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Passive Cooling Methods Adapted for Thermal Comfort in Havelies of Bikaner

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Abstract
In recent years, significant global concerns revolve around issues like climate change, pollution, resource depletion. The increasing temperature on Earth, primarily driven by human activities releases greenhouse gases (about 49.5 gigatons of CO2 per year) into the atmosphere, that has a wide range of impacts on both the environment and society. The Earth's ability to absorb carbon dioxide (CO2) is diminishing, leading to the depletion of the global ecosystem. The planet is undergoing warming, primarily driven by the construction industry, which has seen substantial increases in building materials, techniques, and energy demands. Nevertheless, traditional architecture has a history of practicing climate-responsive design. This research study centers on Bikaner, often referred to as the "City of 1000 Havelis" and is home to various business communities including Daga, Rampuriya, Kothari, and others. Havelies of Bikaner, which have been a source of pride for the Indian mercantile community, i.e. Marwaris, since the 16th century are influenced by social, cultural, climatic, and artistic factors. The planning, material selection, passive features of Haveli protects the inhabitants from the harsh impact of hot and dry climate of city. The narrow streets, thick walls, Aala gila work on wall & floor, courtyard, jharokha controls the indoor thermal balance. It is important to utilize traditional knowledge and integrate it with modern technology for holistic development.

Index Terms –Thermal comfort, Climate responsive Architecture, Passive cooling features

I. Introduction:

Space for living, studying, medical and other activities are the integral part of human life. From the beginning, one of the key factors influencing comfort in all contexts has been climate. It defines the condition of the built environment that allows for comfortable living and working. A poor designed space can create chaos. Early humans lived in caves that saved them from harsh effect of weather.
Since the inception of dwellings the continuous growth can be seen in planning, construction techniques and materials. The vernacular materials and techniques were used for the construction considering the climate, society and location. While In current years the construction industry has seen a massive development in both materials and techniques. Traditionally the materials like clay, stone, wood were used but now a day's modern material like cement, steel are preferred. With this development the criteria's for designing building has also changed. The modern materials and techniques have given the freedom to design high rise buildings. The high rise constructions are solution to the increasing population in urban areas but has resulted in ignoring basic criteria's to be considered while designing space like climate, resources (water, energy, sewage), transport,etc.. The material technology has

reinforced the modern construction and development. Of all **concrete** has changed the civilization. Concrete is favored for its weight and endurance. It's firmness is the most interesting quality. The advantages of the material increased its use but resulted in destroying environment& human living condition. While the use of traditional materials and methods are the desired and economical solution of this problem. The traditionally used local materials are economical , sustainable and as per climate. It has been studied that the thermal comfort in traditional vernacular buildings were far more effective. Especially in places where the climate is extreme the building design becomes even more crucial. The state like Rajasthan mostly has hot-dry climate zone with Thar dessert in one direction. The effects of the climate can be identified in Rajasthan's traditional architectural style. Western Rajasthan's traditional built environment has evolved in response to the adverse effects of a hot, dry climate through careful planning and the use of appropriate materials. Thermal comfort was a conscious contemplation in the design of these buildings. The design incorporates passive cooling techniques such as courtyards, jaalis, shading devices, and wall treatments. The thermal behavior of wall materials and increased thermal mass reduced the heat transfer of these structures significantly. The treatments like lime (meetha chuna) were used on wall and floor as it remained cool in summer and warm in winter. These ancient passive methods and plastering techniques need to be researched and preserved as using it in present context can increase the thermal performance of the building and resolve climatic issues.

Research Importance:

