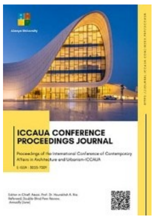

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Open Spaces in Low-Rise Residential Units in India: Urban vs Rural

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Abstract

Open spaces are vital in the spatial, climatic, and socio-cultural fabric of residential architecture. While vernacular rural homes integrate open spaces as multifunctional, climate-responsive elements, urban low-rise residences often treat them as regulatory obligations. Byelaws-driven setbacks have led to a significant gap in understanding how spatial configurations affect microclimate, ventilation, lighting, neighborhood interactions, and openings. This study undertakes a comparative, cross-regional analysis of open spaces in low-rise residential units across urban and rural India, integrating literature review, case studies, spatial composition mapping, and referring to building byelaws and codes. Findings reveal that rural, human-driven open spaces – particularly central courtyards and organically placed courtyards – outperform urban setback-based configurations in terms of microclimate regulations (up to 3 °C lower temperature and better daylight penetration), cross ventilation, and multifunctionality. Though compliant with building byelaws, urban setbacks often result in fragmented, underutilized, and climatically inefficient open spaces. Study recommends that the learnings from regional vernacular architecture be incorporated in urban building byelaws.
Keywords: Open Spaces; Rural Housing; Urban Setbacks; Climate Responsive Design; India.

1. Introduction

Open spaces are fundamental components of residential design, especially in low-rise houses, playing crucial roles in living quality and environmental performance. In India, traditional homes have long incorporated open areas like courtyards, front or backyards, otlas (raised front platforms), and verandhas as integral parts of the dwelling (Roy & Roy, 2016).
These spaces serve multiple purposes- facilitating social interaction and enhancing natural lighting and ventilation. (Gulati, 2020) In contemporary urban settings, however, the provision of open space is often governed by building bylaws that mandate setbacks (minimum open yards) around structures, in contrast to the more organic, human-driven open space configuration seen in rural homes (Byahut, 2020).This is in contrast to rural areas, where the availability of land is generally greater, enabling larger open spaces that often serve multiple purposes, including agriculture(Saxena, 2018) This research paper offers a comprehensive comparative analysis of open spaces in low-rise plotted residential units in urban versus rural contexts across India. It examines how these spaces differ in usage, their functions in household life, and their impact on indoor comfort and the surrounding microclimate(Ar. Vanishree Mysore Ranganath, 2019)
Particular attention is given to regional and climatic variation- for instance, how a courtyard in a hot-dry region like Rajasthan functions versus one in a warm-humid climate like Kerala (Gajjar & Bhavsar, 2019). The discussion further contrasts vernacular, user-driven byelaws with modern byelaws driven by setbacks, drawing evidence-based insights on thermal comfort, community integration, and spatial functionality (Asrani, 2021).

1.1 Background

In Indian vernacular architecture, open spaces such as courtyards have been a ubiquitous feature across regions (Vedhajanani & Lilly Rose, 2016). They appear in myriad forms -havelis of Rajasthan, Nalukettu homes of Kerala, wada houses of Gujarat, reflecting regional cultural and climatic needs (Gajjar & Bhavsar, 2019). Historically, these courtyards and open yards were central to family life and were often shared within the neighbourhoods, reinforcing community bonds in clustered settlements. In modern urban areas, rapid urbanization and changing family structures have led to a decline in such traditional open spaces (Gulati, 2020). Building regulations typically require a fixed open margin around each building (setbacks) to ensure light, air, and privacy, but these often yield fragmented or underutilized strips of open space rather than a cohesive central courtyard and community (Byahut, 2020). With increasing reliance on mechanical cooling and high land values, many urban houses maximize built area and treat open space as leftover, in stark contrast to rural homesteads, where open space is purposefully integrated into daily living. This study explores these contrasts in detail. It draws on scholarly literature, field studies. And building codes to evaluate how open space design influences microclimate moderation, illumination, ventilation, and pollution mitigation in homes (Gulati, 2020).

Furthermore, it investigates how the presence or absence of well-designed open areas affects social interaction both within the household and with the surrounding community. By comparing cases across different climatic zones- from the hot, dry Thar desert to the cold Himalayan hills- the paper highlights climate-responsive strategies inherent in traditional designs (Shama & Motlak, 2019). The ultimate goal is to distill lessons that can inform better housing design and policy: bridging the gap between organic, culturally rooted approaches and formal regulatory frameworks (Nouri, 2015). In the following sections, we first compare the spatial composition of open areas in urban versus rural residences, then analyze their functional roles, environmental benefits, and community connections. We then discuss regional climatic adaptations and finally offer recommendations for integrating the strengths of vernacular emergency planning and bylaws.

1.2 Open Space Composition in Urban vs Rural Houses

1.2.1 Urban Plotted Houses

In Indian cities, low-rise plotted houses are typically constrained by smaller plot sizes and regulatory standards. Municipal bylaws mandate setbacks-minimum open spaces on the front, sides, and rear of the plot, for light, ventilation, and fire access. These setbacks result in peripheral open space wrapping around the building. For example, a common requirement might be a 3m front setback and around 1.5-2m on sides and rear for a single-family house, though exact dimensions vary with the plot size and local rules(Byahut, 2020) . In practice, the composition of open space in urban houses often consists of a narrow front yard, small side strips between the houses and boundary walls, and a backyard or service area. The total open area as a percentage of the plot in urban houses is often limited; many cities' bylaws permit 65-75% ground coverage on small plots, leaving only 25-35% of the land as open space, often fragmented around edges (Byahut, 2020).

This pattern contrasts with older traditional urban homes (eg, courtyard-centric pol houses in Ahmedabad, Chettinad mansions in Tamil Nadu), which, although in dense settings, devoted a significant portion of the site to a central courtyard. Modern urban layouts, however, usually lack a large contiguous open court space due to the push for maximal built-up area and the enforcement of evenly distributed setbacks (Gangwar & Kaur, 2020). As a result, urban open spaces can be characterized as bylaw-driven: their size and placement are predetermined by regulation rather than by occupant preference. While this ensures every dwelling has some open air around it, it can also mean the open areas are residual and not actively used for living functions (Gulati, 2020)

