IMPACT OF CLIMATE CHANGE ON FUTURE THERMAL PERFORMANCE OF RESIDENTIAL ARCHITECTURE OF PUNE, INDIA

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Abstract

This paper examines the impact of passive heating and cooling design options for climate change scenarios in Pune, India, both now and in the future. For the Typical Meteorological Year (TMY), 2050, and 2080 time slices of the Intergovernmental Panel on Climate Change (IPCC) A2 (medium-high) scenario, weather data were compiled. The findings show a strong correlation between the annual bioclimatic summer and winter discomfort hours and the optimum annual cooling and heating energy consumption for the changing climate scenarios. Adaptive thermal comfort graphs using ASHRAE 55 guidelines psychometric chart prepared using climate consultant shows that there will be drop in comfortable from 13% to 11% in 2050 and 9% in 2080. Due to rise in temp. summer months (April, May & June) reduces the maximum comfort hrs.by 2080 and building will require 49% cooling. Due to this energy consumption increase drastically.

Keywords: Bioclimatic Architecture, Future Predictions, And Thermal Performance.

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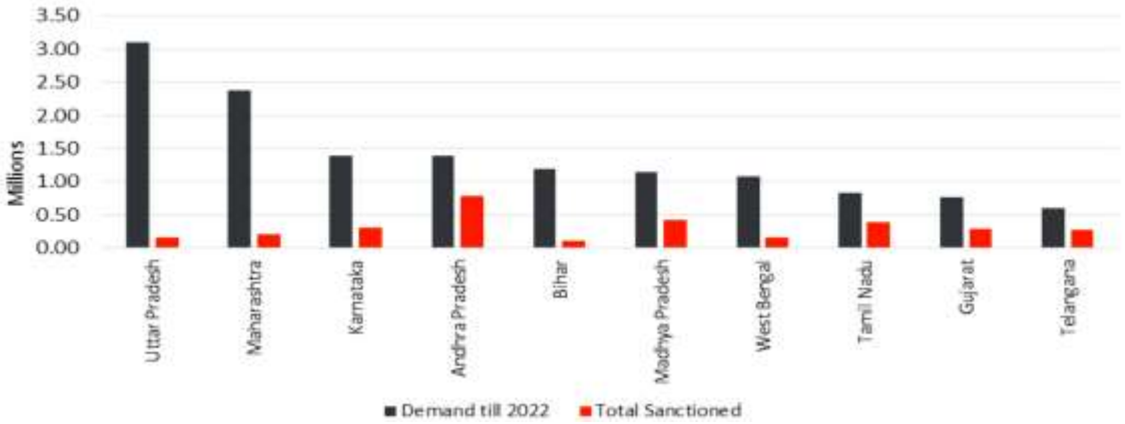
1. Introduction

In recent years, the performance of buildings and human settlements have been seriously threatened by temperature rise caused by climate change (Crawley, 2008). The Paris Agreement, which was agreed at COP21 in Paris in 2015, significantly strengthened global efforts to combat climate change. The main objectives of this Agreement were to achieve carbon neutrality by the middle of the century and keep global warming to 2°C compared to pre-industrial levels (preferably to 1.5°C) (Campagna & Fiorito, 2022).

Climate-sensitive shelter design is ingrained in human experience. Human experience has taught us how to create shelters that are climate-sensitive. A person's third skin is frequently described as a building, with clothing acting as the second to protect the first (biological) skin. These three factors cooperate to maintain the deep body temperature at 37 degrees Celsius (Vakharia & Joshi, 2022). Due to the depletion of energy resources and the threat posed by global warming, the building industry needs to develop sustainably through renewable energies and energy efficiency (Robert Amélie, 2012). Climate factors including wind patterns, sun path, temperature, and others have an impact on both the scale of a building and the scale of an urban area. If sustainability is defined as long-term viability, studying the architecture and urban patterns of old societies that survived the harshness of environment over the course of time may bring passive solutions to both architectural and urbanistic scales of design. (Azarbayjani, 2019). Even today's problems with resource depletion, greenhouse gas emissions, increased energy use, deforestation, and other problems can be solved by vernacular architecture.