The major concerns globally in current years are pollution, water, rainfall, etc. The Earth's average surface temperature has risen by approximately 1.1 degrees Celsius (2.0 degrees Fahrenheit) since the late 19th century. This increase is primarily due to the burning of fossil fuels, deforestation, and other human activities that release carbon dioxide and other greenhouse gases into the atmosphere. The 20 warmest years on record have occurred since 1998, with the most recent years frequently breaking temperature records. The increase in atmospheric temperature due to greenhouse gas(GHG) emission has led to global warming. Among these carbon dioxide (CO_2) has capability to stay in atmosphere for years. CO_2can be emitted from various sources such as natural and man-made. Approx39% of the annual global CO_2 is contribution of construction industry. The embodied energy of building materials and process involved in construction plays a major role in pollution and other factors responsible for the environmental decay. Today we have all facilities due to modern materials and techniques even the lifestyle has changed. Life is comfortable due to services in buildings mechanically, electrically and others. But the energy consumed in the process is affecting the health of people also it is one of the measure reasons contributing for global warming. The modern architectural international style is considered inappropriate as it lacks the local climate and culture consideration. So there is a need to look into our traditional methods adopted in planning and architecture as it is one of the finest example of building designed by using low cost local material, low carbon and as per climate design. The old Indian traditional/vernacular constructions materials & methods are sustainable in nature as it is suited to climatic conditions, creating a comfortable internal environment passively and naturally. Traditional plasters used in ancient buildings were known not just for its finish, durability but also for thermal properties. The treatment was an effective tool in maintaining temperature. While modern materials lack this quality and possess undesirable thermal characteristics. The passive features used in the Havelies are brilliant example of maintaining thermal balance in harsh climate. Therefore, the integration of modern and traditional method is the need of time. So the focus will be on studying the traditional buildings of

Bikaner, Rajasthan and its passive cooling features affecting the thermal comfort like use of plasters, wall treatment, passive cooling methods, etc.

Research Methodology

Considering the nature of research, it was divided in three phases: Collection of data (related to city, climate, havelies), field work and finally its analysis. The research is analytical in nature. The research method will include:

a) Collection of data (Primary & Secondary)

b) Site visit & Study of climate

c) Identifying the role of architectural elements, materials used and passive features of havelies in controlling thermal comfort

Study Area-Bikaner in Western Rajasthan:

The Bikaner is located in western region of Rajasthan. The total area of Bikaner is 30247.90 sq.km and located at east longitude 28º1' , north latitude 73º19' This western part of Rajasthan has Sandy Plains where as its western region has hot arid plains and the eastern part falls under semi-arid plain. This region has sand dunes that cover the 'The Great Desert' .The economic activity of the area is influenced by sparse vegetation available in area. The climate of the region is very hot and arid. The temperature of western part exhibits a variation in temperature in summer from 30 to 48 degree Celsius while in winter 1 to 20 degree Celsius. Hot wind blowing in summer creates problem destroying vegetation, crops resulting in economic losses. The rain is deficient with average rainfall less than 26.37cm in Bikaner region where as less than 20cm on an average in rest of the region. However in east Jalor and Pali districts the semiarid vegetation is available.The Barmer district lies in seismic zone IV hence vulnerable to Natural Disaster where as other districts falls under seismic zone II or Zone III**.** In extremely hot and dry climate the protection is required from the solar radiation, glare and sand dust. The high temperature in summer and nights of winter effects the surfaces of construction resulting in swelling and contraction. Even then the use of local material and passive design features creates comfortable buildings. The air in Bikaner is generally dry, especially during the summer months. The low humidity levels contribute to the intensity of the heat and can cause discomfort, particularly during the hottest parts of the day.

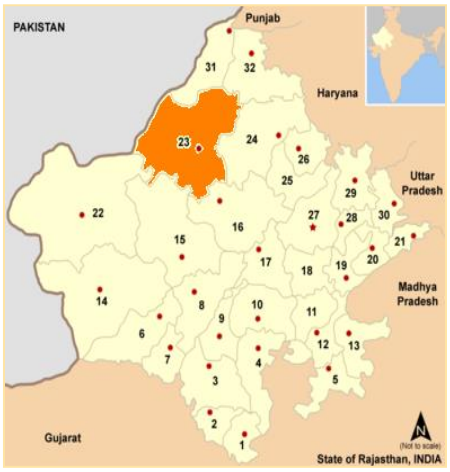

Fig.1 Map of Bikaner in Rajasthan (Source: https://www.rajasthan.gov.in)

Fig.2 Aerial View showing the compact form of city

Haveli:

The homes of wealthy merchants of Bikaner are the remarkable example of Indian architecture. The Havelies are 100 to 400 year old. Tough the etymology is not certain but it includes its origin from "hawa" or wind. The havelies appear narrow, vertical at the front while huge and royal from inside. These houses are called courtyard houses. The rooms are arranged around the courtyard and to increase its size the partial open space is added between room and courtyard. Also an effective tool in creating naturally ventilated environment. The haveli has 3 to 4 floors with partial underground floor being used for water storage in many cases. The orientation of haveli is east-west and streets towards north south to avoid heat and wind storm.