1.2.2 Rural Plotted Houses

In rural India, low-rise houses (often single-story/two-story) are usually situated on larger plots or within family compounds, with an open space configuration driven by the occupants' needs rather than any formal regulations. The composition of open spaces in rural settings tends to be more organic and spacious (Ruda, 1998) A typical rural homestead might include a central courtyard (angana), around which the house or a cluster of rooms is arranged (Gupta & Joshi, 2021)., and ample front-back yards used for farming-related activities, animal rearing, or extensions of the living area (Yuan et al., 2021). Often, multiple structures (living rooms, kitchen huts, storage sheds) are distributed around an open courtyard within a fenced or compound area. The front yard in many villages is an extension of the street- a semi-public space where social interaction occurs and household work like grain drying is done (Gulati, 2020). Side and rear setbacks in the urban sense are not a conscious design element in villages; instead, spacing between structures is determined by practical needs (privacy, access to sun, wind flow, etc) and communal agreements. In many cases, rural homeowners enjoy a high ratio of open spaces to built-up areas. These open areas are human-driven, meaning they result from lifestyle and climate adaptation, rather than any codified rule. The layout of buildings and voids is often geared toward creating a comfortable microenvironment. This was observed in vernacular desert settlements where homes cluster tightly to minimize sun exposure on external walls, thereby sacrificing individuality and setback space for a cooler collective environment. Overall, rural open spaces tend to be larger, more centralized (courtyards), and multifunctional compared to their urban counterparts (Vedhajanani & Lilly Rose, 2016).

Table 1: Comparative Open spaces Characteristics- Urban vs Rural Low-Rise Houses.Source: (Gupta & Joshi, 2021).

Aspect	Urban low-Rise (bylaws-driven setback)	Rural House (Human-driven Space)
Typical Open Space Layout	Fragmented around plot edges (Front yard, side strips, small backyard)	Centralized and spacious (e.g. Central courtyard, front/ backyard) Within a compound. Buildings are arranged around an open core.
Propotion of Open Area	Limited (often 20-35% of plot area open) due to high ground coverage in cities.	Generous (often >50% of Homestead area open) Built Form occupies a smaller portion. Open land left for agriculture, gardens, or future expansion.
Design Determinants	Regulated by municipal bylaws, setbacks are set for light, air, and privacy. Aimed at separating buildings.	Determined by user needs and tradition- e.g., need for outdoor work space, climate adaptation (breeze paths, shade), family/social uses.
Functional Zoning	Front setback is sometimes used to decoratively (garden) or for parking; sidtilitarian (pathway, service), but not major living areas. Privacy walls may isolate These spaces are from the street.	Courtyards and yards are integral living spaces, used for cooking, sleeping on hot nights, drying crops, keeping livestock, and socializing often have a few barriers with the surrounding nature or neighbors.
Relationship to House	The house is typically inward-facing or oriented to the street; setback spaces may feel like leftover gaps around the house. Limited direct integration with indoor spaces (Except perhaps via a veranda in front)	The house opens onto a courtyard/veranda; a seamless flow between indoors and outdoors. Rooms often have doors to the courtyard, making it the focal point of daily life.

1.3 Problem Statement and Research Gap

Open spaces have traditionally played a crucial role in Indian residential architecture, contributing to environmental comfort, social interaction, and cultural continuity. In contemporary urban development, open spaces are largely dictated by rigid building bylaws, resulting in fragmented and underutilized setbacks that do not support thermal comfort or active social use. In contrast, rural houses in India continue to feature organically planned open spaces, such as courtyards and verandahs, that are multifunctional, climate-responsive, and socially embedded. Despite the recognized importance of open spaces, there is a lack of comparative research that evaluates their spatial composition, usability, and environmental performance in both urban and rural low-rise residential settings. Current planning policies and building regulations often emphasize quantitative compliance (e.g., percentage setbacks) over qualitative aspects like spatial continuity, climatic adaptation, or community engagement. As climate change intensifies and cities grow denser, the absence of contextually informed design standards for open spaces in low-rise housing poses challenges to sustainable and livable environments.

Existing literature focuses separately on vernacular rural housing or urban planning norms, with limited comparative analysis between the two. Bylaws typically regulate urban open spaces, resulting in fragmented, underutilized setbacks. Rural open spaces are organically designed, multifunctional, and climate-responsive, yet understudied in formal architectural research. There is a lack of empirical studies examining how open space design affects microclimate, ventilation, and social interaction in both contexts. No comprehensive research addresses how regional climatic and cultural factors influence open space design in low-rise housing across urban and rural India. A clear gap exists in connecting vernacular wisdom with contemporary urban housing policies to inform climate-sensitive and livable design.

This research addresses the need to bridge the knowledge gap between traditional, human-driven open space design and modern regulatory approaches by comparing urban and rural case studies across India.

2. Materials and Methods

This research focuses on understanding and comparing open spaces in low residential units in both urban and rural spaces. For which we have taken 2 case studies of Haryana and Punjab-representing the contrast in North India. The selection of these two states was based on their climatic similarity (hot semi-arid climate), similar cultural contexts, and differences in urbanization patterns, which provided a balanced ground for comparative study.

In each state, two representative sites were selected- one urban and one rural. The urban sites included S.A.S.NAGAR (Mohali, Punjab), Karnal (Haryana), while the rural samples were taken from villages Badhshahpur (Karnal, Haryana) and Samana (Punjab). These two were chosen based on the following criteria:

- The dominance of low-rise residential typologies, typically G+1 or G+2 structures.
- Availability of reliable planning documents, development control regulations (DCR), and recent satellite imagery.
- Presence of distinguishable open space configuration such as courtyards, front and rear setbacks, community spaces, and street widths.
- Geographic and climatic consistency to ensure validity in simulation-based comparison.
- This strategic selection of case study areas allowed the research to effectively analyze the spatial, regulatory, and thermal characteristics of open spaces in various settlement patterns.

2.1 Data Collection

The data used in this study were both quantitative and qualitative and were obtained from a combination of primary fieldwork, government sources, and secondary literature.

a) Secondary Data Collection

- Zoning Regulations and DCR: Documents were accessed from the Town and Country Planning Department of Punjab and Haryana to extract regulations of Floor Area Ratio (FAR), ground coverage, setbacks, and building heights.
- Satellite Imagery and GIS Maps: Open-source platforms such as Google Earth and Bhuvan (ISRO) were used to assess built form, land use patterns, and vegetation cover.
- Census and Development Plans: To understand population density, land use classification, and socio-economic background of selected areas.

b) Primary Data Collection

- On-Site Measurements: For Rural areas, where formal records were less consistent, field surveys were conducted to measure setbacks, open spaces, and built-up areas.
- Photographic Documentation and Sketches: These helped validate simulation models and understand spatial usage patterns.
- Resident Interaction: Informal conversations with residents were conducted to comprehend usage of open spaces, shading strategies, and perception of thermal comfort.

