A Holistic Approach to Hotel Design in Delhi NCR

Apurv Aggarwal[1,2]*, Simos Yannas[1]

1: Architectural Association School of Architecture, London, United Kingdom;
2: Foster + Partners, London, United Kingdom
apurv1403@gmail.com

Abstract

Hotels, with their high energy demand and reliance on air-conditioning present significant design challenges. The paper draws upon occupancy patterns, guest surveys and energy use in built precedents to conduct detailed research on indoor and outdoor design strategies that balance guest comfort with minimal energy usage. These combine passive and mixed-mode approaches that invite protected use of outdoor and transitional spaces and a courtyard. Balconies feature elements such as jaalis, optimized facades, ceiling fans, and misting for comfort. Findings from extensive analytical studies show that use of non-renewable energy can be reduced by 70% while thermal comfort conditions in and around the hotel premises can be improved. The final design offers an attractive, immersive, and energy-efficient experience to guests while providing cost-saving options for hoteliers. It sets an example for future hotel designs in similar urban settings, inspiring sustainability in architecture and energy efficiency.

Keywords - Hotels, Subtropical Climate, Passive Cooling, Adaptive Thermal Comfort, Innovative Design

1. Introduction

Energy consumption in hotels is driven by the high comfort expectations of guests. Some 60% of revenue is reported as being allocated to energy expenses [6], with cooling representing half [15]. The paper reports on research conducted for a new hotel building in the National Capital Region of India. The region boasts more hotels (22,159) than Agra (2,260) and Jaipur (5,426) combined, other top regional tourist destinations in North India [10]. A prominent business hub and a major tourist destination in India, Delhi NCR attracts both business travellers (about 70%) and tourists year-round [11], ensuring high occupancy throughout the year.

The aim of the research was to explore strategies for reducing the high cooling loads characteristic of this building type in the climate of New Delhi. Selected design strategies were rigorously tested and combined in the design. The research outcomes are discussed, considering the unique site, context, and climate, with consideration given to their potential applicability to similar hotel projects. The site is situated within a commercial area surrounded by residential buildings. It covers approximately 2.5 acres, with each side measuring 100 meters.

2. Methods

Design research conducted for the project included surveys and site microclimate studies, dynamic thermal simulation, and daylighting studies. Analysis of Delhi's climatic conditions highlights critical parameters that pose challenges and offer opportunities for informing a hotel design (reference climate file: INDIRA_GANDHI_DELHI-hour.epw):

Solar protection: Optimum shading depths based on solar angles mitigate solar gain during summer while facilitating passive heating from the winter sun.

Variation in Summer and Winter temperature: Delhi experiences high summer temperatures with cool temperatures in the winter months (November to February).

Diurnal Temperature Range: The substantial diurnal temperature variation between October and June offers an opportunity for night-time ventilation for cooling during summers.

Wet Bulb Temperature: During summer months, the substantial difference between Dry Bulb and Wet Bulb temperatures encourages evaporative cooling to enhance comfort.

Prevailing Wind Patterns: To capitalize on prevailing winds that come from the Northwest and Southeast in summer, design elements should encourage a wind chill effect during this season. Incorporating shaded water bodies in their path can further enhance the evaporative cooling effect for outdoor areas.

1.1 Passive design strategies

The research took a base case of a prototypical air-conditioned hotel room interior, double-loaded corridors, fixed windows with Window-to-Wall Ratio (WWR) exceeding 60% and single glazing and conventional double-brick wall construction. The key parameters of this scenario are listed in **Table 1.** The variants studied by simulation with Energy Plus are summarized in **Table 2**.

Table 1: Typical hotel room - thermal simulation model details (CIBSE Guide A)

Room area	Floor height	Window wall ratio	Exterior wall u-value	Windows u-value	Floor u-value	Brick density	Brick specific heat	Concrete density	Concrete specific heat
22 m^2	3.6 m	60%	1.54 $W/m^2.K$	2.61 $W/m^2.K$	2.2 $W/m^2.K$	1750 kg/m^3	1000 J/kg-k	2100 kg/m^3	1000 J/kg-K

Table 2: Typical hotel room - thermal simulation loads

Occupants	Equipment load	Infiltration	Lighting density	Ventilation/area	Ventilation/person
2 persons/ room	7.32 W/m^2	0.000227 $m^3/s-m^2$@4Pa	11.84 W/m^2	0.000305 $m^3/s-m^2$	0.00236 m^3/s

The hotel guest room blocks were aligned along the site perimeters, incorporating courtyards between building blocks, with smaller wings housing other hotel functions. These design choices give rise to lower terraces accessible to guests and upper terraces for potential photovoltaic (PV) panel installation.

