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DESIGN STRATEGIES FOR ADAPTATION TO CLIMATE IN THE SARABHAI AND THE SHODHAN HOUSES BY LE CORBUSIER IN INDIA

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INTRODUCTION

This paper is focused on the study of the application of architectural design strategies in the Sarabhai and Shodhan Houses by Le Corbusier in India, responding to the conditions of Ahmedabad's climate, classified as Aw Tropical wet and Dry or Tropical Savanna Climate. The pertinence of the study of Le Corbusier's design process using climatic data is argued in this chapter. In the Sarabhai house, it was achieved a model of low energy consumption that was designed mostly for optimised natural ventilation and rationalized use of ceiling fans during the warmest summer hours, while in the Shodhan house, a model for efficient use of air-conditioned and standing fans during the warmest hours was achieved. This efficient performance adapted to the climate doesn't neglect the aesthetics and poetry of space that characterise the masterworks of modern architecture in the 20th century.

The design methods of Le Corbusier in India

Le Corbusier was commissioned by the government of India under the leadership of Mahatma Gandhi and Jawaharlal Nehru for the design of the new capital of independent India, Chandigarh and its public buildings; that should embody the modern aspirations of democracy, freedom, progress, equality and peace of the recently independent country, which had radically broken with the former colonial structures of power. Le Corbusier signed a contract that started on the 18th of February of 1951, which included biannual travels to India,[1] and would result in an endeavour that would take 15 years. During this process, he also got some private commissions, including the design of the Shodhan House (1951-54) and the Sarabhai House (1951-56) in Ahmedabad.

To carry on the commissioned work according to the requirements and local context, Le Corbusier contracted a consultancy with the French engineer André Missenard, author of the book *L'homme et le climat* (1937), about the adaptation of modern architecture to tropical climate.[2] Le Corbusier gathered information about temperature, hygrometry, and prevailing winds during his trip to Chandigarh in November 1951. Le Corbusier and his specialist team developed a new design methodology driven by the climate conditions in the region, entailing the use and exploration of new scientific tools like the so-called Grille climatique[3] to respond to the climatic needs of the place.

The Sarabhai House (1956) together with the Shodan House (1954) (Ahmedabad, India) are considered two of the most important works of Le Corbusier produced in the last stage of his career.

There are some academic publications that study the compositional and formal aspects of their architectural design,[4] however, there is no in-depth investigation into how the climatic conditions were a determining factor in the design decisions applied to these projects and their energetic performance. This paper focuses on providing this analysis of the houses.

METHODOLOGY

For this analysis, the original technical information of the houses was obtained from the Fondation Le Corbusier, and the energy performance simulations were done using the software Design Builder and the Energy Plus weather data files for Ahmedabad for current conditions. A detailed 3D model with the thermal properties of the materials according to the construction details and a BIM model to analyse the formal and technical aspects were done in Design Builder and Revit respectively. Due to the high amount of climatic data needed to analyse the energy performance during a year and the limitations to obtaining it from on-site measurements, there is a range of inaccuracy on the outcome of the simulations if compared with real measurements for one day, however, the overall results are based on the reliability of the Energy Plus[5] weather data files, and the thermal properties, characteristics, and combinations of the materials found in the original construction details.

THE CLIMATIC ANALYSIS OF AHMEDABAD AW TROPICAL SAVANNA OR TROPICAL WET AND DRY CLIMATE

The Tropical Savanna or Tropical wet and dry climate is characterised by a wet and dry season less pronounced than in the tropical monsoon climate. Temperatures are hot and change little throughout the year.[6]

In summary, the weather of Ahmedabad is a complex challenge for a designer due to the variations of temperature and relative humidity throughout the year, which oscillate between 10 and 40 Cº and the relative humidity levels between 95% and 25% respectively. Another particular characteristic is the high level of solar radiation, which on average is 500 W/m^2, reaching monthly peaks of almost 1,000 W/m^2. Most of the year the temperature is warm, between 24 and 38 Cº with relative humidity levels changing progressively between the dry and the wet season (between June and October) when the cloud coverage area is above 60%. The winds are of a maximum speed of 4 m/s, the prevailing wind coming from the southwest between April and August.

The average values of today coincide with the climatic data collected by Le Corbusier in 1951, however, climate change is recorded in the maximum and minimum values (the green strips in the graph shown in Figure 1.)

