight in summers to minimize heat gain in summer, and there is no need for shading in the north. The designer has assigned a uniform character to provide uniform shading devices in the north and south. Windows often need protection from rain, so it is justified to provide horizontal shading in the north and south.

Source : Gaurav Gangwar

Figure 9. Concept of Light Shelf on Windows and shading device

Source: Gaurav Gangwar

Figure 10. Glass bricks on East and West façade for Natural light in the basement

The external façade provided the proper size of the windows on the north and south for natural daylight; the small silt windows on the exterior façade on the east and west façades were provided with glass bricks for natural daylight in the basement rooms, as shown in Fig 10. The light shelf concept is also used to bring the light deeper in rooms by reflecting light from top glazed Surfaces of windows, as shown in Fig 9. The ceramic tile on the top of the horizontal shading reflects the light from outside to enter deeper inside the rooms through a window above the shading device, as shown in Fig 9. The windows have been provided in the sunken courtyard to allow natural light in rooms, as shown in Fig 11. The dome on the director's room has been provided with the fiber material to filter the light below, as shown in Fig 15. [21]

Source: Gaurav Gangwar

Figure 11. Natural light in Library through the sunken courtyard (Basement)

c). Courtyards as Climate Modifier

Source: Gaurav Gangwar

Figure 12. Sunken Courtyard at the Main entrance landscape and water bodies

The Courtyards are the essence of the project. There are two sunken courtyards, the main courtyard is at the

entrance, and the other is diagonally positioned for better air circulation. The entire floor is sunken, and the sunken courtyard provides natural light and ventilation in all the rooms around it, especially the Library in the basement. The main courtyard has a water fountain and landscaping, as seen in Fig 12, shaded in the summer. It is a perfect place to sit in the summers, as shown in Fig 13, and small meetings are taking place in this courtyard. The courtyards act as a light well, but they also act as climate modifiers; this serves the courtyard's purpose. The author has observed a significant difference in temperature in the basement and upper floor of the courtyard. [21, 22, 23, 24]

Source: Gaurav Gangwar

Figure 13. Sunken Courtyard at the Main entrance for sitting purpose

d). Sustainable Building Materials

The work areas located on the ground and first floor are protected by specially insulated exterior walls (expanded polyethylene) in the east and west direction to reduce heat gain in summers. This insulation material, expanded polyethylene, is a layer between two half thick brick walls (115 mm), as shown in Fig 14. [21, 23] The insulating wall reduces the air conditioner load too and saves energy.

The use of ceramic tiles (broken pieces) is on the dome to reflect the direct sunlight to reduce heat gain in summers, and the use of fiber material is on the top of the dome is insulation material that prevents heat gain shown in Fig 15. The insulation material on the dome also reduces the air conditioner load and saves energy.

Source: Space Design Consultant

Figure 14. Section of Building showing Materials

Source: Gaurav Gangwar

Figure 15. Ceramic Tile and Fiber material on the roof of the dome

4.3.1.2. Energy Conservation

a) Evaporative Cooling Concept

There is a fascinating concept of cooling called the evaporative cooling concept. The first stage ensures standard direct evaporative cooling in which the addition of moisture cools the air. In the second stage, the air is indirectly cooled by passing it through a heat exchanger that carries cooled water without humidity. By regulating these two phases of operation, cooling can be accomplished with some degree of humidity control. Ducts carrying cooling airflow are running through the courtyards' passageways, and outlets are placed to blow cooled air into the working areas, as shown in Fig 16. [21]

This system is not working at present for various reasons; the first is that people's lifestyle has changed and they need more cooling; this system needs a lot of maintenance. Centralized air-conditioning has been replaced for this system.