Solar protection: Provided by balcony projections and additional elements designed to shield against direct solar exposure.

Thermal Mass and Night Ventilation: Use of high thermal capacity materials such as rammed earth walls, exposed concrete flooring, and exposed cement coffered ceilings [2, 9]. Doors with reduced WWR of 50% enable guests to access balconies and enhance air exchange **(Table 3).**

Evaporative cooling: Passive Downdraught Evaporative Cooling (PDEC) systems applied to guest rooms for cooling [3, 4]. Air is circulated through shower towers located within the hotel premises. Cooled air is then distributed to rooms via mechanical ventilation systems (**Figure 1**). In tandem with these mechanical systems, solar chimneys are incorporated, inspired by a hotel design in Amsterdam [13], strategically positioned throughout the building to generate negative pressure and expedite the expulsion of hot air from the rooms. The sizing and distribution of the shower towers and solar chimneys align with specifications presented in Table 4. The overall building mass is configured to optimize solar access to these chimneys, thereby enhancing their operational efficiency, as depicted in **Figure 2**. The indoor temperature is calculated according to [7].

Table 3: Improved hotel room - thermal simulation model details (CIBSE Guide A)

Room area	Floor height	Window wall ratio	Wall u-value	Windows u-value	Floor u-value	Earth density	Earth specific heat	Concrete density	Concrete specific heat
22 m^2	3.6 m	50%	1.43 $W/m^2.K$	1.38 $W/m^2.K$	1.62 $W/m^2.K$	1500 kg/m^3	1800 J/kg-k	2100 kg/m^3	1000 J/kg-K

Table 4: Data to calculate size of solar chimneys and shower towers [13]

	No. of rooms (A)	Total area of rooms (estimated m²) (B)	No. of units (C)	Height (m) (D)	Sectional area (estimated m²) (E)	Total area (m²) = CxD (F)	Rooms per unit = A/C (G)	Room area per unit area = B/E (H)
Solar chimneys	198	3606	2	33	2.275	4.55	99	792.5
Shower towers	195	3606	1	33	3.62	3.62	198	996.1