It is essential to analyze the energy implications of housing development to avoid the lock-in of a sizable inefficient dwelling unit given the challenge of meeting the demand for affordable housing and the National objectives (Fig-1). Energy consumption can be significantly reduced by adopting energy optimisation to provide thermally comfortable housing, which is vital from a resilience approach. It is crucial to implement suitable passive cooling solutions in buildings to lower the high electricity level consumed by air conditioning. (Mohammadi et al., 2017). Due to their lack of access to adequate housing and basic amenities, urban poor people are particularly at risk from the effects of climate change, such as temperature increases and urban heat islands. Constructing climate-resilient housing will lessen these risks in terms of energy use as well as health. The study analyses climate change and its outcomes for Pune's traditional architecture in light of rising temperatures.

Figure 1 States having highest housing demand and its corresponding sanctioned stock (Source: Kumar, S., Singh, M., Chandiwala, S., Sneha, S., & George, G. (2018).



Climate of Pune (Warm humid)

Pune lies in warm-humid climatic zone. Being Warm, humid climates with high humidity and fluctuating degrees of rainfall and temperature characterize the lengthy coastline areas. The yearly and diurnal temperature variations in warm-humid regions are minimal. Throughout, the temperature fluctuates about the skin temperature. Thermal comfort inside can only be obtained by proper ventilation when combined with high humidity and continuous rain for 3–5 months(Indraganti, 2018).

Summer (March–May), Monsoon (June – September) and Winter (December – February) Pune experiences three distinct seasons (Fig. a & b) (Gohain et al., 2021). Typical summer months have maximum temp. 35°C to 39°C with recorded maximum temperature 43.3^0 C on 30thApril 1897. Typical winter months have minimum temperature of 11.3^0C with recorded minimum temperature of 1.7^0 C on 17th Jan 1935. The average annual Rainfall is 76.3 cm with 49 Rainy days average annual (Climate Research and Services; Pune, 2021) (table-1).

Table 1 Indian Meteorological Data for Pune (Source IMD)

Sr. No.	Parameter	Units	Remarks
	Average annual Maximum Temp.	31.7^{0}C	
	Average annual Minimum Temp.	17.8^{0}C	
	Mean Maximum Temp. of Hottest Months	37.3^{0}C.	April & May
	Mean Minimum Temp. of Hottest Months	21.1^{0}C	
	Mean Maximum Temp. of Coldest Months	29.7^{0}C	Jan & Dec
	Mean Minimum Temp. of Coldest Months	11.3^{0}C	
	Recorded Maximum Temp.	43.3^{0}C	30thApril 1897.
	Recorded Minimum Temp.	1.7^{0}C	17th Jan 1935
	RH – Monsoon (Morning)	77% - 86%	
	RH – Monsoon (Afternoon)	66% - 79%	
	RH - summer season	27% & 54%	afternoon and morning are about resp.

Climate change and weather data analysis

A structure's primary goal is to protect its residents from the elements. The practical use of these elements will depend on local cultural norms, resources, aptitude, and manner of life. Adaptability to climate change is one of a building's more recent functional requirements (Aysha & Mani, 2017).. Report published by The Energy and Resources Institute (MSAAPC, 2014) suggested rise in average temperature by 2030 over different regions of Maharashtra with the baseline and IMD data increase in temperature of 1-1.5o C during all seasons with warm nights are increasing more in the Pune and situation will be more critical in 2050 and by 2070 there will be 2.5 – 3^{o} C rise in daily average temperature in Pune. The Study is focusing on the vernacular features which act as passive design features and their practices in the summer and winter seasons. Study is also analyzing the impact of rise in temperature due to climate change on the built environment. The main objective of a structure is to shield its occupants from the elements. These features' actual implementation will be influenced by regional cultural practises, resources, aptitude, and way of life. A more recent functional necessity for a building is climate change adaptability.