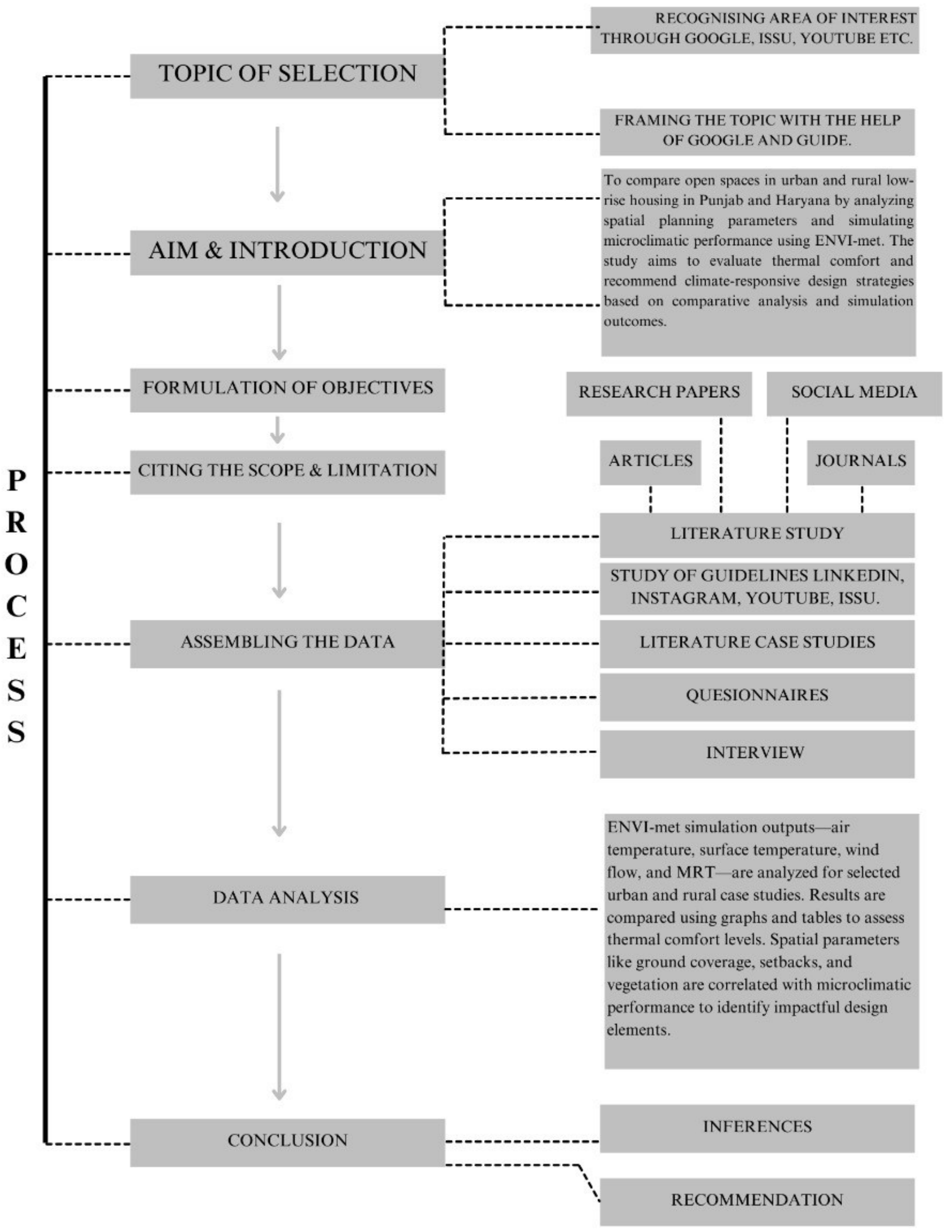

Figure 1. Research Methodology of the present investigation (Authors).

2.2 Key Parameters Recorded

One of the key datasets used in this research was extracted from the Haryana Building Code,2017 issued by the government of Haryana. Table 03 outlines the planning norms applicable to various residential plot sizes in urban areas of Haryana. It details maximum permissible ground coverage, Floor Area Ratio(FAR), building height limits, setbacks, and basement permission for different plot categories, ranging from up to 100 sqm to above 1000 sqm. For instance, smaller plots (up to 100 sqm) are allowed a ground coverage of 66% and a FAR of 165%, while larger plots (above 500 sqm) are restricted to 60% ground coverage and a FAR of 100%. The table also prvides information on minimum front and rear setbacks and confirms that only a single-level basement is permitted across all categories. This data served as a baseline for comparing open space standards and regulatory practices in urban settings with observed patterns in rural residential areas.

Table 2. Different plot sizes of Haryana with various ground coverage and setback (Urban Area).Source: Haryana Government The Haryana Building Code, 2017.

Sr.No	Plot Area	Maximum Permissible Ground Cove	Permissible FA	Maximum Perm Height (G+3 including Stilt S+4)	Minimum Fron Rear setback (in	Permissible Basement
1.	Up to 100 Sqm	66%	165%	15.0	F1.5, R1.0	Single Level
2.	Above 100-250 Sqm	66%	145%	15.0	F2.5, R2.0	Single Level
3.	Above 250-350 Sqm	60%	130%	15.0	F3.0, R3.0	Single Level
4.	Above 350-500 Sqm	60%	120%	15.0	F3.0, R3.0	Single Level
5.	Above 500-1000 Sqm	60%	100%	15.0	F4.5, R4.5	Single Level

Another essential dataset used in this research was derived from the Punjab Urban Planning and Development Authority (PUDA) Building By-Laws. The table outlines permissible development controls for different residential plot sizes in urban areas of Punjab. These include Maximum allowable ground coverage, Floor Area Ratio (FAR), building height, and basement permissions. Unlike Haryana's Fixed percentages, Punjab's building regulation apply variable formulas based on plot size to calculate ground coverage. For instance, for plots between 60-100 sqm, the permissible ground coverage is calculated using a modified formula: 0.70 X (Plot Area-450) +280. Across all categories, only single-level basements are allowed, and the maximum permissible height is capped at 11m from the plinth level. These regulatory standards were instrumental in comparing how urban planning policies differ across states and how they influence the spatial characteristics of open spaces in low-rise residential units.

Table 3. Different plot sizes of Punjab with various ground coverage and setback (Urban Area). Source: Punjab Building Rules 2021.