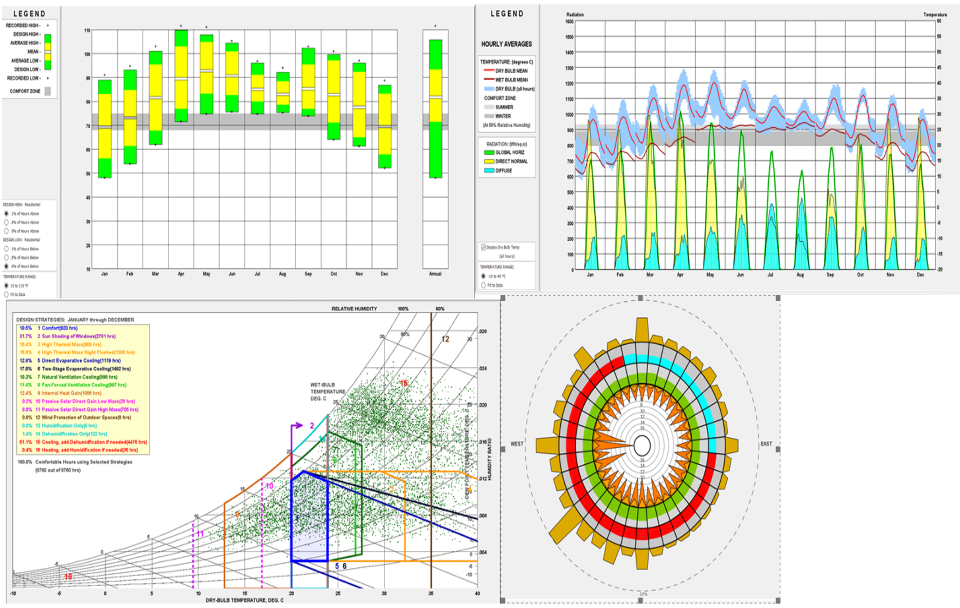

Figure 1. Climatic data for Ahmedabad, Temperature ranges, solar radiation ranges, winds wheel and Psychrometric chart of Givonni.[7]

THE SARABHAI HOUSE

Architectural Concept and Design Strategies for Adaptation to Climate

A system of half-cylinder Catalan vaults inside an axial grid aligned towards the main summer wind currents is supported by reinforced concrete beams aligned in the same direction and supported by bearing brick walls distributed according to the functional needs in the same grid, These structural walls are not too long to allow spatial continuity and connection between the different spaces, there is a system of wooden partition walls that can be opened and closed according to the needs of function and thermal comfort. Over the impermeabilized surface of the roof, above the Catalan vaults, there is a half-a-meter thick layer of soil covered with local grass and weeds that became a garden of lawn and charming flowers to be used at night when the outdoor temperatures are pleasant and which also acts as thermal shield tackling the high levels of solar radiation during most of the year and cooling the internal surface of the roof.[8] High thermal mass materials are used for the night flush effect and heat dissipation at night.

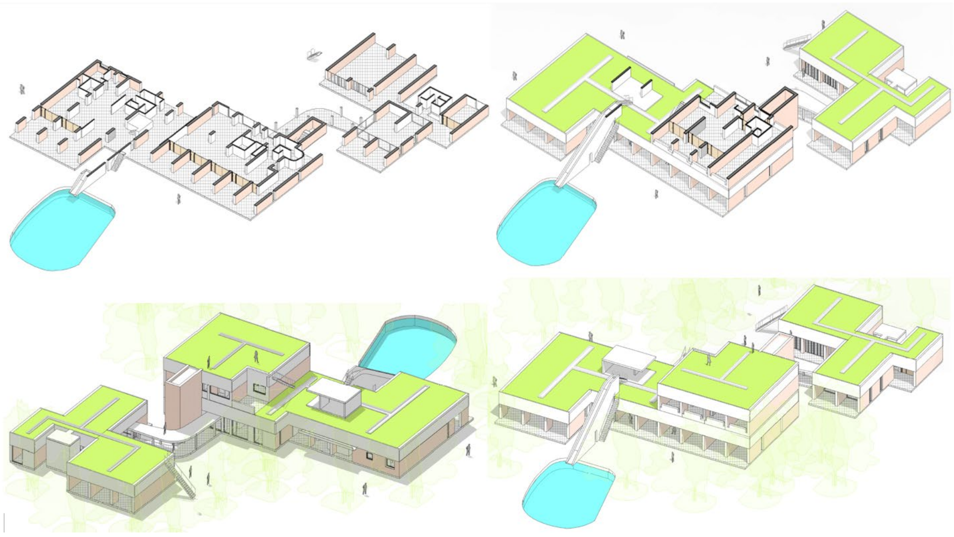

Figure 2. Axonometric views of the Sarabhai house. Source: Drawing by the author.