Climate Responsive Strategies in Warm Humid Climate

Indraganti, (2018) research explores the bio-climatic vernacular architecture of different climate zones in India. Additionally, it gives examples of how a contemporary vernacular incorporated the bio-climatic spirit. In warm-humid climatic zones outside temperature, precipitation days, and Rh% The importance of flowing air in the interiors at body level plays a very important role. This requires an envelope with sufficient weather protection that is perforated. There isn't much of a temperature difference between indoors and out. Wada house from a warm, humid environment is inefficient at enhancing the fabric's thermal capacity. Airy semi-enclosed transition zones provide much better comfort conditions than the interiors in such a situation.

Shastry et al., (2014) analysis shows rise in temperature by 7^{O} to 10^{O} C by adoption of modern design and building material in summer months increases the need of HVAC systems to achieve indoor comfort. The presence envelope feature like roof overhang keep the room 3.5^{O} C cooler. The survey shows that the average occupant

expressed by the people in vernacular dwelling would lie outside the extended thermal comfort zone provided in Givoni's Bio- Climatic chart.

Thermal Performance

The climate-responsive architecture developed by the indigenous people is a valuable resource of history-long experiences that we can learn from (Al-Sallal & Rahmani, 2019). The weather in tropical climate countries is predominantly manifest in high humidity, high temperature, and intense solar insolation. In response to these climatic characteristics, traditional tropical vernacular housing is predominantly dependent on natural ventilation and passive cooling for thermal comfort (Zune et al., 2020). The resources for the built environment are derived naturally as in traditional/vernacular practices or manufactured as in conventional/modern practices. The built environment also depends on energy for its operation and maintenance to maintain live ability and productivity in the living environment (Aysha & Mani, 2017). Bioclimatic potential changes with a changing climate and therefore traditionally applied bioclimatic strategies at a particular location may become inefficient with time. This is particularly relevant in the conceptual stage of climate responsive building design for decision making as the architect can choose the most appropriate passive strategies with respect to present and future climate change scenarios (Kishore, 2022). The clothing of occupants is also an adaptation technique. However, the positioning and operability of openings should be given priority during the design process to ensure privacy (Aysha & Mani, 2017).

Vernacular architecture of Pune

The concept "local context" - including the climate - is a decisive factor in creating architectural spaces, along with the influence of cultural aspects (Nguyen et al., 2019). India numerous and varied building traditions have evolved in response to the sociocultural, economic, and thermal needs of the population; they demonstrate an extremely intricate thermal adaptation. (Gupta RR, 2013). The word "Wada" comes from the Sanskrit word "Vata," which indicates a plot of land intended for a house. The traditional dwelling, or "Wada," could be a single family's home or a collection of houses. Typically, it refers to a courtyard house mansion. (Sushama S. Dhepe, 2017). This House form belonged to both the ruling elite and the general populace. When it refers to historical, cultural, and economic factors, this typology is quite important. Even though there are multiple differences in size, scale, and economic standing, all Wadas share several fundamental components and features. There is an internal verandah around the courtyard for protection from rain and sun (Dili et al., 2010). Wadas housed the Brahmin aristocracy, the built form shows a significant Mughal influence in their design through the integration of courtyards with fountains, pools, terraces, arches, lattice windows, and balconies. Symmetry is an indispensable aspect of these houses. Wadas rise to two to three floors (Alapure et al., 2017).

The courtyard and the blocks around it are laid out strictly following the rules of dimensions, scale and proportions. Depending on the size and importance of the household, the buildings may have one or two upper storeys or further modules with enclosed courtyards. The enclosed courtyard is usually sunken. The verandahs opening to the courtyards prevent the intense solar radiation (Dili et al., 2010). The dense built fabric obstructs the entrance of the wind and the light into the individual spaces of vernacular dwellings. The majority of vernacular dwellings in the specific neighbourhood have been preserved to their original form, using traditional building materials and techniques (Michael et al., 2017).

Indoor temperature is relatively cooler in comparison to outdoor temperature. Temperature variations between indoor and outdoor temperature during the daytime are quite high, 6–8 °C, which indicates the passive-cooling efficiency of the Wada (Alapure et al., 2017).