Thermal Comfort: In context of past and present

A building or space must provide a **favorable thermal environment**. As per international standard the definition of thermal comfort EN ISO 7730 is "the condition of mind which expresses satisfaction with the thermal environment". In simple words, is the comfortable condition where a person is not feeling too hot or too cold. Rather it's an experience that differs from person to person in similar space based on various criteria. Thermal comfort cannot be measured in degrees or expressed as an average range of temperature. Air temperature, mean radiant temperature, relative humidity, and air velocity are the physical factors that affect how warm or cold the human body feels. The metabolic rate, human clothing, activities are other parameters create impact. As per ASHARE a general comfort zone is defined and depicted in a psychometric chart, as seen in Fig.3.

We can see that the comfort zone varies for each climate zone.

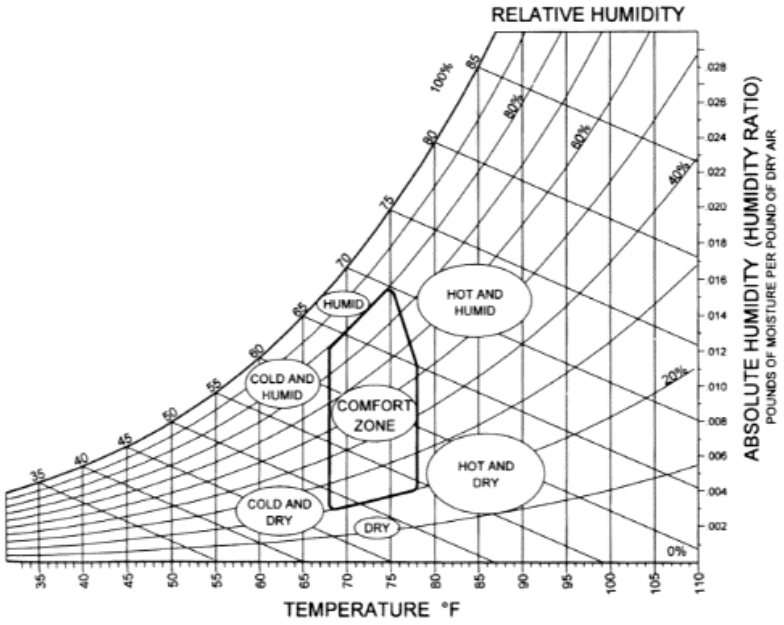

Fig.3 Comfort zone in Psychometric chart

The Indoor air quality and thermal comfort can be improved by using passive design features being used in traditional Indian architecture.

Passive design features

The diverse climatic conditions of India range from conditions like extreme hot, dry, rainy, humid, excessive cold, etc. For balancing these extremities natural ways should be adapted and energy should be used efficiently. Even the foundation of Indian Vedic philosophy is Human and environmental relation. The architectural heritage of our country reached to its peak due to sensible use of energy in space. Considering the current scenario the cost of energy is increasing in buildings. Due to modern technology and mechanical devices thermal comfort can be achieved but at cost our health and increased budget. We must include passive techniques adapted in traditional Indian architecture (like Havelies) to improve life quality and develop climate responsive architecture. There are various examples in our traditional architecture designed as per climatic needs and condition of the space. Passive features used in design were:

Courtyard Effect: is one of the most common features of old Indian homes. It's the center of social and cultural activities in our families**.** Also plays significant role in balancing indoor environment. Courtyard generally had direct effect of weather like the air becomes hot and rises up to replace it cool air takes its place. The cool air flow from each level and through the openings keeping the space temperature cool. The roof levels helps in diverting the air towards the courtyard. Generally the openings is provided at lower and upper level on every floor for proper air circulation. This is applicable in humid weather as well to keep the space cool. The intense temperature can be controlled by dual courtyard concept in which one had the vegetation, tree, even water body sometimes while another open to the sun but connected to each other for air movement. While Bikaner Havelies comparatively have small courtyards. The heat is stored during the day needs to dissipate at night. Proper openings, partial

open space all assists in radiating heat from both outer and inner surface. The projections aids in shading space.