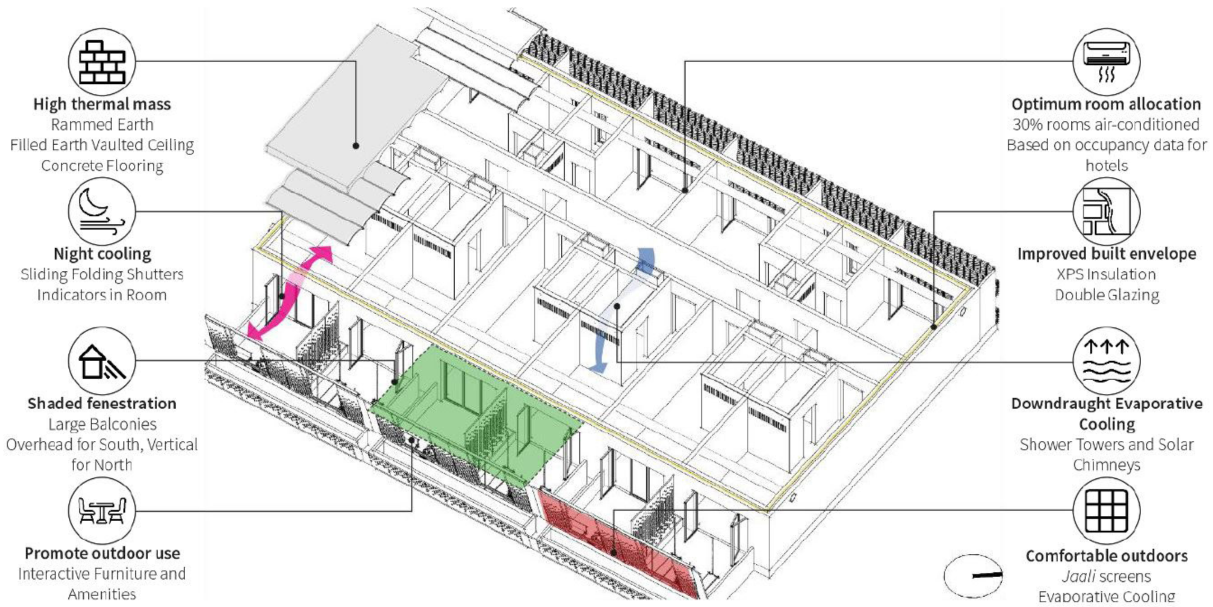


Figure 1: Indoor comfort strategies

1.2 Reducing cooling demand

Optimum room allocation: Hotels often contend with low daytime occupancy rates, particularly between 9 am and 6 pm when outdoor temperatures are at their highest. In such instances occupancy levels are as low as 10%, leaving a substantial majority of hotel rooms vacant during these hours [8]. To address this issue of unnecessarily using A/Cs when not even required, a stringent approach has been adopted where only 40% of the rooms are equipped with the option to utilize mechanical air conditioning (Figure 1). This is substantiated by an extensive survey conducted for this project among 126 North India hotel guests. The survey results revealed that while approximately 58% of respondents expressed a preference for alternative cooling methods over traditional air conditioning, a notable 40.5% of guests still opted for air conditioning even when it was not necessary.

Promotion of Outdoor Use: The survey also unveiled that guests (up to 65%) prefer spending time outdoors, if such facilities such as swimming pools or interactive landscape are made available. In addition to the provision of such amenities, we emphasize the importance of designing outdoor spaces for maximum comfort. To achieve this, a UTCI study identified outdoor areas requiring intervention (Figure 3), subsequently implementing passive design strategies, as discussed in the subsequent sections.

Solar Control: The approach to solar control involves winter sun access to south-facing facades (Figure 2). To further enhance solar control, the façade feature jaali screens [15] with their efficacy tested in Honeybee radiation analysis for both southeast and northwest facades, to arrive at an efficient geometric pattern (Figure 4). Additionally, by creating voids in building mass, shaded spaces are introduced to serve as outdoor seating areas (Figure 2).