Building Mass

Different construction materials have varying densities and capacities for storing and transferring heat. These characteristics, which include the ability to retain or release heat, define the buildings' thermal mass. Passive cooling and heating can both be accomplished using thermal mass (Bugenings & Kamari, 2022). Wada's greater thermal mass aids in establishing stable conditions inside the constructed shape. Hence, Wada's passive traditional methods are used to reduce both daytime and night time temperatures. These regionally specific traditional structures have passive cooling systems built right into them that respond to the climate (Alapure et al., 2017). The home uses its attic not simply for storage but also as a shield between the inside rooms and the sweltering summer sun and also reduces the temperature of below floors in summer (Alapure et al., 2017).

Openings and Shading Strategies

Solar shading systems are designed to block sun radiation, preventing warming inside the structure. By using a building's geometry, vegetation, or specific shading equipment, one can create solar shading. (Bugenings & Kamari, 2022). One of the distinctive features of the Wada is its balconies, which are also depicted in many of its well-known pictures. They are present on the first floor levels of the façade, with the exception of the ground floor. This opening occurs far more frequently than windows, which are only visible in a few spots and are almost usually on the last story. They typically measure 1.20-1.00 m wide and 2.20-2.40 m height (Rubio-Bellido et al., 2015).

Bioclimatic Analysis Future Strategies

Bioclimatic studies and related tools are essential for Architects to visualize and understand the local climate in relation to thermal comfort. Bioclimatic tools are primarily psychrometric charts used for investigating whether the local climate of a certain location can provide human thermal comfort (Khambadkone & Jain, 2017).

Design of a structure that takes into account the local climate and uses passive techniques to create a favorable indoor atmosphere with the least energy usage possible (Bugenings & Kamari, 2022). According to the Givoni bioclimatic chart in a Warm-humid climate, natural ventilation and solar shading are the most effective passive design strategies for improving thermal comfort (UN Habitat, 2014). Material selection should satisfy the needs of the user along with the environmental concerns, as the EE associated with manufactured building materials are high. Any material chosen should be less energy consuming as well as less polluting to the environment(Aysha & Mani, 2017). Adaptive Comfort model is defined in ASHRAE Standard 55, which it applies in naturally ventilated spaces where people can open and close windows. Indoor conditions are acceptable when average outdoor air temperatures are between 10 °C and 33.5 °C, and when indoor temperatures can be held within a specified 10 degree indoor operative temperature range (Rubio-Bellido et al., 2015).

The comfort model selected is defined in the 2005 ASHRAE Handbook of Fundamentals, which considers the aforementioned variables. Both models run in Climate Consultant, a tool developed by the UCLA Energy Design Tools Group, which uses Energy Plus Weather Data (EPW) files for each location (Rubio-Bellido et al., 2015).

The current bioclimatic classification and the sparsely conducted bioclimatic studies of India do not adequately address the climatic diversity of the country. Another interesting observation revealed that most of the bioclimatic studies did not consider the actual thermal comfort expectations, clothing preferences and behavioral adaptations of people living in their respective climatic zones (Khambadkone & Jain, 2017).

Based on the linear relationship between temperature amplitude and vapour pressure of the outdoor air, Baruch Givoni developed bio-climatic charts that predict the building comfort based on prevailing outdoor conditions. They facilitate an analysis of the local climatic characteristics on a psychrometric chart, which gives the concurrent combination of temperature and humidity at any given time for a specific air mass. ASHRAE thermal comfort zone can be plotted on the bio-climatic chart, and passive strategies that help in maintaining thermal comfort inside the buildings (evaporative cooling, thermal mass, natural ventilation cooling and passive heating) are also defined (Shastry et al., 2014).

Passive features in vernacular architecture of Pune

Thermal comfort inside a building affects how much energy its environmental systems use, and they are crucial to the sustainability of the structure. According to definitions, thermal comfort is the mental state that conveys happiness with the surroundings in relation to air temperature, humidity, and wind speed. (Dili et al., 2010).