The Sarabhai house is designed to run almost the whole year only with natural ventilation. The system of Catalan vault modules is oriented towards, the main winds of summer. The extensive green roof with 50 cm of dirt over the impermeabilized surface of the Catalan vaults acts as a shield against solar radiation and has the effect of transpiration and cooling the internal surface of the roof. Two ceiling fans are in each vault module to be used during the warmest hours of the year, the doors are designed to be completely open or closed for natural ventilation, fans or air conditioning use. There are operable blinds of natural fibre to tackle the solar radiation in critical hours, of the afternoon. The walls holding up the vaulted ceilings have openings of various sizes, creating a flowing, interconnected space. Heavy wooden doors block out heat from the garden during the warmest hours of the day or are kept open to allow cross ventilation. Concrete fins and brise-soleils complete the composition of the exterior walls to further shield the building from the sun and block solar gains. The house includes an air conditioning system for three zones, although is almost not used as the natural ventilation and the ceiling fans are enough for thermal comfort in the warmest hours. Many high-canopy trees around the house act as natural parasols.[9]

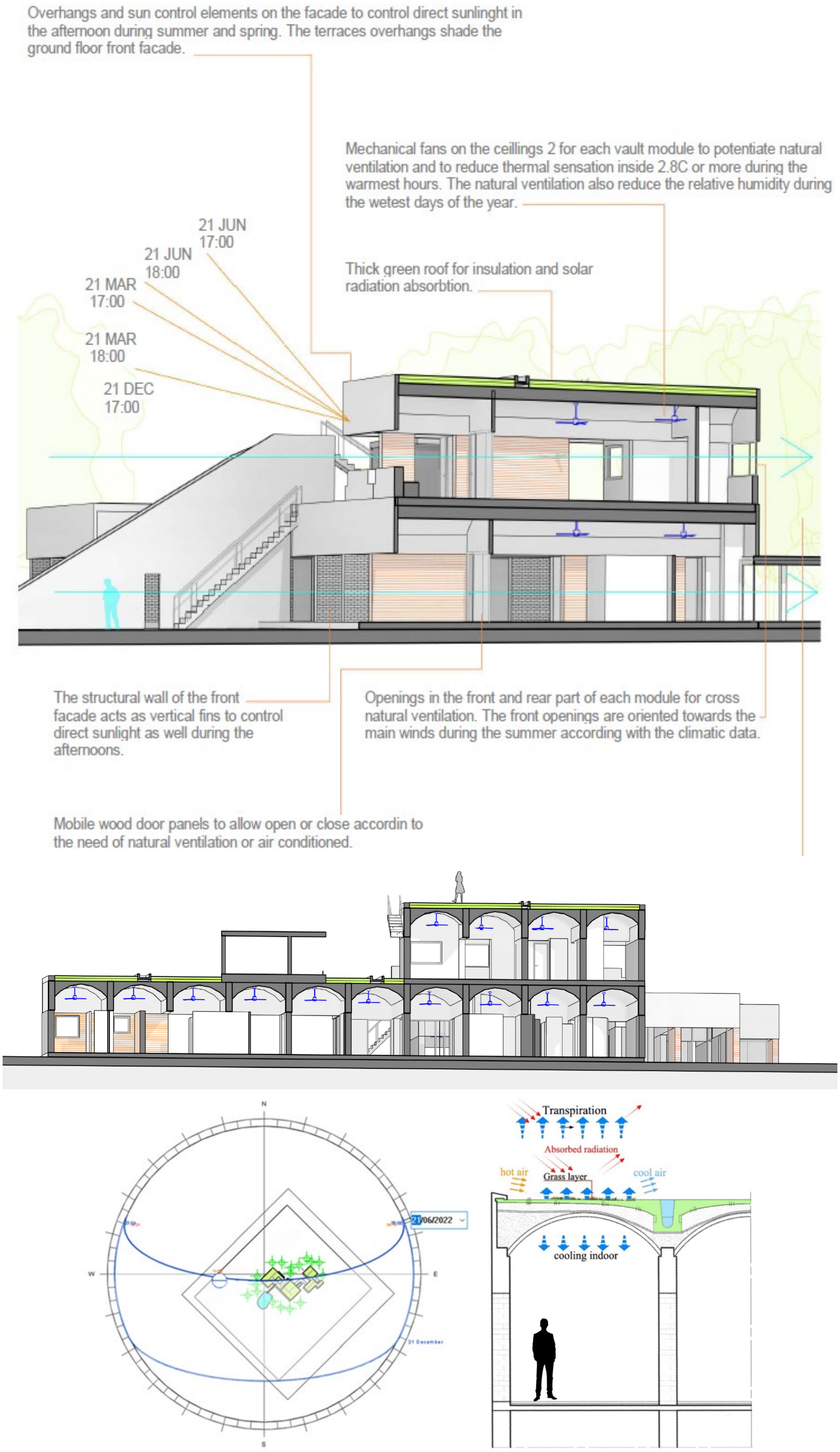

Figure 3. Design strategies applied in the Sarabhai House, longitudinal-section, location site plan with sun path and detail of the green roof. Source: Drawing by the author.

Design Builder Energy Performance Simulations for the Sarabhai House

Monthly simulation for one year with natural ventilation and fans turned off.