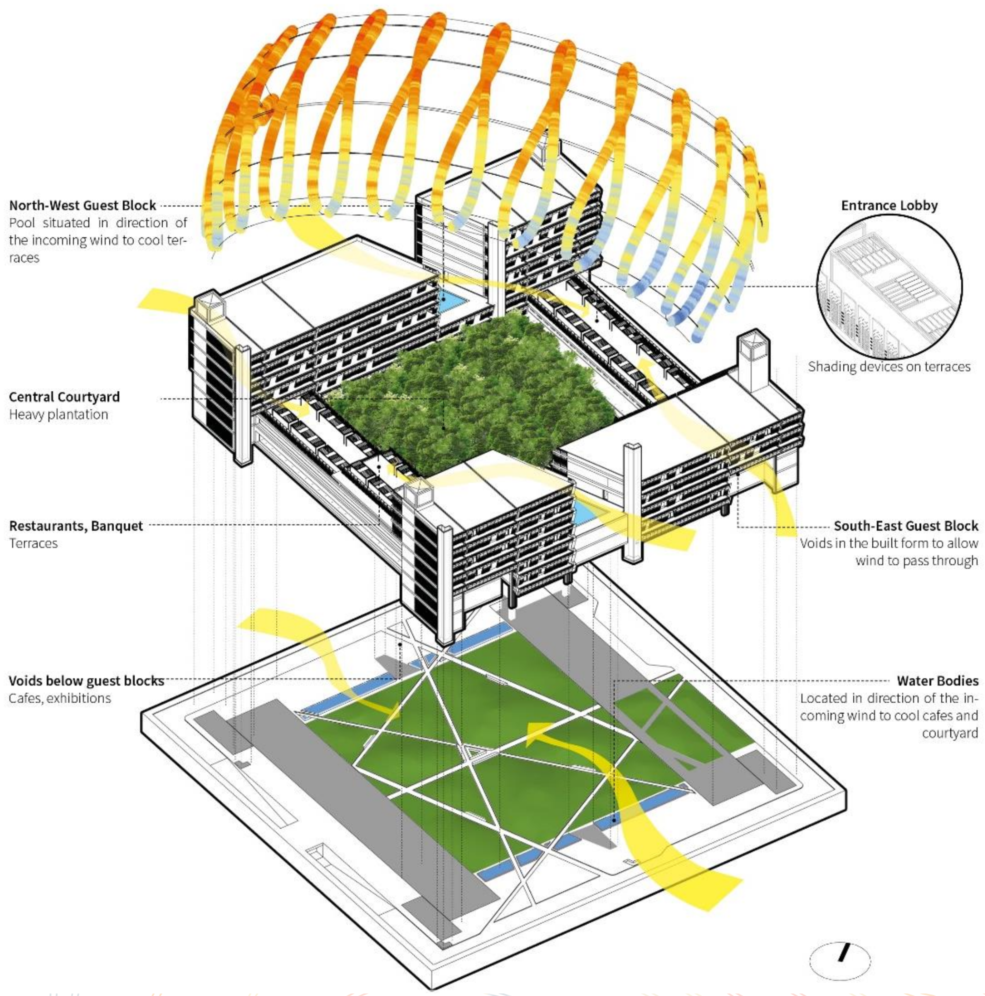


Figure 2: Development of building form and Outdoor comfort strategies

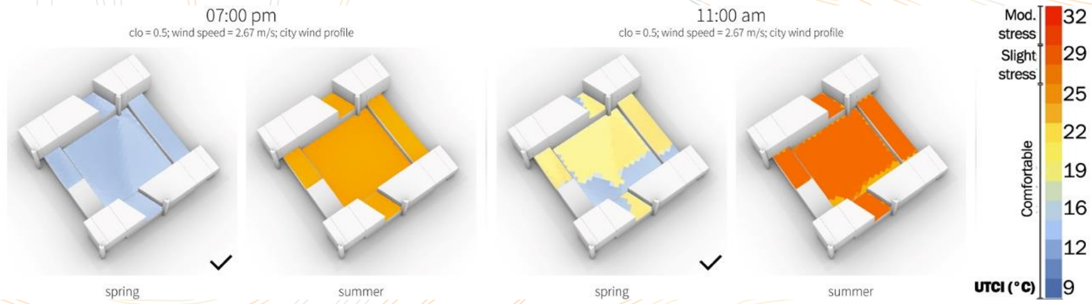


Figure 3: UTCI at 11am and 7pm on Spring Equinox and Summer Solstice

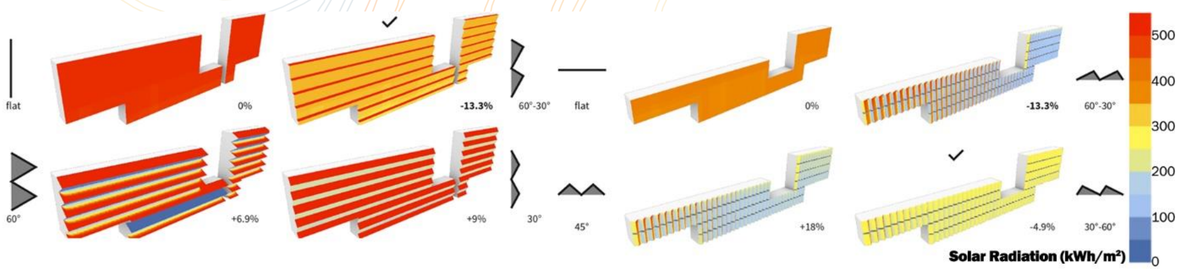


Figure 4: Solar radiation analysis for SW (left) and NW (right) facade from March 21 to Sept21 for different facade designs

Wind Chill Effect: To harness the benefits of natural ventilation, Computational Fluid Dynamics (CFD) studies informed the sculpting of the building mass to facilitate the ingress of wind into courtyards and terraces (Figure 2). To augment guest comfort on balconies, low-energy ceiling fans have been provided, further enhancing the wind chill effect.

Evaporative Cooling: Covered water bodies and swimming pools in alignment with the prevailing wind direction (Figure 2) enhance comfort levels through evaporative cooling for guests frequenting the courtyard and terraces. Moreover, balconies have been equipped with the option for misting, further enhancing guest comfort.

1.3 Renewable energy generation

Based on a usable roof area of 1400 m2 (60% of the total roof area), and an average solar radiation of 5.45 kWh/m2/day for Delhi [1], a plant size of 210 kW generates an annual yield of approx. 301,000 kWh/year, which translates to 83 kWh/m2, when accounting for the total area encompassing the guest rooms (Table 4). Assumptions include approx. 19% nominal efficiency (Standard Module type), fixed array modules, 14% system losses and 20% PV panel tilt towards south).