Dhepe Sushama S., (2017) explore relevance between two types of architecture with help of case study analysis was done for plan form (Character and geometry), Space (Spatial configuration), Semi-open and Open spaces (Courtyard & verandah), Structural elements (Wall, roof, Staircase) and façade aspects to understand modification done of traditional architecture for contemporary architecture. This study increases the awareness amongst contemporary designers to adopt the regional design features and integrate traditional architectural style, characteristics, elements into conventional designs.

Wada contain two or three courtyards that are surrounded by various rooms. The first courtyard is designated as a public space for social gatherings, while the second courtyard is reserved for female-only rooms. The courtyard design is a long-term design plan that may meet a variety of functional, social, and bioclimatic needs. In Wada architecture, the courtyard is an integral part. Within one of the courtyards of the Wada, there is also a well and Tree which modifies the microclimate of built environment (Alapure et al., 2014). The courtyard design is a long-term design plan that may meet a variety of needs, including practical, social, and bioclimatic considerations.

2. Methodology

IPCC (Intergovernmental Panel on Climate Change) hadcm3 file and Climate change world weather file generator is use to generate synthetic weather data file for 2020, 2050 & 2080 years. The climate change world weather file generator (CCWorldWeatherGen) uses IPCC TAR model summary data of the HadCM3 (Hadley Centre Coupled Model, version 3) A2 experiment ensemble which is available from the IPCC DDC. Tool creates climate change weather files that are prepared for use in simulation programmes for building performance. It is based on Microsoft® Excel and converts "present-day" EPW weather information into climate change EPW or TMY2 weather files, which are compatible with most building performance modelling software. This tool's weather file generating algorithms are based on the so-called "morphing" methodology for transforming meteorological data to account for climate change, which was created by Belcher, Hacker, and Powell. shows a noticeable increase in temperature throughout the year for the minimum, average, and maximum temperatures. In this paper, IPCC data are used to simulate future energy performance of two types of buildings. TMY data are obtained by the Climatic Change Weather Files Generator. The A2 scenario describes a heterogeneous world, with slow population increase, differences among regions and social classes. The result is a medium-high emissions scenario (Palme et al., 2013).

Rise in temperature in Pune City

To understand Rise is temperature of Pune region weather data analysis has been for 30years of weather data using India Meteorological Data for Monthly Minimum and Maximum Temperature of from 1990 to 2019. The (Fig-3) illustrates an increasing trend for Pune city based on annual variation in maximum temperatures for the months of hottest month - April, Peak summer (April - May), and summer average (March - June). The average decadal temperatures show a 1.00–1.5 °C increase from 1990–2000 to 2009–2019. The influence of the temperature rise brought on by climate change is likely demonstrated by this maximum temperature increase throughout the hottest summer months in Pune.

As part of further study, the ASHARE Standard 55 current handbook of fundamental Model is taken into consideration, and the climate consultant tool is used. Dry bulb temperature, clothing level, metabolic activity, air velocity, humidity, and mean radiant temperature are the factors that determine thermal comfort. It is thought that the mean radiant temperature indoors is very similar to the temperature of a dry bulb. The PMV (Predicted Mean Vote) approach is used to determine the comfort zone for the majority of people. Residential settings offer a larger comfort range than buildings with centralized HVAC systems since people can dress according to the season and feel comfortable in greater air velocities.

Future Weather Data File

The constructed area of Pune has seen diurnal temperature fluctuations as a result of rapid urbanization and population increase and caused urban Heat Island effect (Parishwad & Shinkar, 2017). Wadas are created with the meteorological parameters of the location or region in mind. The rectangular linear plan with two or three floors has a central courtyard with surrounding verandah and rooms. Solar gains are controlled in Wada by taking into account the opening widths and timber windows, as well as the high thermal mass of the exterior wall, in order to reduce heat gain in the inside environment from the solar gain that is transmitted via the building envelope(Alapure et al., 2017). The transitions shift the indoor environmental conditions from a psychrometric zone of ventilation/evaporative cooling to a zone that would require active air conditioning. Limited accessibility to such advanced ventila- tion systems results in increasing discomfort among the occupants (Shastry et al., 2014). Cooling degree-hours (CDH) is used as a quantitative indicator for the evaluation of the cooling performance efficiency of the different ventilation strategies under study (Michael et al., 2017). The low-tech methods used in vernacular architecture can be used to create buildings and environments well-suited to local climate and culture (Nguyen et al., 2019).