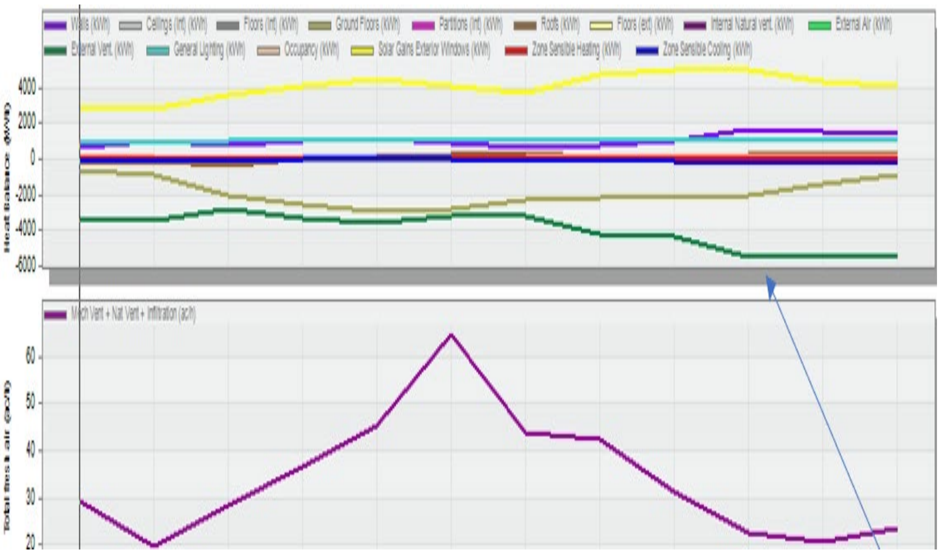

Figure 4. Heat balance graph and total ventilation graph for the monthly simulation for one year of Design Builder for the Sarabhai House.

In the monthly heat balance simulation graph, we can observe the negative green line showing the amount of energy saved by the natural ventilation[10] and the night flush effect generated by the high thermal mass materials of the ground floor at night like a negative brown line. In the upper part, the summatory of the heat gains shows a big amount for solar gains that in real life are less by the shade high canopy trees around and use of blinds in the critical hours of the afternoon sun (these factors are not simulated by the software). It should be noted that the ceiling fans are necessary when the outdoor temperature exceeds the thermal comfort temperature in some critical hours of summer, when the house should be closed, and the ceiling fans turned on. The cero line in the heat balance graph represents the thermal comfort: according to ASHRAE 55-2004 is between 24 Cº and 28 Cº wearing summer clothes.[11]

Hourly simulation for May 15th one of the warmest days of summer

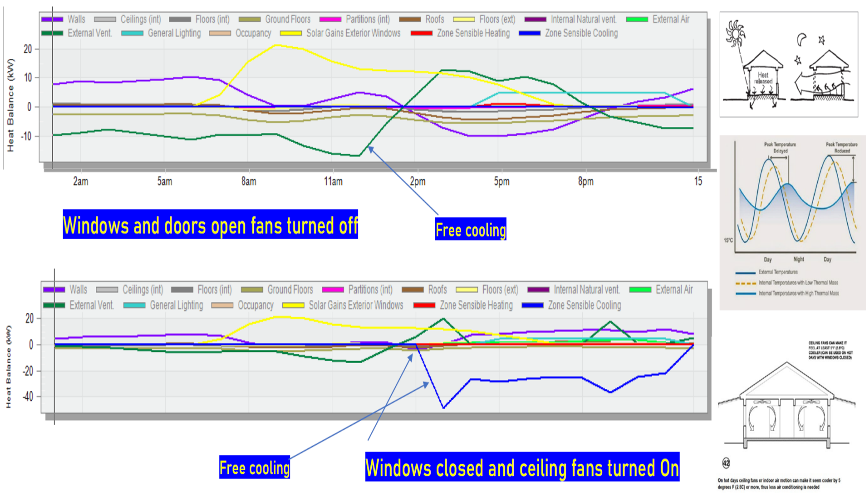

Figure 5. Heat balance graphs from Design Builder simulation with fans turned off windows and doors open, and doors and windows closed with fans turned on.