3. Results

Figures 5 and **Figure 6** illustrate the comprehensive deployment of these strategies on an exceptionally hot day in May and throughout the hottest month of June. The data shows the combined efficacy of the proposed strategies in managing energy loads, resulting in a noteworthy reduction of 21 to 43 kWh/day/room compared to a conventionally air-conditioned room (**Figure 7**).

Achieving outdoor thermal comfort is relatively straightforward except during summer daytime **(Figure 3)**. Nonetheless, solar protection and evaporative cooling alongside harnessing favourable airflow can significantly ameliorate the Universal Thermal Climate Index (UTCI) to a notably more comfortable range **(Figure 8).**

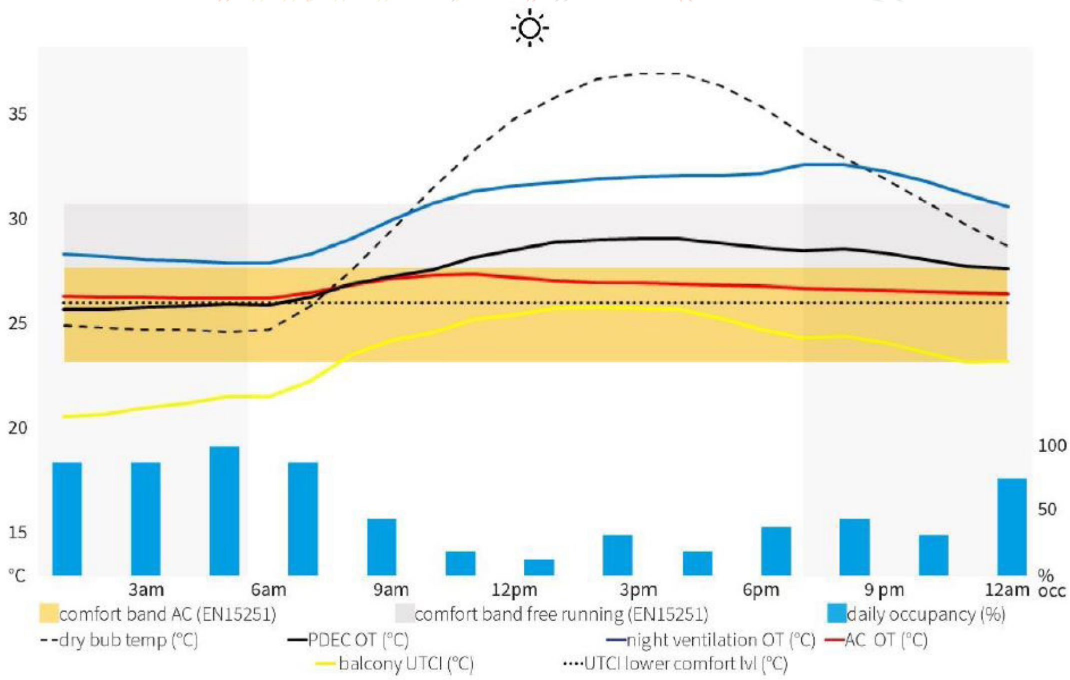


Figure 5: Thermal performance of final guest room design for an extremely hot day

A benchmark comparison against the Bureau of Energy Efficiency (BEE) India energy standards for hotels, stipulating 279 kWh/m²/year [5], showcases that the proposed target achieves an Energy Performance Index (EPI) of approx. 158 kWh/m²/year. Furthermore, the PV panels present the potential to further reduce energy consumption to approx. 75 kWh/m²/year. Consequently, this results in savings exceeding 200 kWh/m²/year when juxtaposed with hotel guest rooms (**Table 5**) relying solely on air-conditioning (**Figure 9**).

