

From precedent to performance: A coded comparative analysis of climate-responsive façade strategies in ten contemporary Indian school buildings

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Architectural precedents are widely used to guide climate-responsive school design in India, yet the evidential status of what they communicate is rarely examined. This study analyses ten contemporary school buildings (pre-school, primary-secondary and special-needs) completed between 2013 and 2024 across hot-dry, composite, warm-humid and temperate climates. Published project documentation was coded against a twelve-strategy façade codebook that distinguishes strategies stated by designers from those identifiable only in drawings or photographs. Prevalence, co-occurrence and climate stratification were then analysed, and each strategy was mapped against peer-reviewed performance evidence retrieved through a structured search of 2015-2026 literature. Courtyards (8 of 10 cases), jaali screens (7) and high-mass masonry or earth envelopes (7) dominated, and frequently appeared together. Out of 59 strategy instances, 24 (41%) were visible but never articulated in project texts; recessed openings, which are present in five cases, were never stated at all. No case reported measured performance, and the only two numerical claims were unverified. The evidence map shows that the most common strategies, jaalis and massive envelopes, have no peer-reviewed evaluation in Indian school buildings, while the most influential envelope parameter in the international literature, window-to-wall ratio, was not reported by any case. Two climate misfits were identified: a lightweight envelope in a hot-dry setting and high-mass walling in warm-humid settings. The study argues that precedents should be treated as hypotheses rather than evidence, and it proposes a translation framework that converts each recurring strategy into measurable parameters, performance metrics and evaluation methods for the next research phase.

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1. Introduction

Indian children spend six to eight hours a day, and for roughly two hundred days a year in the classrooms that are mostly naturally ventilated. Field studies in composite and humid subtropical climates have recorded indoor operative temperatures well above conventional comfort limits during the school year (Jindal, 2018; Lala et al., 2022; Singh et al., 2018). A national review of classroom indoor environmental quality concluded that thermal, visual and air-quality conditions in Indian schools are poorly characterised and frequently inadequate (Kapoor et al., 2021). Daylight access in classrooms has also been associated with pupils' school performance (Baloch et al., 2020). The façade is the main element that mediates solar gain, daylight, glare and air movement in such buildings. In most Indian school projects, it is also the element on which the architect has the most design freedom and the least performance guidance.

In this vacuum, model studies have become a dominant mode of knowledge transfer in Indian architectural education and practice. Award-winning schools by Biome Environmental Solutions, Sanjay Puri Architects, Diana Kellogg Architects and others circulate widely through architectural media. They are routinely presented as models of "climate-responsive" design, with courtyards, jaalis, exposed brick, recessed windows and shaded verandahs offered as evidence of environmental intelligence. Precedent-based reasoning is a legitimate design method (Eilouti, 2009). However, its evidential status depends on what the precedent actually documents. A photograph of a deep brick reveal shows a design intention. It does not show how much solar gain that reveal removes, whether the classroom behind it is adequately daylit, or whether students are comfortable.

The international literature now offers substantial performance evidence for individual passive strategies in school buildings (Díaz-López et al., 2022). Examples include courtyard geometry and orientation (Salameh, 2024; Salameh et al., 2024; Zhu et al., 2023), perforated solar screens (Gaber

et al., 2025; Wagdy et al., 2015), window-to-wall ratio and shading optimisation (Lakhdari et al., 2021) and the overheating risk of lightweight classrooms (Amankwaa et al., 2025; Manfren et al., 2026). Within India, performance studies of climate-responsive buildings remain scarce and concentrate on offices, housing and institutional campuses rather than schools (Kumar et al., 2017; Manu et al., 2019). The result is a structural disconnect. The strategies that practitioners see in celebrated precedents are not necessarily those that research has evaluated, and the strategies that research has evaluated are not necessarily those that practitioners use.

A companion systematic review by the first author synthesised peer-reviewed evidence on façade strategies for schools, with emphasis on the composite climate (Junankar, 2026). That review answered what the literature knows. The present study asks the complementary question of what Indian practice does, and how well that practice is supported by evidence. Specifically, it addresses four research questions:

RQ1. Which façade and envelope strategies recur in contemporary, professionally documented Indian school buildings, and in what combinations?

RQ2. How explicitly are these strategies articulated by designers, and what is the evidential quality of the performance claims made for them?

RQ3. How do strategy choices vary with climate zone, and are there apparent climate misfits?

RQ4. To what extent is each recurring strategy supported by peer-reviewed performance evidence, internationally and in Indian educational buildings, and how can it be translated into measurable parameters for future evaluation?

The study makes three contributions. First, it introduces an evidence-level coding procedure for precedent analysis that separates designer statements from visual inference. Second, it provides a practice-evidence matrix that locates each strategy by its prevalence in practice and the strength of its evidence base. Third, it offers a translation framework that converts qualitative

precedent strategies into the quantitative parameters needed for simulation and field studies.

1.1 Precedent analysis and its evidential limits

Case-based and precedent-based research occupies an established place in architectural inquiry. Its strength lies in capturing the integration of many design decisions within a real context, which experimental methods tend to isolate (Groat & Wang, 2013). Multiple-case designs strengthen analytical generalisation when cases are selected by explicit criteria, when sources are triangulated and when cross-case patterns are analysed systematically (Yin, 2018). Eilouti (2009) frames precedents as recyclable design knowledge. He also cautions that the knowledge extracted depends on the representational filter through which the precedent is accessed.