As we can observe in the graph for the hourly simulation of May 15th the outdoor air temperature rises above thermal comfort from 2 pm till 8 pm. In the heat balance simulation graph, with natural ventilation (with windows and doors opened) we can see that there is almost heat balance by the counter effect of the heat dissipation throughout the brick walls, the ground floor and the roof (purple, brown and dark yellow negative lines in the graph). It is important again to take into account that the high canopy trees and the blinds reduce the solar gains (positive yellow line) during these hours, however, the shade of the trees is not simulated by the software. On the other hand, we see that when the windows are closed and the fans are turned on, there is high efficiency, and thermal comfort is enhanced by the effect of sensitive cooling (negative blue line).[12]
This thermodynamic behaviour is described by the scholar Susan Ubbelohde who spent a day of summer in the house.[13]

THE SHODHAN HOUSE

Architectural Concept and Design Strategies for Adaptation to Climate

Compositionally the house is an eroded cube of reinforced concrete where the subtractions of mass under a parasol roof generate shaded interior spaces and staggered terraces. The design is similar to the Villa Savoy where the five postulates of Le Corbusier's modern architecture are applied, but in this case, adapted to the weather of Tropical Savana in a very accurate and rational way. The orthogonal structural grid of rectangular columns and beams of ferroconcrete allows the dynamism of the spaces in the different floors that are independent closed boxes, terraces, and voids while the independent enclosure walls of the façade and the shaders (vertical and horizontal) respond to the climatic needs and the sun movement of the place. Important as well is the use of the ramp as an articulation element for the different levels and the provision of an architectural promenade.[14]

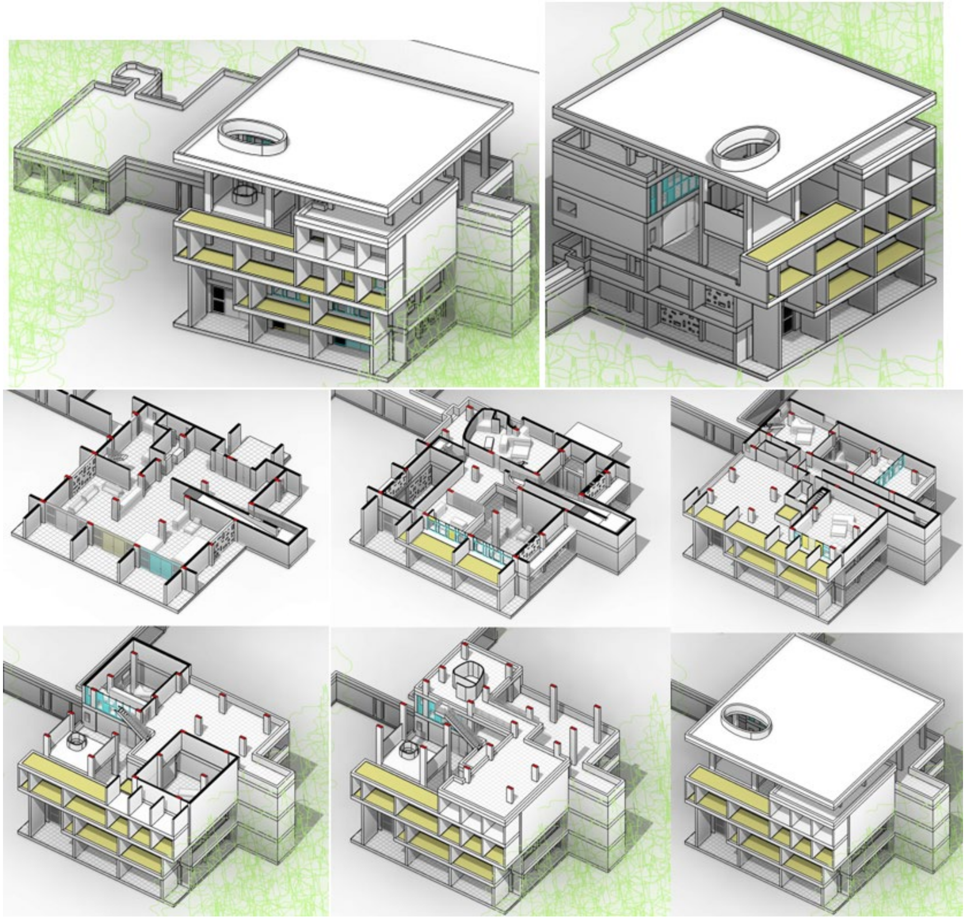

Figure 6. Axonometric views of the Shodhan house. Source: Drawing by the author.

The Shodhan house is designed to optimise the thermal comfort and energy efficiency for cooling in the internal spaces inside closed boxes under the parasol roof, next to and under the shaded gardened terraces. It is oriented towards the main winds of summer to enhance natural ventilation, but also it is designed to run with air conditioning or standing fans when needed. Operable windows are oriented towards the main winds of summer to enhance natural ventilation. The shaded-gardened terraces are designed to be used at night and to dissipate heat. Double-height private spaces with a mezzanine under and next to the shaded terraces are designed for both natural ventilation and air conditioning.