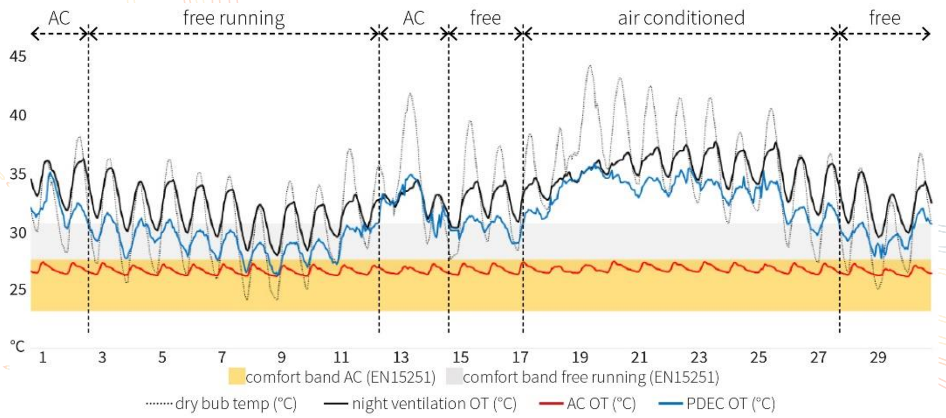
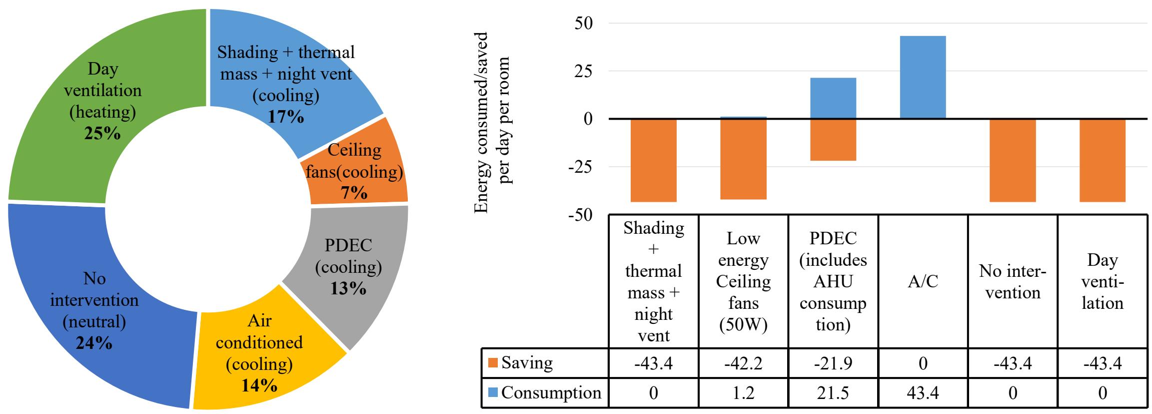


Figure 6: Thermal performance of final guest room design for a mixed mode room - depicting durations when a guest can use AC or not in June

Table 5: Assumptions for guest room energy consumption

Free running room area	Mixed mood (AC) room area	Lighting loads	Equipment loads	Total rooms in hotel
22.06 m^2	18.4 m^2	54 kWh/m^2/year	28.4 kWh/m^2/year	222



	Shading + thermal mass + night vent	Low energy Ceiling fans (50W)	PDEC (includes AHU consumption)	A/C	No intervention	Day ventilation
Saving	-43.4	-42.2	-21.9	0	-43.4	-43.4
Consumption	0	1.2	21.5	43.4	0	0

Figure 7: Annual hourly energy distribution (total hours 8760) for different strategies (left) and Energy consumption/savings of these strategies per guest room (right) in kWh/day/room compared to an air conditioned guest room

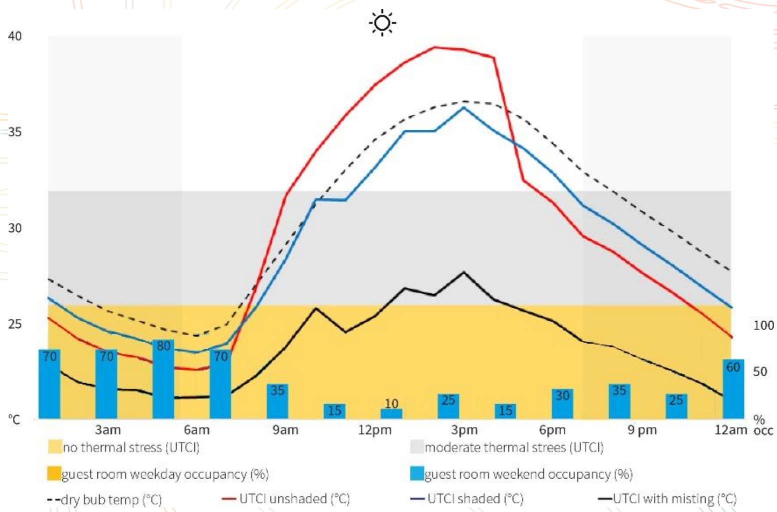


Figure 8: UTCI performance for courtyard - without shading, with shading by trees and for areas with misting or effective evaporative cooling by water bodies