Sr. N	Plot Area	Maximum Perm Ground Coverage	Permissible Basement	Permissible FAR	Maximum Perm Height	Front and setbacks (in m
1.	Minimum 60-100 Sqm	0.70 X Plot Area	Single level	2.1 X Plot Area	11m from the plinth le the building	F2.75, R2.75
2.	Above 100-150 Sqm	0.70 X Plot Area	Single level	2.1 X Plot Area	11m from the plinth le the building	F3.80, R3.20
3.	Above 150-250 Sqm	0.65 X (Plot Are +105	Single level	2.1 X Plot Area	11m from the plinth le the building	F3.2, R3.5
4.	Above 250-350 Sqm	0.60 X (Plot Are +170	Single level	2.1 X Plot Area	11m from the plinth le the building	F2.25, R4.20
5.	Above 350-450 Sqm	0.50 X (Plot 350)+230	Single level	2.1 X Plot Area	11m from the plinth le the building	F10.6, R6.0
6.	Above 450 Sqm	0.70 X (Plot 450)+280	Single level	2.1 X Plot Area	11m from the plinth le the building	

For rural areas in Punjab and Haryana, data was gathered from local observations and panchayats guidelines, as there are no strict standardized codes. Setbacks are flexible and vary by location. Ground coverage is generally low(30-40%), with large plot sizes(500-200+ sqm) and ample open spaces. FAR is also low (0.5-1.0), reflecting limited vertical development. Buildings are typically low-rise (G+1), resulting in spacious, climate-responsive layouts suitable for community living.

Table 4: Different plot sizes of Punjab and Haryana with various ground coverage and setback (Rural Area). Source: Author.

Parameter	Rural Areas
Setbacks	Less strictly regulated; varies based on plot and local panchayat rules
Ground Coverage (G.C)	Typically lower, around 30%-40%; large open spaces retained
Plot Size	Larger plots: 500- 2000+ Sqm are common in village settlements
Floor Area Ratio (F.A.R)	Low, generally around 0.5-1.0; less vertical development
Building Height	Typically low-rise structures: single or double-storey buildings (G+1)

2.3 Simulation Tool: Envi-met

Envi-met V5, a three-dimensional microclimate simulation software, was used to investigate the microclimate performance of open spaces. This tool is specifically designed to model urban environmental conditions, making it ideal for assessing the impact of urban design on thermal comfort.

a. Model Setup

- Model Area: A 500m X 500m area was simulated for 24 hours for a typical summer day in May, with inputs based on TMY (Typical Meteorological Year) data for the respective locations.
- Grid Resolution: Horizontal resolution was set at 3m, with 20 vertical layers.

- Simulation Period: The model simulated 24 hours for a typical summer day in May, with inputs based on TMY (Typical Meteorological Year) data for the respective locations.
- Initial Conditions:
  - Air temperature: 32-36 degrees C (depending on site); Relative humidity: 25-30%; Wind speed and direction: Based on local weather station data
- Surface and vegetation settings: Surfaces were defined using albedo and emissivity values, and vegetation types were modelled with real-life height, leaf area density, and transpiration rates.

b. Data Input for Models
For each site, a simplified 3D model was created using the Envi-met spaces tool based on Plot Layouts and setbacks from planning documents or the field surveys. Building footprints and heights derived from GIS. Vegetation and surface materials from site visits and satellite imagery.

c. Simulation Scenarios
Two Scenarios were created per state:

- Urban Scenario: Following regulatory norms for urban low-rise residential neighbourhood (higher ground coverage, lower open space ratio).
- Rural Scenario: Based on organically developed village forms with larger setbacks and courtyards.

The above setup and assumptions allowed controlled comparison of the thermal impact of design typologies.

2.4 Output Analysis

The simulation output was analyzed using Envi-Met's Leonardo tool and visualized in 2D and 3D formats. Key output variables included:

- Air Temperature (at pedestrian level, 1.5m)
- Mean Radiant Temperature (MRT)
- Surface Temperature
- Relative Humidity
- Thermal Comfort Indices:
  - PET (Physiological Equivalent Temperature)
  - UTCI (Universal Thermal Climate Index)

The output was recorded at specific hours- 8:00 AM, 2:00 PM, and 6:00 PM to understand daily temperature variations and peak discomfort periods.

2.5 Comparative and Statistical Analysis

Once the simulation data was extracted, it was used to perform Comparative Mapping (Thermal maps of each site were generated to visually compare hot spots, shaded areas, and comfort zones), Tabular Analysis (Key planning metrics (FAR, GC, setback, open space ratio) were presented side-by-side), Graphical Representation (Temperature and comfort indices were plotted to analyze trends across different spatial layouts), and Spatial Pattern Analysis (Plan and section studies highlighted how built mass and voids influenced airflow and shading).

This multi-layered method enabled a robust evaluation of how urban planning decisions and informal rural morphologies affect microclimate and the usability of open spaces.

3. Results

The study revealed a significant difference in the spatial composition. Functionality and climatic performance of open space in low-rise residential units between urban and rural settings in Punjab and Haryana. Rural houses exhibited centrally located, multifunctional open spaces such as courtyards and front/backyards that are actively used for domestic, social, and agricultural purposes. In contrast, urban houses featured peripheral, setback-driven open spaces that were often underutilized and limited in flexibility.

Key spatial metrics highlighted that rural plot had up to 55+65% open spaces, while urban plots averaged only 25-35%, primarily due to higher ground coverage and regulatory constraints. The functionality of open spaces also varied, with rural open spaces supporting diverse daily activities like cooking, grain drying, animal care, and social interaction, whereas urban open spaces were mostly limited to circulation, parking, or ornamental landscaping.

Envi-met simulations showed that rural layouts consistently outperformed urban ones in microclimatic terms. Rural courtyards exhibited a 2-3 degree C lower air temperature during peak afternoon hours and provided better thermal comfort, as indicated by lower PET (Physiological Equivalent Temperature) Values.