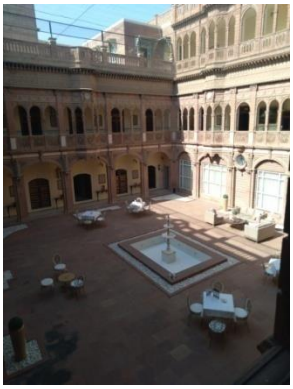

Fig.4 Courtyard of Rampuriya Haveli (Source: Author)

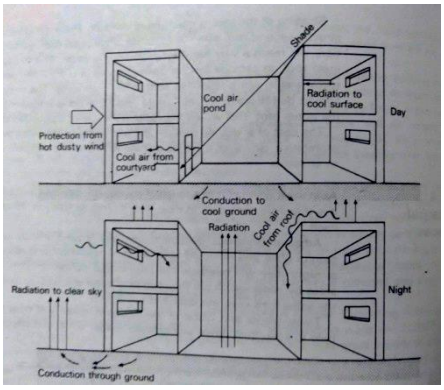

Fig.5 Air circulation in courtyard design from Manual of Tropical Housing and Building (Pg.206)

Fig.6 Courtyard of a Haveli (Source: Author)

Cooling and heating techniques using thermal mass& textures: Various materials have different thermal capacities. Selection of appropriate surface material reduces the heat load of the building. Increase mass or various treatments result in balancing environmental parameters. The walls are generally 24"or more made of small bricks cladded with lime plaster(meetha chuna is heated and filtered twice before application) or Dulmera stone. The stone claddings were intricately carved that increases the surface area resulting in distribution of solar heat. The interior wall insulation is ensured by fine finished lime plaster made of lime, marble powder and polished with semi-precious stone. Though the process of preparation is long still lime has been used for generations and evolved as a dynamic

breathing material. Lime plaster is highly breathable, allowing moisture to pass through the walls. Lime plaster is hygroscopic so it has the ability to absorb and release moisture from the surrounding environment. This property helps in reducing the sensation of stickiness and discomfort caused by high humidity levels, especially during monsoon or humid periods.

Fig.7a,b,c Araish a Traditional Lime Plastering Process, Finish & application on wall (Source:12a IGNCA. http://asi.nic.in/asi_exca_imp_rajasthan.asp , b&c Author)

The lime based plaster ensures heat conduction in winter and reducing heat in summers. Lime improves humidity evaporation. It allows water vapor to circulate through wall without degrading it. (refer Fig. 7a & b).
More Passive design features can be seen in traditional architecture according to the climate.

Room Sizes, high ceilings and heavy roof:
Havelies have a combination of compact size rooms with low and high ceiling. They are generally square with double height. With reference to courtyard size the room area is generally restricted. The high ceilings have moderate temperatures. Havelies rooms have heights more than 12’ to 15’. While the Jharokhas are generally at low height so it can be reached while sitting on the floor. As the area increases this result in temperature reduction. Insulated layer on Roof: Due to extreme heat the roof is insulated by using double layer of stone slab with wooden ceiling (Sal/Sagwan wood). The stone slabs are joined by lime mortar. The top layer is finished with lime plaster and mortar so the sunlight should be reflected.

Fig.8 Trick mirror & Raja Ravi Varma style paintings at Sopani Haveli

Fig.9 Wooden ceiling for heat insulation (Source: Author)



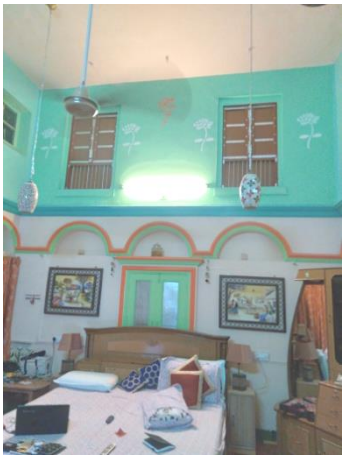

Fig 10a,b & c Ceiling is made out of slabs as shown and covered with wooden false ceiling for better insulation. In 10c double height room can be seen with windows for proper ventilation (Source: Author)

Haveli Envelops: Verandah, Overhang and Balconies/Opening, Window & Doors:

The building envelop plays an important role in managing the heat. The doors, window , jharokha, wall, roof all were designed carefully considering the environmental parameters. The façade material, doors, windows have high thermal inertia. The load bearing masonry exterior walls are cladded with intricately carved Dulmera sandstone. In interior these walls are plastered with lime. The doors and windows are made out of wood that reduces the heat conduction. The thick wooden section with heavy floral carving and stone jaalis enhances the thermal character of house.