Source: Gaurav Gangwar

Figure 16. Evaporative Cooling Duct in the Library (Basement)

b) Solar Water Heaters

Source: Gaurav Gangwar

Figure 17. Solar Water Heater on the terrace

The cafeteria and staff quarters have been fitted with a

solar water heater of 250 liters per day, as shown in Fig 17. [21] Hot water is useful for the cafeteria, as per the author's interview. Solar water heaters are saving energy in buildings.

c) Roof Garden

The terrace garden with a modern pavilion is situated on the second floor's terrace, ideal for a large gathering in the winters, as shown in Fig 18. This terrace garden is very well linked to the cafeteria and works very effectively for users in the winters. The terrace garden also lowers the heat insulation on the lower floors. The insulation of the terrace garden decreases the air-conditioned load of the building. [21]

Source: Gaurav Gangwar

Figure 18. Terrace Garden on top of the second floor

d) Earth Contact

The building has been sunken to one floor, and the whole floor takes advantage of the contact of the earth around it to minimize the heat in the basement. Earth contact also decreases the air-conditioned load of the building.

Inferences:

1. The building's orientation is very well done and makes natural daylight, so efficient ventilation decreases the building's heat gain.
2. The windows and shading devices' design provide sufficient natural light, ventilation, and reduces the heat in summer.
3. The sunken courtyard concept is very innovative and works effectively as a climate modifier, lighting, and ventilation system.
4. The earth contact is an excellent feature of this building to minimize the cooling load of the building.
5. The Roof garden is very well designed to integrate with the cafeteria and decrease its cooling and heating load due to its insulation properties.
6. The building materials such as exposed brick and stone are useful for reducing energy consumption, but these materials improve the building's aesthetics.

This building was designed to incorporate a meaningful use of passive strategies such as orientation, courtyard, verandah, windows and shading devices, earth contact, roof garden, and sustainable building materials. This approach lacks India's new small sustainable projects because designers emphasize active sustainable design techniques to achieve rating systems. The active strategies such as the evaporative cooling system, solar water heater have also been used to complement the passive strategies.

4.3.2. Case Study 2: Solar Energy Center, Gurgaon

Table 3. Project statistics of Solar Energy Center

Type of building	Institutional/ Residential
Covered area	6943 sqm
Site Area	200 Acres
Completed	1990
Location	Gurgaon
Climate	Composite
Architects	Vinod Gupta
Landscape	-

Source: Energy Efficient Buildings in India [14]

This project is located in the composite climate of Gurugram, formerly known as Gurgaon, Haryana, India, and project statistics are shown in Table 3.

The project is an office complex consisting of a Technical and Administration Block, a workshop block, and a guest house. The Technical Administration Block includes the Administration, Library, Cafeteria, Laboratories and Testing Areas, and the Solar Simulator Section. This paper will only deal with sustainable design strategies for the Technological and Administrative Block. [26]

Concept: The courtyards are the essential feature of the traditional Indian architecture used in the administrative and technical block. The fountain and landscaping are also important features of this main block to serve as a climate modifier.

4.3.2.1. Climate Responsive Strategies

a) Optimum Orientation

The technical and administrative blocks do not have a specific orientation, as they are structured around square courtyards, as seen in Fig 19. [25]

Source: Energy Efficient Buildings in India [14]

Figure 19. Ground Floor Plan

b) Fenestration and Shading, Natural Daylighting and ventilation

The windows are split into two sections, one at standard height and the other just below the vault, as shown in Fig 17. The lower windows provide ventilation, natural daylight, and an outside view. The upper windows are explicitly designed for natural daylight deep within the workspace, even though they are partitioned. The windows are placed on both sides of the workspace to ensure natural daylight. [21, 25, 26]

The windows have been fitted with proper shading devices to reduce the glare, as shown in Fig 20. The horizontal shading device was planned concerning the south, while the measurement of vertical shading devices is considering the east and west direction. The windows' arrangement in such a way that they endure winter sunshine at least half a day. [21,26]

Source: Gaurav Gangwar

Figure 20. Shading device on windows

c) Courtyards as a Climate Modifier

Source: Gaurav Gangwar

Figure 21. Courtyard-1 at Entrance with fountain, waterbody

Source: Gaurav Gangwar

Figure 22. Courtyard-2 after the Entrance for siting purpose

The site restrictions being minimal due to the availability of a site area of 200 acres. The architect was free to determine the appropriate form, and thus the building was conceived as a low scattered structure arranged around the courtyards, as shown in Fig 19. [21]