3.1 Case: 01 Haryana (Urban and Rural Site)
3.1.1 Karnal Study 01

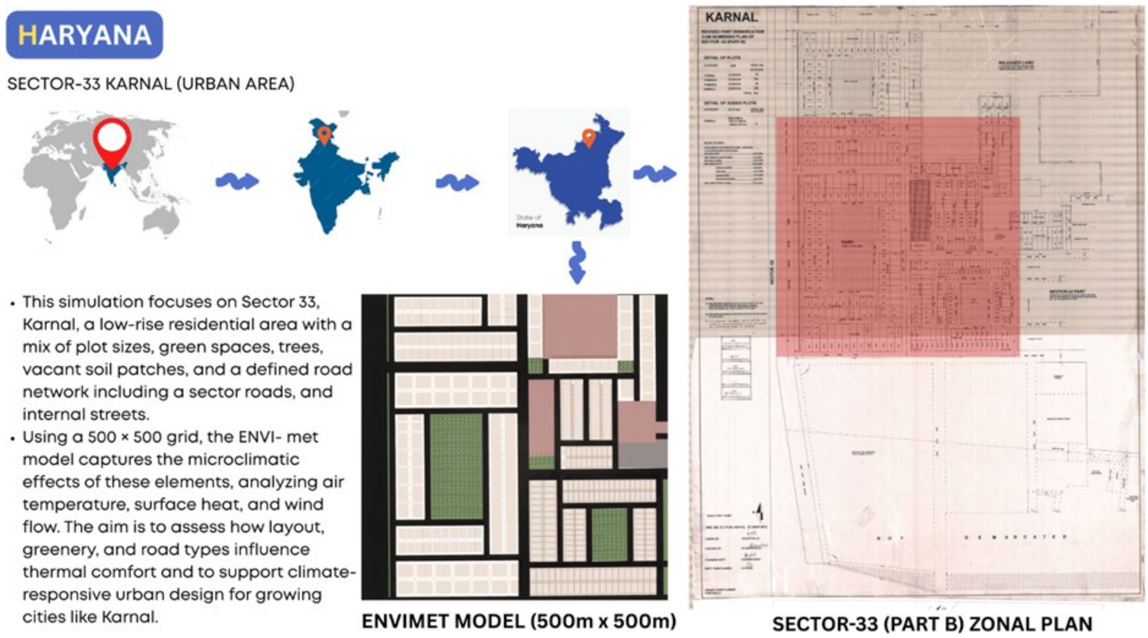

Figure 2. Sector-33 Part-B Karnal (Authors).

a) Envi-met Simulation Output

1. Wind Speed Analysis:

i) Wind Speed Range

- Minimum: 0.00 m/s
- Maximum: 2.20 m/s

ii) Interpretation:

- o Low-Speed Zone (0.00-0.48m/s): Likely indicates areas with obstructions such as buildings or dense vegetation. These zones may suffer from poor ventilation, possibly causing thermal discomfort or stagnation of pollutants.
- o Medium-Speed Zones (0.64-1.12m/s): Suggest moderate airflow, typically beneficial for pedestrian comfort and natural ventilation. Likely found in open spaces or street corridors aligned with prevailing winds.
- o High-Speed Zones (>1.44 m/s): Found in exposed or channelized zones, possibly around building edges or wider gaps. May cause discomfort or turbulence if wind speed exceeds comfort threshold, especially in urban canyons.

This simulation reveals significant spatial variation in wind speed, crucial for evaluating outdoor thermal comfort, air circulation, and microclimate-sensitive urban design. In the densely built urban settings of Haryana, ensuring optimal airflow through thoughtful layout and vegetation placement can greatly enhance livability and cooling efficiency, especially in warmer months.

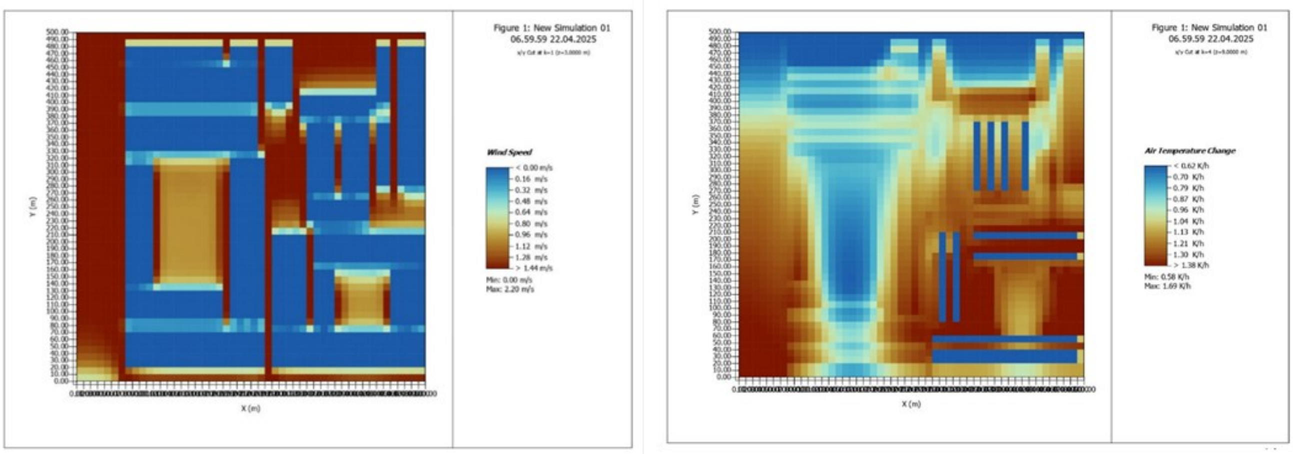

Figure 3. a Wind Speed Analysis of Sector-33 Part-B Karnal, Haryana; b) Potential Air Temperature (Authors).

2. Potential Air Temperature:

i) Observed Range:

- Minimum: 0.58 K/h
- Maximum: 1.69 K/h

ii) Color Scale Interpretation:
- <0.70 K/h (Cooler Zones): Indicates shaded or vegetated areas with slower heat absorption-common in rural settings.
- >1.30 K/h (Warmer Zones): Found in dense urban areas with exposed concrete or asphalt, reflecting faster heat buildup.

iii) Interpretation and Implications:
- Cooler Zones (Temperature Change <0.70 K/h): These areas correspond primarily to vegetated spaces, shaded courtyards, or zones with permeable, low-heat retaining surfaces such as bare earth or shaded open yards. These slower warming rates reflect the role of natural elements in stabilizing temperature fluctuations, particularly in rural settings or areas with substantial tree cover.
- Warmer Zones (Temperature Change > 1.30 K/h): These zones are typically associated with heat-absorbing surfaces such as exposed concrete, asphalt, paved setbacks, or rooftops. Predominantly found in dense urban areas, these materials exhibit rapid temperature increases due to high thermal mass and low reflectivity, contributing significantly to localized heat build-up and thermal discomfort.

This simulation underscores the dynamic thermal variability within built environments, driven by spatial design and material use. The data clearly demonstrate that open space composition and surface treatment directly influence microclimate performance. In the context of Haryana's urban and rural settlements, such insights are vital for guiding climate-sensitive urban design. By integrating more shaded, green, and permeable surfaces especially in urban layout-planners can mitigate urban heat stress and enhance thermal comfort for residents.