The external walls consist of three layers: concrete, air cavity with a vapour barrier, glass wool insulation and finished with painted wood panels to avoid external heat gains in the air-conditioned spaces.[15] High thermal mass materials are used for the night flush effect and heat dissipation at night.[16] The exterior walls of the interior spaces protected under the parasol roof are painted in white colour, as recommended in tropical climates to reflect any solar radiation throughout the year.[17] The brise-soleils enhance natural lighting. The set of design strategies applied tackle almost completely the solar heat gains.[18]

The house is designed for a minimised use of air conditioning in the closed boxes in the shadow next to the shaded and gardened terraces or for thermal comfort with standing fans.

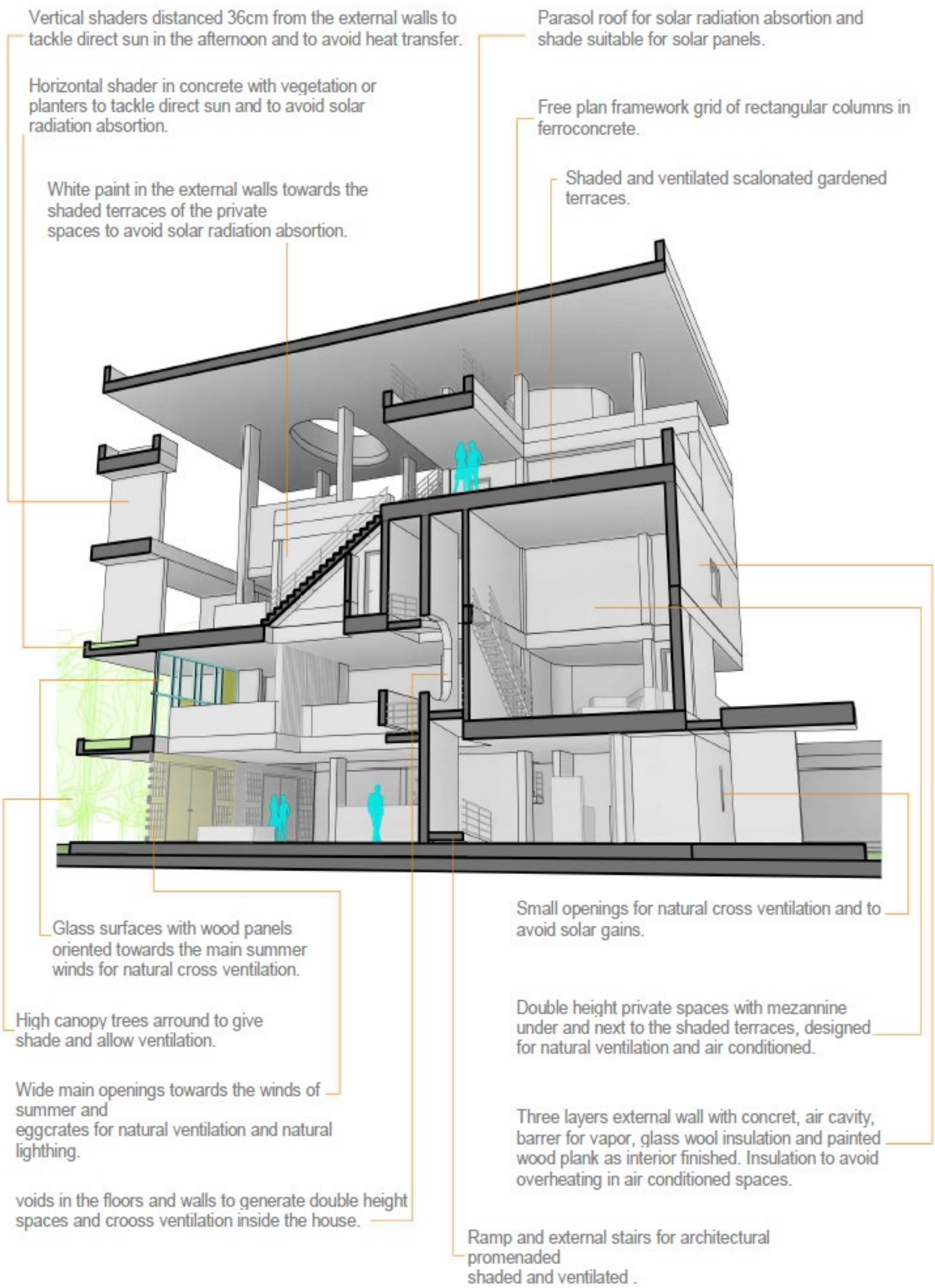

Figure 7. Perspective section of the Shodhan House showing the design strategies for adaptation to climate applied. Source: Drawing by the author.

Design Builder Energy Performance Simulations for the Shodhan House.
Monthly simulation for one year with fans turned on and windows and doors closed.