There are four courtyards in the house. The courtyard designing serves as a source of daylight & ventilation and, creates a microclimate, and use for meetings and siting purposes, as shown in Fig 22. All four courtyards are scattered to create a surprise for any visitor; landscaping and other surface treatment are different in all four courtyards. The vegetation and fountain, waterbody, create a different ambiance and microclimate, as shown in Fig 21. [21]

d) Sustainable Building Materials

The building roofs are vaulted, and all vaults' orientations are not in the same direction. It is not a very good solution because few vaults face the right orientation to minimize heat gain in summer, and the rest are not facing the right orientation. The vaulted roof was treated with insulating material and reflective material such as ceramic tiles, as shown in Fig 23. The walls are made of hollow concrete blocks to mitigate heat in summer. [21, 25, 26] The insulation on walls and roof creates less demand for cooling in summer and indirectly saves energy.

Source: Gaurav Gangwar

Figure 23. Reflective material ceramic tile on Roofs

4.3.2.2. Energy Conservation

a) Roof Top Cooling system

There is an integration of roof cooling systems, such as the terrace greenhouse, jute-matting on the roof, and continuously sprayed water. Also, there is an installation of reflective ceramic tiles to minimize heat gain in summer. The jute-matting device is not working now, as shown in Fig 23. [21, 26]

b) Solar Plant

The building is related to the development of innovative solar energy technologies. We can see an installation of a solar thermal plant of adequate capacity, as shown in Fig 24. The solar panel is also used to generate renewable energy through various roofs and other parts of the house, as shown in Fig 25. [21, 26]

Source: Gaurav Gangwar

Figure 24. Solar thermal plant for power generation

Source: Gaurav Gangwar

Figure 25. Solar panels on the Rooftop

Inferences:

1. The building does not have a specific orientation; it cannot be considered the right solution.
2. The windows' design is lower and higher to allow adequate levels of natural light in the rooms, and the arrangement of the shading devices is appropriate.
3. The implementation of the traditional concept of the courtyard is in its pure sense as a climate modifier.
4. The solar plant works very efficiently.
5. There are building materials, such as a hollow concrete block on walls and insulation material on roofs to reduce energy consumption.

This building aims to integrate the efficient use of passive techniques to use courtyard and landscaping, window design, and shading devices. Active techniques such as solar thermal plants and solar panels also operate effectively.

4.3.3. Case Study 3: PEDA Office Complex, Chandigarh

This project is located in the composite climate of Chandigarh, and project statistics are shown in Table -4.

Table 4. Project statistics of PEDA Office Complex

Type of building	Commercial (Office)
Total Covered area	7000 m ²
Site Area	1.49 Acre
Completed	2004
Location	Chandigarh
Climate	Composite
Architects	Arvind Krishan and Kunal Jain
Landscape	-

Source: Energy Efficient Buildings in India [14]

Punjab Energy Development Agency (PEDA) is a state nodal agency responsible for the development of new & renewable energy and non-conventional energy in the state of Punjab. [27]

Concept: The PEDA complex is designed to respond to Chandigarh's composite climate and urban context. The building's design is in such a way that creates a larger volume, i.e., the atrium at the center, as shown in Fig 26, and to integrate the overlapping upper floors into this main volume. This roof of this main volume is established in response to solar geometry, and this feature of the roof is prominently visible from the entrance to this building. [21, 27]

Source: Energy Efficient Buildings in India [14]

Figure 26. Ground Floor Plan

4.3.3.1. Climate Responsive Design

a) Optimum Orientation

The site is minimal in size, and the building is the result of the shape of the site. It was, therefore, not possible to orient the building in a specific direction. The entire façade of the complex has used different strategies to reduce heat gain during the summer. The design of the building envelope attenuates external atmospheric conditions. [21, 27]

b) Fenestration and Shading, Natural Daylighting and ventilation

the heat gain from the direct solar radiation; projections on each rib are designed as self-shading in summers, as shown in Fig 27. Glazing on these ribs allows for natural light within the office complex. [21, 27]