Analysis & Results for Future Scenarios

Climate change A2(A2a, A2b & A2c) scenario generated using ccworldweather tool for year 2080 using climate consultant Comfortable hrs without using active strategy shows 9 % (788 hrs). Adaptive thermal comfort graphs using ASHRAE 50 guidelines psychometric chart prepared using climate consultant shows that there will be drop in comfortable from 13% to 11% in 2050 and 9% in 2080. Due to rise in temp. months (April, May, June, Sept & Oct) reduces the maximum comfort hrs.by 2080 (fig-4) and building will require more cooling.

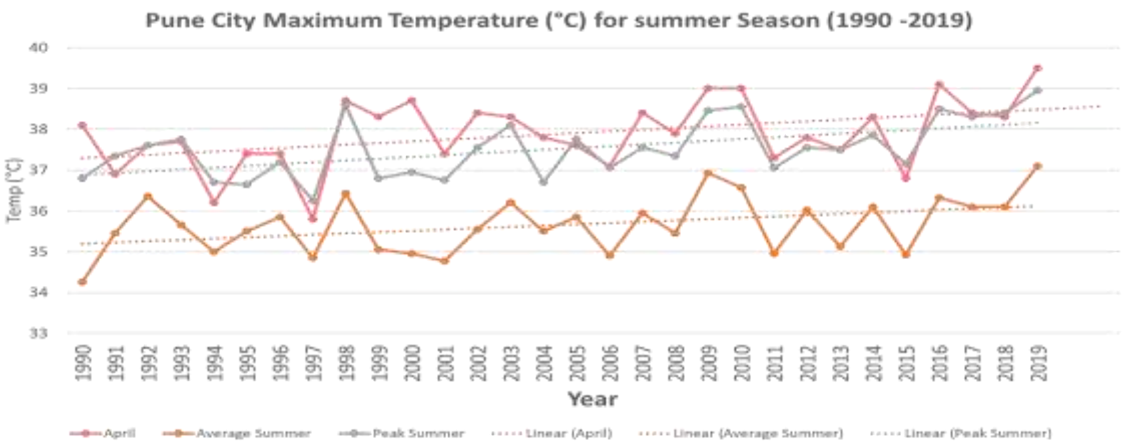


Figure 3 Graphs are plotted as per Weather Data from IMD

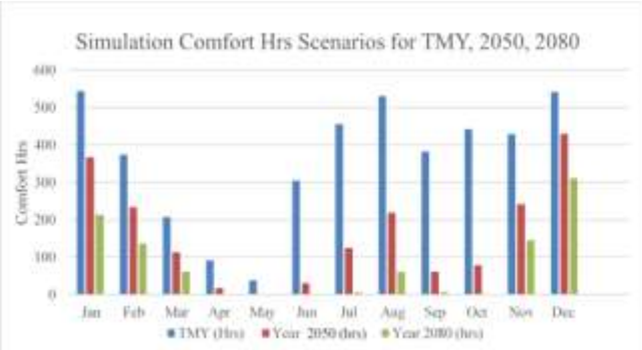


Figure 4 Simulation Comfort Hrs Scenarios for TMY, 2050,

Due to this energy consumption increase drastically. In comparison to the TMY climate scenario, all passive design criteria will be considerably less important in the future for reducing energy usage. This is due to the denominator in the future climate scenarios, which is the significantly increased construction energy use (Liu et al., 2020).