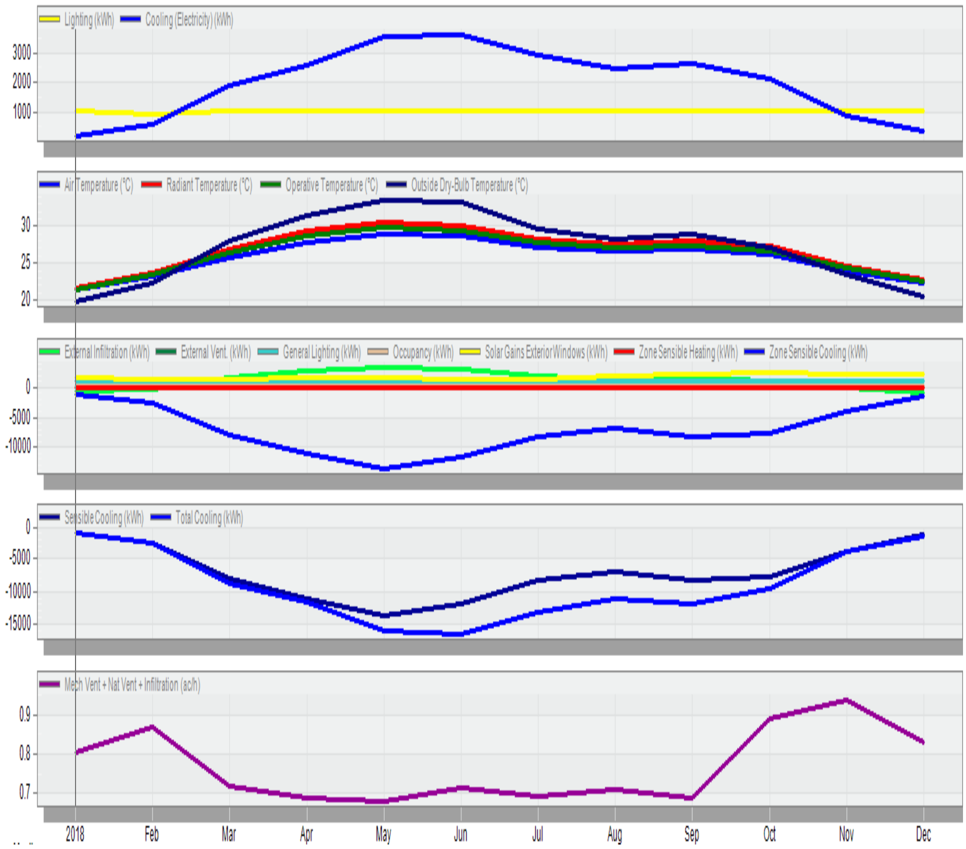

Figure 8. Simulations outcome graph for the Shodhan house, yearly energy consumption, air temperature, heat balance, total cooling savings and ventilation graph.

As we can observe in the simulation results for the monthly energy performance the heat gains of the house are very few, thanks to the set of strategies to avoid heat gains, being these: the parasol roof, the shaders, the insulated walls with air cavity and thermal insulation, the latticed shaded openings and the architectural configuration of closed boxes and shaded gardened terraces. As a negative blue line, we can observe the savings of energy for sensible cooling with the standing fans in combination with the set of design strategies. The house is especially efficient during the summer months, being an architectural concept ideal for functions that require air conditioning, steady thermal comfort and moist control throughout the whole year.