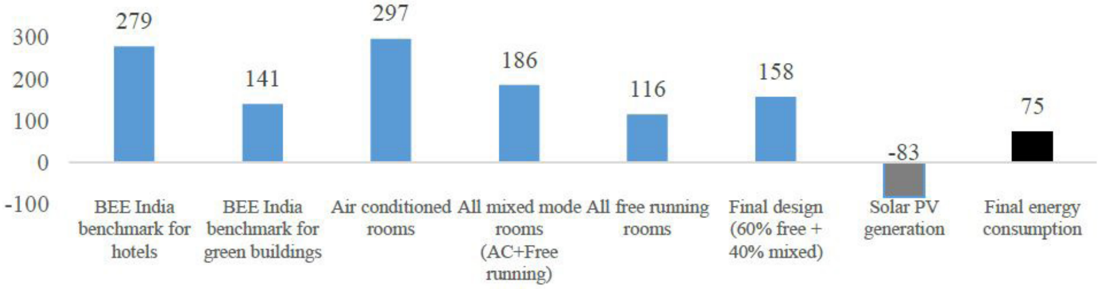


Figure 9: Final energy consumption of proposed hotel rooms compared to energy benchmarks (kWh/m2/year)

4. Discussion

In Delhi's extreme weather conditions, particularly during the sweltering summer peak, complete abandonment of air conditioning may not be a feasible proposition. This limitation stems from the high standards of guest comfort that such establishments are committed to providing. Nevertheless, the research has shown that a judicious fusion of passive cooling strategies, smart allocation of air-conditioned and non-air-conditioned rooms, and informed influence on guest behaviour, guided by contextual insights, can significantly mitigate the excessive reliance on air conditioning.

Outdoor areas, conventionally not subjected to conditioning, can achieve thermal comfort conditions through prudent application of passive design strategies. Encouraging their use can effectively reduce the necessity for guests to seek refuge indoors thus according outdoor spaces an equal significance in the design process. The adoption of sustainable building practices, encompassing the utilization of high thermal mass materials for construction and finishes, as well as the incorporation of local sandstone jaali for facades, contribute to an aesthetically pleasing architectural language (Figure 10) that is attuned to the specific climatic context while simultaneously appealing to the sensibilities of hotel visitors.

Furthermore, the research paper accentuates the role of building managers in comprehending the local climate and being equipped with the knowledge to judiciously apply specific strategies. The integration of technology can be instrumental in facilitating this process. Ultimately, in an era where hotels actively promote sustainability and cultivate a green image, the accrued carbon and monetary savings can be promoted and shared with guests.
It is imperative to acknowledge that the practical implementation of the aforementioned practices necessitates tailored research tailored to specific projects. These projects may vary in accordance with location, climate, user occupancy patterns, and the unique branding associated with a particular type of hotel.

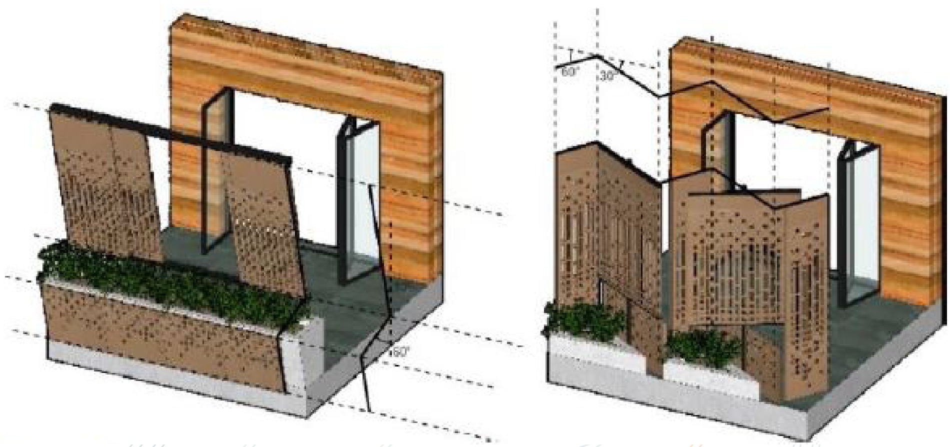


Figure 10: Typical south east facade (left) and typical north east facade (right)

5. Conclusion

The goal of this research paper has been to enhance guest comfort while simultaneously reducing energy demand. The examined design strategies are applicable to hotels of various scales and can help achieve lower energy targets. The study has revealed that basic enhancements, such as effective solar protection and night ventilation, can extend thermal comfort hours in guest rooms by up to 40% over the year. Moreover, during hot-dry periods, evaporative cooling techniques can enhance comfort by an additional 27%, effectively addressing typical summer daytime conditions. Combining shower towers with solar chimneys can prove effective in efficiently circulating air. These findings underscore the importance of adaptable building designs that cater to different seasons, with strategies ranging from PDEC in summers to simple ventilation in monsoons and material with high thermal mass in winter.