Impact of Passive Strategies using Bioclimatic Analysis Using Climate Consultant

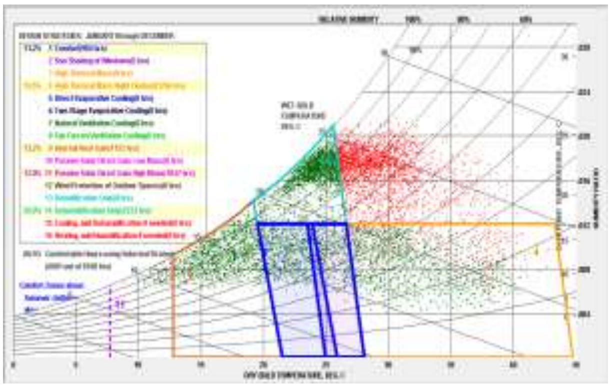


Figure 5 Bioclimatic analysis using TMY weather Data

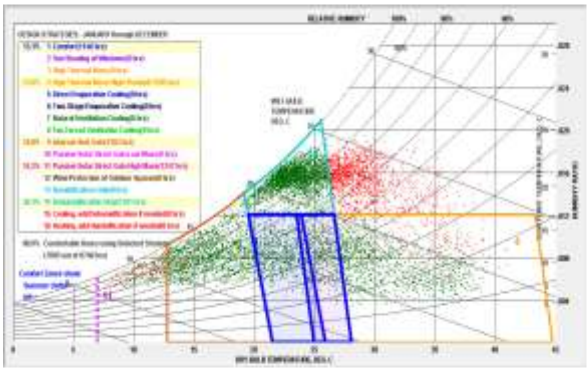


Figure 6 Bioclimatic analysis using 2050 weather Data

Observations:

By applying passive Design Strategies (High Thermal mass with Night Flush, Internal Heat Gain, Passive Solar Direct Gain High Mass) Active Strategies (Dehumidification) . TMY file (Fig-5) shows almost 81% Comfortable hours and remaining 19% can be achieve with help of HVAC systems. Year 2050 file (Fig-6) shows almost 69 % (12% less than TMY) Comfortable hours and remaining 31% can be achieve with help of HVAC systems. Year 2080 file (Fig-7) shows almost 51 % (38% less than TMY) Comfortable hours and remaining 49% can be achieve with help of HVAC systems

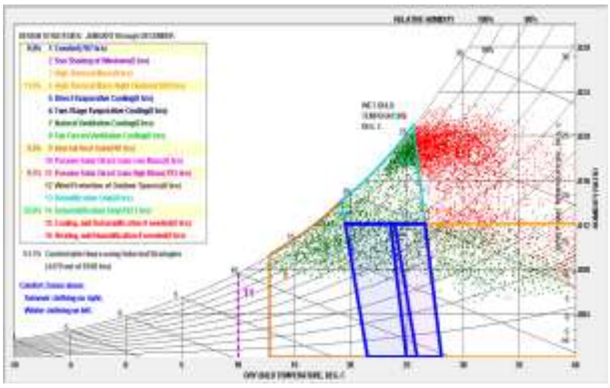


Figure 7 Bioclimatic analysis using 2080 weather Data

3. Conclusion

Using the CCWorldWeatherGen tool, the effects of climate change on houses were evaluated for the years 2050 and 2080 under IPCC SRES scenarios A2 (A2a, A2b, & A2c). Climate change raised outdoor temperatures year-round, influencing the internal environment as well. The effects of climate change were more obvious in Pune, where the warm, humid atmosphere made indoor temperatures higher than usual and necessitated the usage of cooling appliances. Winter outdoor temperatures are dropping as a result of climate change, while summer temperatures are rising. In the second part of the century, higher summer temperatures are likely. As a result of rising interior temperatures due to climate change will increase energy demand due cooling demand in the dwellings.

Buildings that are climate-responsively designed are urgently needed in Pune, especially in light of upcoming climate change events. The use of passive techniques would, to some extent, lessen the impact of climate change. If the environment gets warmer, the potential savings (in%) in annual energy use and the discomfort hours would go down. The observation mentioned above demonstrates that as yearly mean temperature and annual mean global solar radiation rise, the passive techniques currently in use will gradually lose their effectiveness. The design of new residential structures must consider both current and future climatic conditions, and existing structures must be retrofitted with suitable building envelope materials in light of a possible future with climate change.

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