The complex's central atrium has a main entrance, a reception, a water body, a cafeteria, and a sitting room. This natural daylight at this atrium is made possible through the roof, as seen in Fig 28. A lightweight space frame supports the roof. This roof is built with a hyperbolic shell roof so that daylight can admit without glare. Glass solar panels are mounted on this roof to produce electricity for various building purposes, as shown in Fig 28. [21, 27]

Source: Gaurav Gangwar

Figure 27. Domical structure on the south side

There is a domical structure on the south side to reduce

Source: Gaurav Gangwar

Figure 28. Atrium and Roof system

The floating and overlapping slab with interpenetrating vertical cutting allow free and fast air movement, reducing the suffocating effect. [27]

c) Sustainable Building Materials

The entire complex consists of a single envelope, and the outer wall of this envelope is made of a double wall with a 2 "(two-inch) space between for insulation purposes. [21, 27] All roofs, except the atrium roof, are insulated with a double insulation system to prevent the roof's heat. [27]

4.3.3.2. Energy Conservation

Source: Gaurav Gangwar

Figure 29. Water bodies and fountain in the atrium

25 Kwp building-integrated solar photovoltaic power plant has been set up to meet the complex's necessary electricity requirements. As mentioned earlier, installing these solar panels is on the atrium roof, as shown in Fig 28. [21, 27]

Fig. 29 shows that water bodies' construction with waterfalls and fountains is in the atrium of the complex to cool the whole complex in the summers. [21, 27]

The wind tower was built in the Centre to allow cold air to enter the atrium and hot air to escape from the atrium, as shown in Fig 28. This system is not in working condition; otherwise, it would significantly affect air conditioning. [21, 27]

Inferences:

1. The building does not have a particular orientation due to space constraints on the site.
2. The innovative concept of the south-facing dome structure works very well, not allowing direct sunlight to minimize the summer heat gain. Natural daylight from the atrium roof is also operating quite efficiently as this is a unique concept for dealing with roofs.
3. The construction of the water bodies and the wind towers is so well designed that the microclimate of this building will be excellent if it operates efficiently.

4. The solar plant of 25 Kwp is working very efficiently.
5. The cavity wall concept and double insulation on the roof will reduce the heat gain in summer and reduce winter heat losses.

There is an efficient use of modern passive strategies in building, such as south-facing passive dome structure techniques, cavity walls, double insulation, and water bodies. There are also active strategies, such as the solar thermal plant, and the wind tower has been designed, and the solar thermal plant operates efficiently.

5. Conclusions and Recommendation

Sustainable Design in India is at an early stage of growth. This advancement is vital to resolve numerous issues such as climate change, water shortage, energy crisis, and environmental pollution. Just 5 percent of India's buildings are designed as green buildings, and 95 percent of buildings are built as conventional buildings, responsible for the various issues discussed earlier. There is not enough exploration of sustainable design features of traditional architecture in India, so there is a need to study traditional buildings' sustainability.

Designing a building in a composite climate is the most challenging task since it combines three main climates: hot-dry, warm-humid, and cold-sunny. In contrast to each other, the buildings should react positively to all three climatic conditions. The composite climate analysis shows the need to reduce heat gain in summer, increase heat loss in summer, increase heat gain in winter, reduce heat loss in winter, decrease heat gain, and allow more ventilation for the hot-humid condition. There is an integration of various passive design features of traditional architecture such as verandah, courtyard, and earth contact in two case studies: the American Institute of Indian Studies and the Solar Energy Center. On the other hand, the PEDDA complex is designed based on a new modern design feature, such as the southern dome structure, water bodies, and wall insulation, as passive design strategies in response to composite climate. Active strategies such as solar panels, wind towers, and solar water heater have been used in all three cases. It is important to note that passive strategies have been the primary ones in all three case studies, and active strategies have only complemented passive strategies. In response to the same composite climate, the use of passive design techniques is often different. It clearly shows that architectural creativity often plays a crucial role in the design of buildings in response to the same climate conditions. These case studies accomplish the goal of sustainable design and address the identity of the Indian context, particularly the local context. The researcher recommends more similar research should be carried out on different kinds of climates and other types of buildings in the same

composite climate.

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