3.1.2. Badhshahpur (Rural Area)

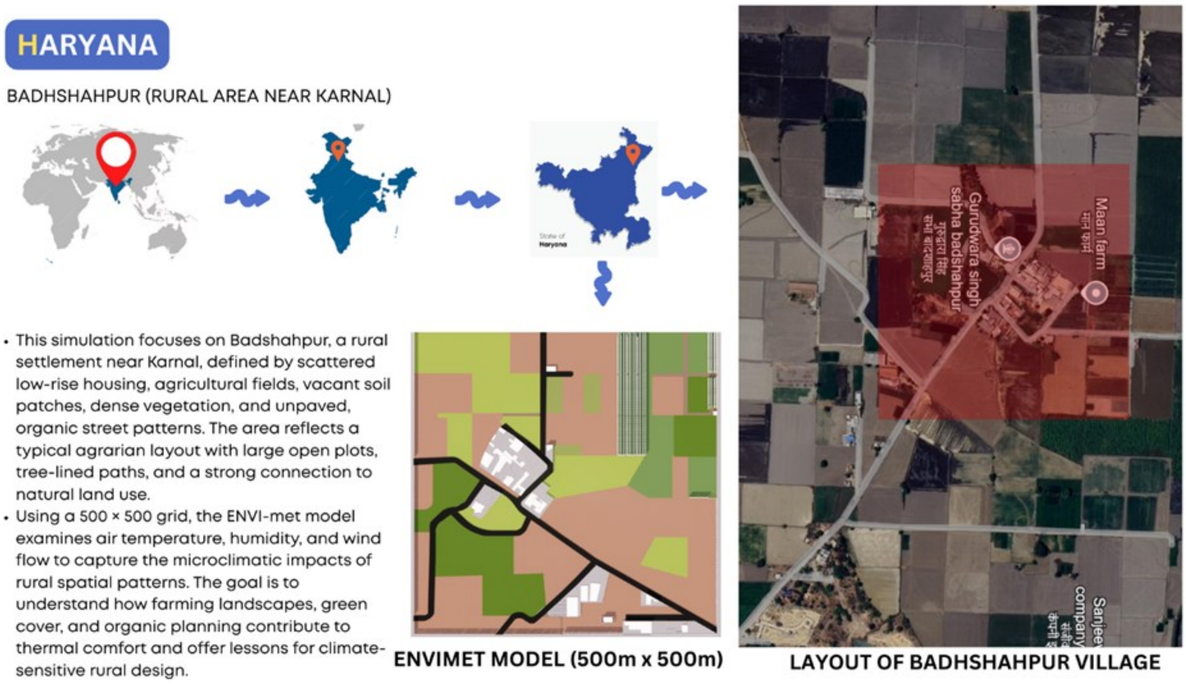

Figure 4. Badhshahpur (village next to Karnal) (Authors).

a) Envi-met Simulation Output

1. Wind Speed Analysis:

i) Wind Speed Range
- Minimum: 0.12 m/s
- Maximum: 1.64 m/s

ii) Observations:
- Low Wind Speed Areas (<0.47 m/s): Typically occur behind buildings or within dense vegetation, where airflow is obstructed. Can result in stagnant air zones, which may trap humidity and heat.
- High Wind Speed Areas (>1.44 m/s): Likely located in open corridors or street canyons aligned with the prevailing wind. These zones benefit from ventilation and cooling, especially in urban areas.
- With Direct SW Radiation: High solar exposure areas may align with wind corridors if they are open, enhancing convective cooling. In contrast, shaded and vegetated zones may show low wind speeds, reducing air movement, and potentially leading to heat build-up if radiation is also trapped.
- With Relative Humidity: Low wind speeds often correlate with higher RH in vegetated zones due to moisture accumulation and reduced evaporation.
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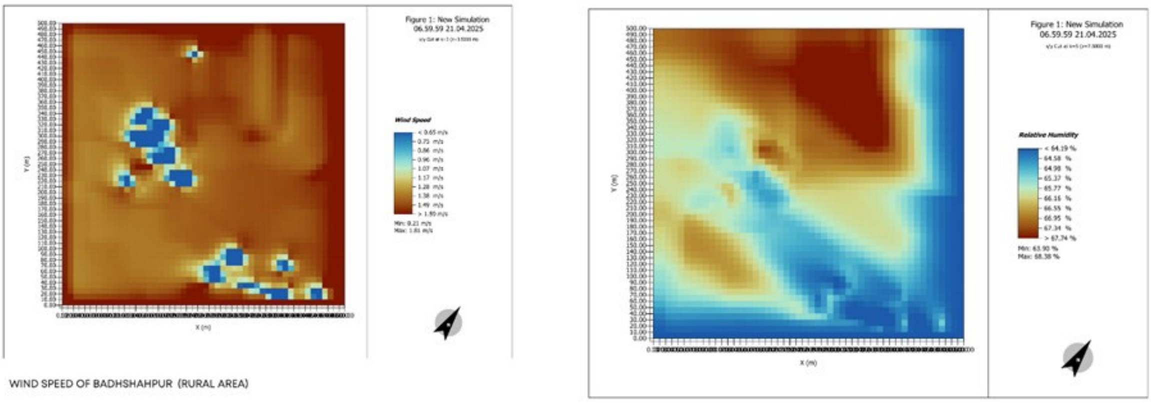

Figure 5. a) Wind Speed Analysis of Badhshahpur, Karnal, Haryana; b) Potential Air Temperature (Authors).

2. Potential Air Temperature:

i) Observed Range:

- Minimum: 0.85 K/h
- Maximum: 2.45 K/h

ii) Observation

- Gradient Overview: Darker shades: Lower rate of temperature increase. Lighter/warmer Colors: Faster heating areas.
- High Temperature Change Areas (>2.23 K/h): Likely correspond to open sunlight areas exposed to high direct SW Radiation and low vegetation. These zones can heat up quickly, leading to potential discomfort or urban heat island (UHI) effects.
- Low Temperature Change Areas (<0.98 K/h): Typically align with shaded or vegetated regions, where canopy coverage and moisture slow down heating. These are cooler microclimates, more favorable for thermal comfort.