Hourly Simulation for May 15th one of the warmest days of Summer

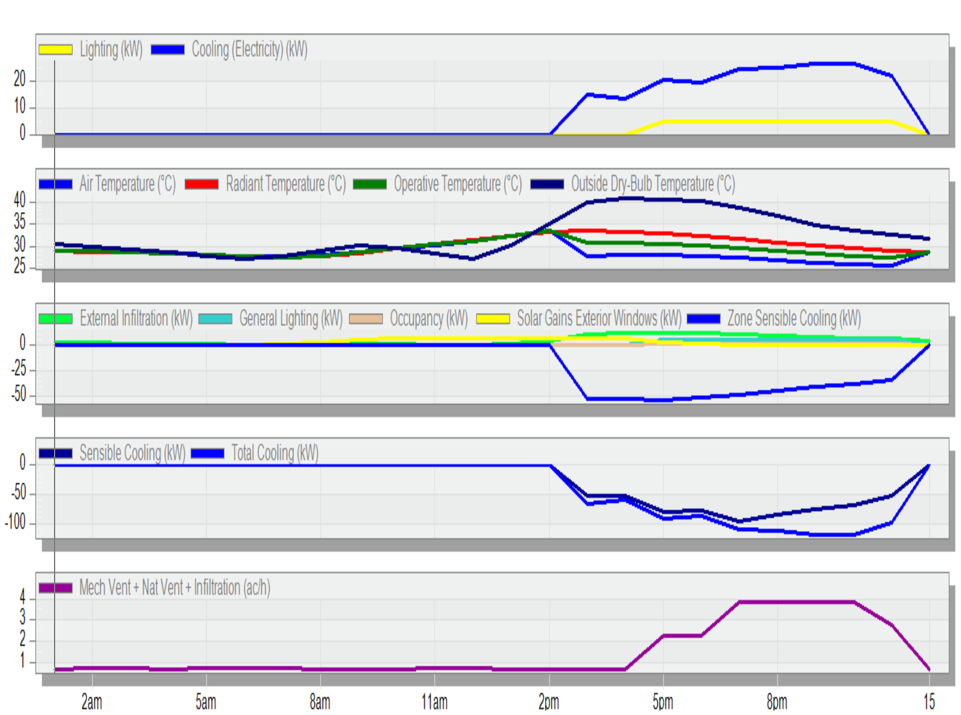

Figure 9. Simulations outcome graph for the Shodhan house, for 15th of May, air temperature, heat balance, total cooling savings and ventilation graph.

In the hourly simulation for May 15th, we can observe the high efficacy of the set of design strategies applied to tackle passive solar gains, there are almost no passive solar gains from 2 AM till 2 PM and the house is in thermal balance during these hours, from 2 PM till 9 PM, hours when the outdoor air temperature rises above thermal comfort, the standing fans are turned on, there are big energy savings for the sensitive cooling effect. The internal temperature of the house inside the thermal comfort range is steadier than in the Sarabhai house. The same would happen with the air-conditioning in any of the closed spaces, which would work very efficiently only for 7 hours a day during the warmest days of summer. In the cooling graph, we can observe that the sensible cooling effect is bigger than the cooling load representing big energy savings thanks to the effectiveness of the set of design strategies applied.

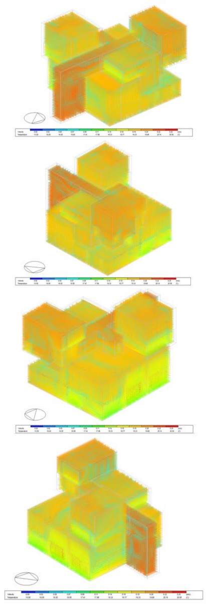

Figure 10. Interior photograph of the Shodhan house showing the latticed shaded openings from inside, the double height voids, the ferroconcrete frame and the standing fan.[19]

CONCLUSIONS

Le Corbusier achieved a high degree of energy efficiency and thermal comfort in these two houses, fulfilling the requirements of his clients who asked for low running costs for cooling. This was an alternative trend in the post-war period.

The efficiency of these strategies is verified in the heat balance graph of the energy simulations where is possible to measure the equilibrium between heat gains and losses, which keeps both houses in thermal comfort. Is possible to see how the design strategies tackle excessive solar gains and optimise natural ventilation. The combined effect of the design elements can be read as a big energy saving in Kwh yearly because the external energy necessary to equilibrate the thermodynamic system is very few compared with a building designed without design strategies for adaptation to climate.

The Sarabhai House, like many of Le Corbusier's projects, is acknowledged as a masterpiece of modern architecture and has been studied mainly for its spatial, aesthetic and compositional qualities as a relevant cultural production of the modern movement by authors like Kenneth Frampton, V. Doshi and Sussan Ubbelohde. In this paper, we recognise as well the early achievements of Le Corbusier in the attempt for adaptation to climate, sustainability, thermal comfort and energy efficiency.

In the case of the Shodhan House, the design strategies for adaptation to climate are highly effective for energy efficiency using air conditioning or standing fans and the design principles are applicable for contemporary practice in tropical zones due to the flexibility that allows it to be adapted to many contemporary uses like educational, health care, institutional, cultural facilities, single, medium, and high-density housing in parts of the tropical developing world where processes of modernisation are happening in remote regions.

It was also demonstrated the relevance and timelessness of modern architecture masterpieces and of the work of Le Corbusier that as mentioned by the architect Balakrishna Doshi established a standard and a framework for everything that was subsequent after it till our times and that opened possibilities for contemporary sustainable architecture after the end of the fossil fuels era.[20]

NOTES

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[12] Stein and Reynolds, *Mechanical and Electrical Equipment for Buildings*. (ASHRAE Fundamentals) 376. Also see Edward Arens and Hui Zhang, *Comfort and Health: Design Criteria and Guidelines for Air Movement and Humidity in Ventilated and Evaporatively Cooled Houses*, CEDR Research Report, (UC Berkley, January 25, 1995). 18-28.
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[15] Edward R Ford. *The Details of Modern Architecture. Volume 2. 1928-1988.* (The MIT Press 2003.) 6.41
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[16] Samuel Amos-Abanyie. *Effects of Thermal Mass, Window Size, and Night-Time Ventilation on Peak Indoor Air Temperature in the Warm-Humid Climate of Ghana*. *The Scientific World Journal,* (Wiley, June 2013),1-9.
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