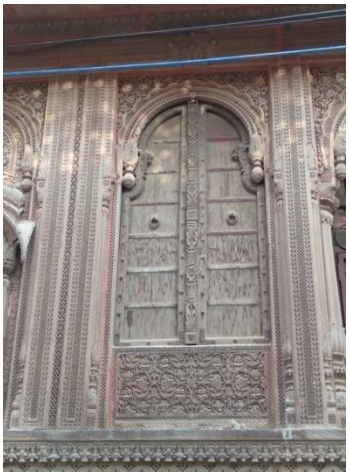
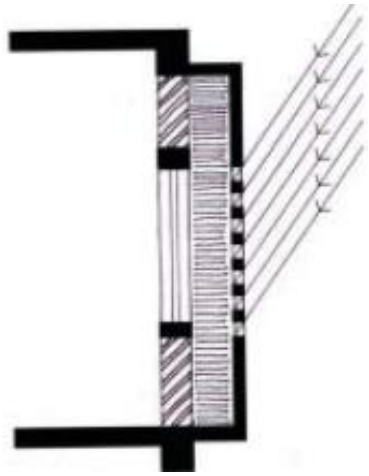

Fig.11a,b & c Jharokhas with jaalis for natural light , ventilation and privacy. Screens lower the air temperature, thus delivering a relatively cooler indoor environment (Source: a&b Author, c- https://cpwd.gov.in/Publication/IGDBooklet)

The Jharokhas are carved box like projections from the haveli casted in sandstone. Generally vertical of size 3'x6'. It has opening, sandstone floor crowned with arch. It creates a shadow effect in the street. The jaalis in jharokha cools the air stream and provides natural ventilation. This was used for sitting and enjoying the views of street by the females without hampering the privacy.

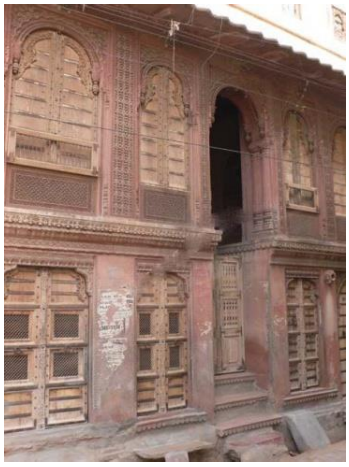

Fig.12a,b & c The external wall surfaces are carved and textured so that the area should increase hence the heat will be distributed (Source: Author)

Wide street which becomes narrow on top to reduce the effect of sunlight during day hours

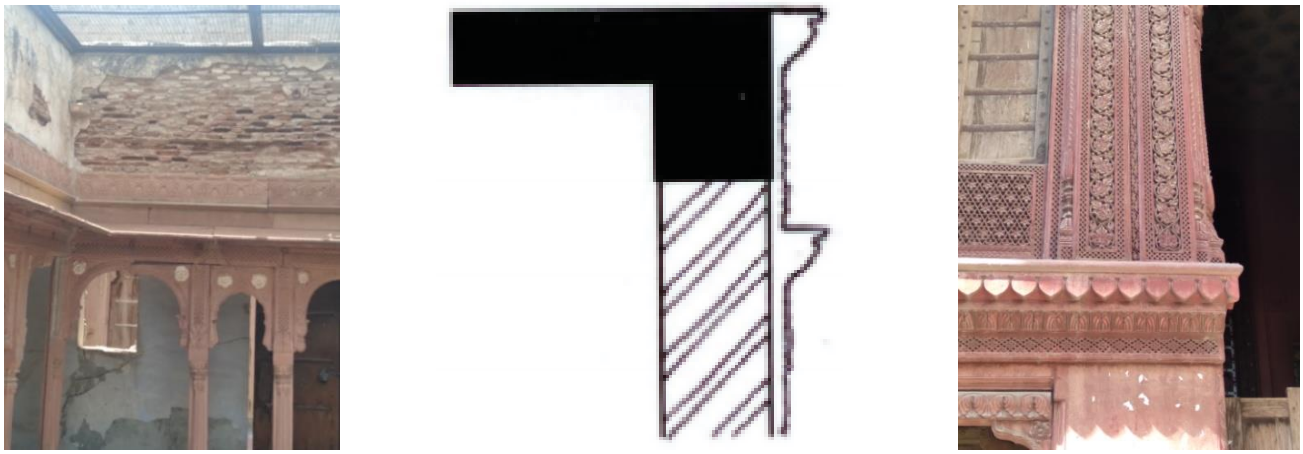

Fig.13a,b & c The external wall surfaces are carved and textured so that the area should increase hence the heat will be distributed (Source: a&c Author, b- https://cpwd.gov.in/Publication/IGDBooklet)