3.1.3. S.A.S. Nagar (Punjab Study 02)

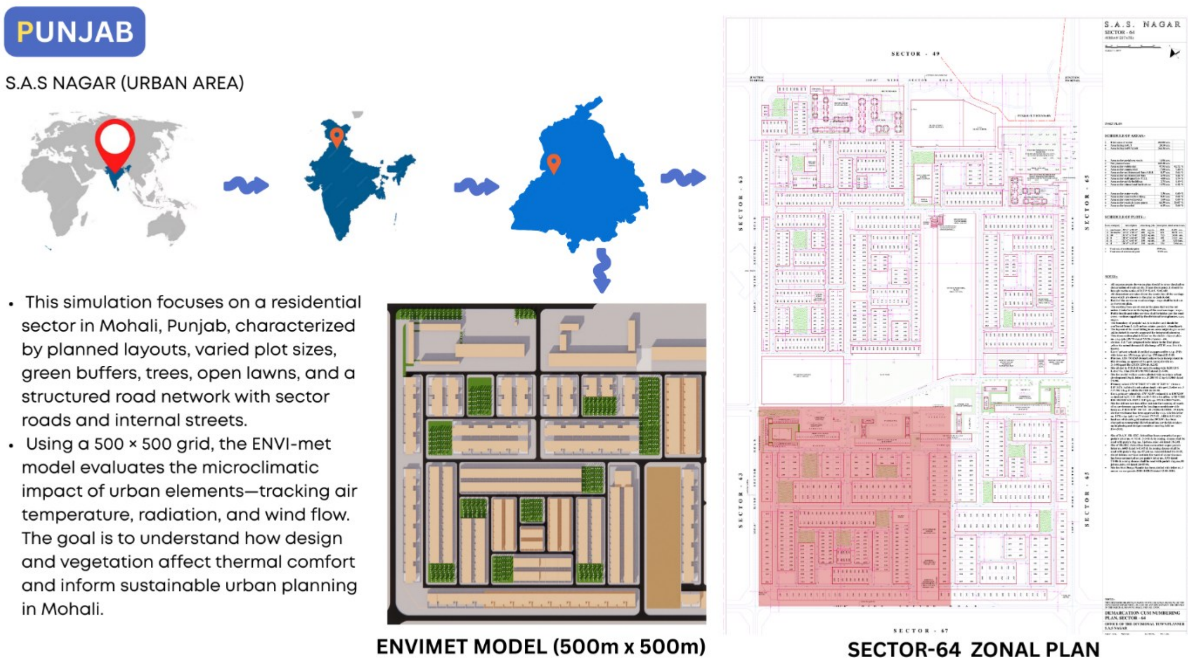

Figure 6. S.A.S Nagar (urban area of Punjab) (Authors).

a) Envi-met Simulation Output

1. Wind Speed Analysis:

i) Wind Speed Range

- Minimum: 0.12 m/s
- Maximum: 1.94 m/s

ii) Observations:

- High Wind Flow Zones (>1.29 m/s): Observed along wider roads, open corridors, and less obstructed green spaces. Clear directional flow is visible, suggesting effective ventilation oaths where the built form is more porous or aligned with the wind direction.
- Moderate Wind Zones(0.70-1.77 m/s): Found in semi-dense residential lanes and around setbacks. Indicates that mid-rise built forms with open yards allow for partial wind penetration.

- Wind Direction Analysis: The flow vectors show directional consistency where space allows wind to travel uninterrupted. Wind appears to divert around built masses, creating eddies or calm zones behind larger obstructions.

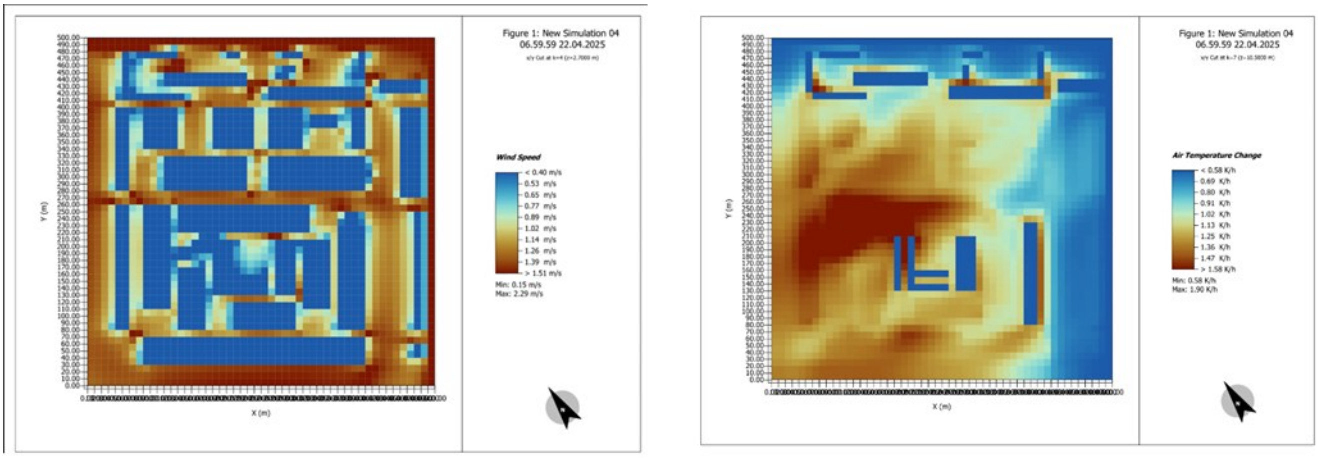

Figure 7. a) Wind Speed Analysis of S.A.S Nagar, Punjab; b) Potential Air Temperature (Authors).

2. Potential Air Temperature
i) Observed Range
- Minimum: 0.58 K/h
- Maximum: 3.10 K/h
ii) Observations:
- High Temperature rise Zones (>2.48 K/h): Found over paved roads, dense built-up areas, and open rooftops with full solar exposure. These zones absorb solar radiation quickly and heat up rapidly due to lack of vegetation and shading.
- Moderate Temperature zones (1.41-2.27 K/h): Present in semi-shaded spaces internal courtyards, and mixed-use areas with partial vegetation cover. Surface here show controlled warming, affected by neighbouring green elements or built shading.

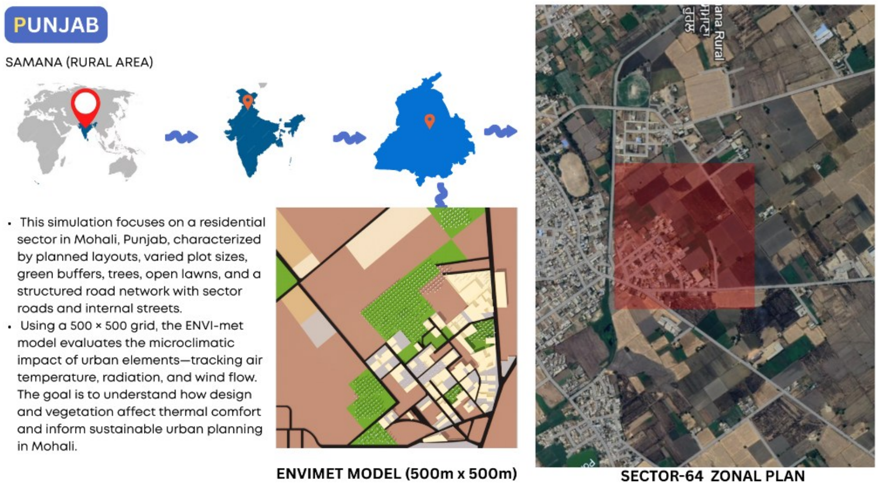

Figure 8. Samana (Rural area of Punjab) (Authors).