This research has underscored the significance of comfortable and inviting outdoor spaces. Guests are naturally drawn to outdoor amenities designed for thermal comfort. Applying principles like those used indoors—shaded spaces, induced air movement, and evaporative cooling—dramatically enhance outdoor user comfort. Thoughtful design, such as well-placed jaali screens for shading, adds to building aesthetics. The final design seeks to offer an aesthetically pleasing, engaging, and comfortable experience for guests.

7. References

[1] Alliance for Sustainable Energy, LLC. (2023, 03 14). PVWatts® Calculator. Retrieved from NREL's PVWatts® Calculator: https://pvwatts.nrel.gov/index.php

[2] ALVA Architects. (2021, January 19). The Lalit Mangar. Retrieved January 19, 2021, from http://alva.co.in/: http://alva.co.in/project/the-lalit-mangar

[3] Bronsema, B. (2013). Earth, Wind & Fire - Natuurlijke Airconditioning. Delft: Uitgeverij Eburon.

[4] Bronsema, B., Bruggema, H., Bokel, R., Meerstadt, O., Quist, M., Spoel, W. V., . . . Veerman, J. (2018, October). Earth, Wind & Fire: The Evolution of an Innovation (1) – 'Earth': Natural ventilation and air-conditioning using the climate cascade. REHVA Journal, 65-74.

[5] Bureau of Energy Efficiency, India. (2017). Energy Conservation Building Code 2017. New Delhi: Bureau of Energy Efficiency.

[6] CBRE. (2016). 2016 Trends in the U.S. Hotel Industry. USA: CBRE.

[7] Ford, B., Francis, E., Schiano-Phan, R., Thomas, P., Alvarez, S., Molina, J., . . . Errell, E. (2010). The Architecture & Engineering of Downdraught Cooling: A Design Sourcebook. (B. Ford, R. Schiano-Phan, & E. Francis, Eds.) UK: PHDC Press.

[8] Gallo, A., Gonzalez-Aguilar, J., Prodanovic, M., & Romero, M. (2014). Analysis of Demand and Energy Saving at Different Types of Hotels with Integration of Solar Systems and Geothermal Heat Pumps. EuroSun2014 Scientific Committee. Aix-les-Bains: International Solar Energy Society.

[9] Gupta, S. (2019, June 02). An ode to the lost architecture of rammed earth – Lalit Mangar Hotel. Retrieved January 19, 2021, from https://www.stirworld.com/: https://www.stirworld.com/inspire-visits-an-ode-tothe-lost-architecture-of-rammed-earth-ndash-lalit-mangar-hotel

[10] Hospitality Biz. (2011, August 18). Hotel industry in independent India: A journey from nowhere to everywhere. Retrieved August 14, 2020, from http://www.hospitalitybizindia.com/: http://www.hospitalitybizindia.com/detailNews.aspx?aid=11506&sid=20

[11] Kansara, D. (2019). Indian Hotel Industry - Review & Prospects. Mumbai: CARE Ratings Ltd.

[12] Ministry of New And Renewable Energy. (2021, January 01). Solar Rooftop Calculator. Retrieved January 23, 2021, from solarrooftop.gov.in: https://solarrooftop.gov.in/rooftop_calculator

[13] OZ Architect. (2019, December 01). Hotel Breeze Ijburg, Amsterdam. Retrieved January 20, 2021, from https://www.ozarchitect.nl/: https://www.ozarchitect.nl/projects/hotel-breeze-ijburg/

[14] Studio Lotus. (2015, January 01). RAAS Jodhpur. Retrieved January 19, 2021, from https://studiolotus.in/: https://studiolotus.in/showcase/raas-jodhpur/35

[15] Vasudevan, R., Cherail, K., Bhatia, R., & Jayaram, N. (2011). Energy Efficieny in India: History and Overview. New Delhi: Alliance for an Energy Efficient Economy.