Streets and Building Orientation

The streets in Bikaner are organized against the direction of wind storm. The streets are north-south while the havelies oriented to east-west. The buildings orientation is such that the longer walls should be north facing and shorter walls face east and west. The shading effect can be seen in fig. …… The narrow streets and leveled buildings emphasize the shadow effect.

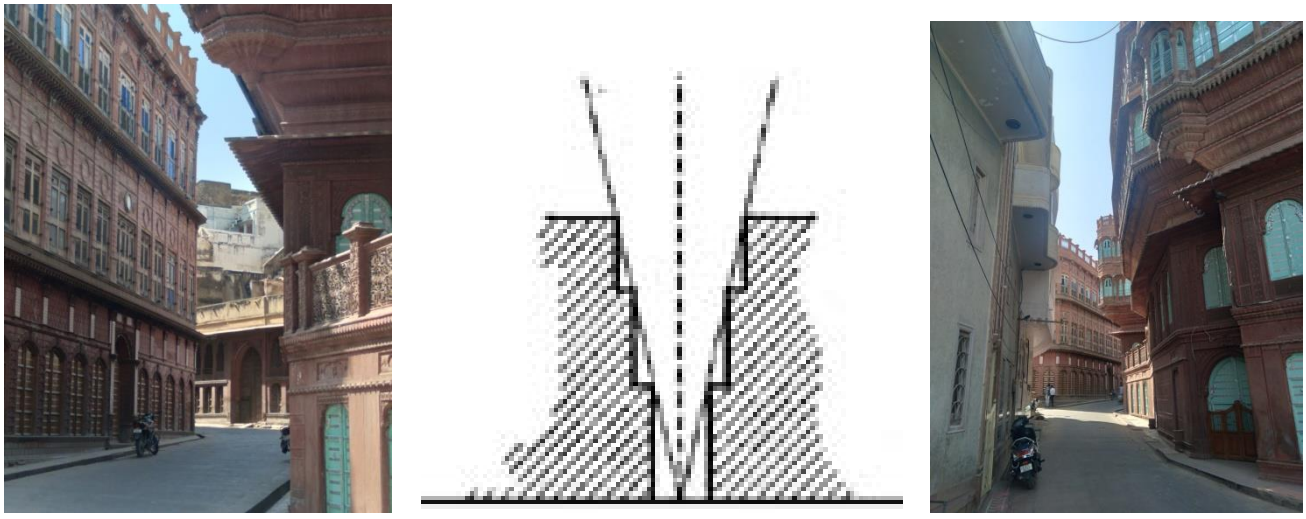

Fig.14a,b & c The havelies are constructed considering they provide shadow to each other.In image shaded streets can be seen during day hour. Street which becomes narrow on bottom to reduce the effect of sunlight during day hours (Source: a&c Author, b- https://cpwd.gov.in/Publication/IGDBooklet)

The clusters of havelies play an active role in controlling heat. The adaption of indigenous concepts like as courtyards and small streets is a powerful defense against harsh weather. Careful space composition in response to climate can be the answer for the built environment in hot and arid climates.

Fig.15a,b & c The building forms are compact with open, partial open and closed spaces (Source: Author)

Conclusion:

Rebuilding the human environment is currently the biggest priority for the construction sector worldwide. Our ecosystem is at danger due to problems like global warming, pollution, rising population, and uncontrolled cities. While traditional architecture might be linked to the ideal balance between the environment and people. Even if change is inevitable, good planning that considers every conceivable scenario has the ability to protect our legacy and create a more welcoming atmosphere. Instead, funding should be given to research and planning for climate-responsive architecture. Conventional building practices in terms of thermal comfort, air quality, and traditional architecture are excellent examples even today. India's dry, hot climate makes it necessary for buildings to have courtyards and other passive elements. The quality of the space can be improved by controlling openings, materials, and building orientation. It is now vital to rebuild our cities while taking into account regional factors. Before our environment becomes intolerable, researchers, architects, engineers, the government, and users must work together.

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