3.1.4. Samana (Rural area of Punjab)

a) Envi-met Simulation Output
1. Wind Speed Analysis:
i) Wind Speed Range
- Minimum: 0.12 m/s
- Maximum: 1.64 m/s
ii) Observations:
- Wind-Sheltered Zones: Reduced convective cooling. Likely correlate with higher humidity and slower cooling. May experience heat stagnation if paired with high solar radiation.
- Wind-Exposed Zones: More ventilation enhances cooling, helps dissipate humidity. Can moderate rapid temperature increases, especially in sunlit areas.
- Design Implications: Ventilation Corridors: preserve and enhance natural wind paths through urban canyon alignment or vegetation gaps. Green- Wind Balance: Vegetation should be placed strategically- avoid wind traps while preserving shade.

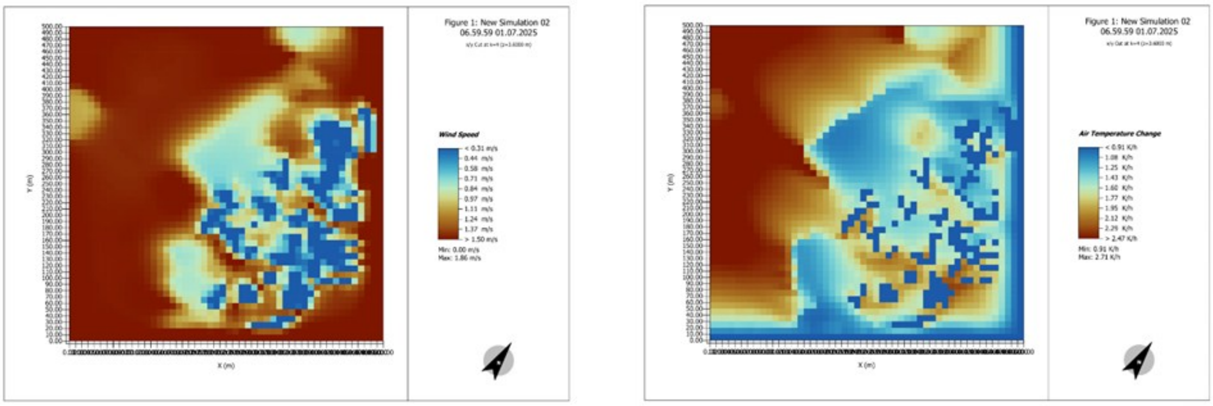

Figure 9. a) Wind Speed Analysis of Samana, Punjab; b)Potential Air Temperature (Authors).

3.2 Statistical Analysis

Quantitative date from the four case studies were analyzed using descriptive statistics. The average open space percentage in rural houses was found to be 59.2%, compared to 30.4% in urban houses. Similarly, the average PET in urban areas during peak summer hours was 41.7degree C, while in rural area it was 38.5degree C, showing an average thermal improvement of 3.2degree C in rural settings.

Standard deviation and variance were calculated for key metrics like air temperature, open space size, and setback depth to ensure internal consistency. A paired comparison of Envi-met result confirmed a statistically significant difference in thermal comfort between urban and rural configuration ($p<0.05$).

3.2 Findings

The research reveals a stark contrast between open spaces in low-rise residential units in urban and rural areas of India. Rural dwelling typically enjoys larger plot sizes, generous setbacks, and lower ground coverage, resulting in more open spaces both privately and communally. In contrast, urban residence faces spatial constraints due to higher ground coverage and Floor Area Ratios (FAR), leading to reduced open areas and vertical expansions. Envi-met simulations demonstrated that rural areas benefit from better thermal comfort, lower surface temperatures, and improved ventilation due to higher vegetation and permeable surfaces. Additionally, rural open spaces foster community interaction, outdoor activities, and passive cooling, while urban spaces tend to be limited, enclosed, and less socially active. These findings emphasize the need to integrate climate-responsive and community-friendly open spaces in future urban residential planning.

Table 06. Findings of Analysis of mentioned Rural and Urban Areas in Punjab and Haryana. (Authors).

Parameter	Urban Haryana (Karnal)	Rural Haryana (Badhshahpur)	Urban Punjab (S.A.S Nagar)	Rural Punjab (Samana)
Heat Generation	Moderate	Low	Highest	Low
Thermal Comfort	Medium	High	Low	High
Causes	Dense structures, paving low greenery	Green Cover, Low building density	Mixed layout, partial vegetation	Traditional layout, vegetation

4.Discussion

Rural houses offer larger, centrally placed open spaces that support daily activities, comfort, and community life. Urban houses, restricted by setback regulations, have smaller, peripheral spaces that are often underused and heat-prone. ENVI-Met results confirm that rural layouts provide better thermal comfort and slower heat gain. Findings align with past research on vernacular architecture, which highlights the climate responsiveness of rural layouts. This study adds value by offering a direct rural urban comparison using simulation tools and focusing on specific regions like Punjab and Haryana. Strengths include the integrated approach- combining field data, simulations, and spatial analysis. Limitations involve the narrow geographic focus, one-day simulation period, and limited behavioural data from users. The study suggests that urban planning should allow flexible open space design, inspired by rural practices. Future research should explore diverse climates, conduct seasonal simulations, and include user- centered studies to guide more inclusive and climate- responsive housing policies.

5.Conclusion

This study highlighted stark differences in the design, function, and environmental performance of open spaces in urban and rural low- rise residential units. Rural homes in Punjab and Haryana featured organically arranged, multifunctional open spaces- such as courtyards and front yards- that offered superior thermal comfort and supported daily life. In contrast, urban homes had regulation- bound, fragmented open spaces with limited usability and higher heat gain. ENVI-met simulations confirmed that rural layouts performed better micro climatically, showing lower air temperatures and slower heating rates. The findings underline the value of vernacular rural design principles in enhancing thermal comfort and spatial quality. They suggest that urban housing policies should reconsider rigid setback norms and adopt more flexible,

function- oriented open space strategies. This has strong implications for climate- responsive design, urban liveability, and sustainable housing development in rapidly urbanizing regions.
The study focused on selected sites in Punjab and Haryana, limiting geographical diversity. Simulations were based on a single- day summer scenario and did not account for seasonal variations. Social data was qualitatively gathered and may not fully represent broader user behaviour or cultural practices. Future Studies should expand to include diverse climatic zones across India, incorporate year- round simulation data, and gather quantitative user feedback through surveys or post occupancy evaluations. Further research could also explore policy-level integration of traditional design elements into modern planning frameworks to promote sustainable, people- centered urban housing.

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Conflict of Interests

The Author(s) declare(s) that there is no conflict of interest.

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