For contemporary buildings, that filter is usually architectural media. Project texts are written by or with the designers, photographs are composed by professional photographers, and drawings are curated for publication. Such sources are well suited to documenting design intent but not to documenting performance. The broader building-performance literature shows why this distinction matters. Measured energy use departs from design-stage predictions by an average of about +34%, with wide variance (van Dronkelaar et al., 2016). The causes span modelling assumptions, occupant behaviour and operation (de Menezes et al., 2012; de Wilde, 2014). Green-certified buildings frequently save less than predicted (Geng et al., 2019). In India, building performance evaluation is in its infancy and is constrained by the lack of trained evaluators (Gupta et al., 2019). If calculated predictions diverge from measured outcomes, designer narratives without any calculation are weaker evidence still.

1.2 Evidence on recurring passive strategies in schools

Courtyards: Courtyards are among the best-studied passive strategies in school buildings. In a hot-arid case, an optimised courtyard lowered building temperature by 1.9 °C and reduced

sensible cooling load by 19-27% (Salameh, 2024). Courtyard orientation produced differences of about 1.7-1.8 °C between schools (Salameh et al., 2024). A review of courtyard microclimate studies identified four mechanisms: solar control, airflow organisation, evaporative cooling and thermal buffering (Zhou et al., 2025). A separate review of 92 studies found that north-south orientation and aspect ratios above 2 give the best shading in hot climates (Zhu et al., 2023). In India, a campus study in the composite climate of Roorkee identified aspect ratio as the dominant variable and recommended north-south courtyards with aspect ratios above 2:1 (Parashar et al., 2025). A vegetated courtyard at an educational building in Tiruchirappalli recorded mean radiant temperatures 5-7 °C below a non-vegetated counterpart (Peter et al., 2024). One large parametric study introduces a caution, however. It found that courtyard dimensions explained less than 3% of the variance in cooling demand and discomfort, compared with more than 40% for window-to-wall ratio and insulation (Aloshan et al., 2025).

Perforated screens and jaalis: Parametric studies of solar screens converge on depth ratios around 1:1, downward-tilted openings and moderate perforation as daylight-optimal in hot climates (Wagdy et al., 2015). Hybrid optimisation reports large gains in useful daylight and reductions in solar gain relative to fins (Gaber et al., 2025). Jaali-specific studies in India have examined perforation ratios for daylight (Manu et al., 2021), visual, thermal and perceptual performance (Rehman et al., 2021), and energy demand in Jaipur's hot semi-arid climate (Chaudhary et al., 2026). A bio-based jaali prototype has also been tested in Delhi (Debnath et al., 2026). A critical review of perforated screens notes that occupant-comfort outcomes remain largely untested (Naik et al., 2022). None of these jaali studies was conducted in a classroom.

Self-shading and recessed openings: A review of 38 studies confirms that self-shading façades reduce heat gain but finds little consensus on the best angles, forms and orientations (Lionar et al., 2024). Self-shading building forms showed

maximum energy-saving potentials of 14-23% across Chinese climates (Zhang et al., 2024). Window recess as a distinct variable, independent of external shading devices, has received little study in hot climates.

Thermal mass: In the composite climate of India, field monitoring of high-mass residential buildings defined a bioclimatic boundary for effective thermal mass up to an average monthly maximum of about 38.4 °C at low humidity (Kumar et al., 2017). Monitored high-mass offices in Jaipur avoided an additional 40% of summer discomfort time (Kumar et al., 2018). Bioclimatic analysis identifies thermal mass with night ventilation as effective in the composite climate but places natural ventilation first in all Indian zones (Bhamare et al., 2020). The evidence is not uniformly favourable. In warm climates, aerated concrete and hollow clay block walls reduced peak indoor operative temperature by 6-7 °C relative to conventional walls (Selvaraj et al., 2021). In low-income housing, aerated concrete achieved 20.7% lower indoor temperature than compressed stabilised earth blocks (Rajput et al., 2024). In tropical classrooms, ventilation dominated cooling, and the independent benefit of thermal mass was about 0.3 °C (Maduabum et al., 2026). Embodied-energy analyses discourage burnt clay brick (Jain et al., 2024), whereas compressed stabilised earth construction has the lowest initial embodied energy among Indian walling options (Sen et al., 2021).

Lightweight envelopes: Long-term monitoring of 16 classrooms in Accra found that metal-roofed rooms reached 39.8 °C, exceeded outdoor temperature by up to 5.9 °C and were overheated for 72.5% of occupied hours (Amankwaa et al., 2025). In a stock-scale study of English schools, lightweight, single-sided, highly glazed classrooms carried the highest overheating risk (Manfren et al., 2026). In a German study, lightweight schools needed substantially more solar protection than heavyweight schools to avoid overheating (Camacho-Montano et al., 2020). In an Indian composite-climate school with mild-steel roofing, 70.6% of users were dissatisfied with thermal conditions, and roof insulation was predicted to lower summer

operative temperature by 2.5 °C (Nagul et al., 2025). For existing naturally ventilated schools in Chennai, simulated envelope retrofit packages reduced whole-building temperatures by up to 3.2 °C in summer (Surendran et al., 2023). White roofs on two Indian school buildings reduced average indoor air temperature by about 1.5-2.1 °C (Garg et al., 2016).

Semi-open spaces, vegetation and form: In a naturally ventilated Indian institutional building, transition spaces reduced indoor temperature by about 0.5-2 °C (Devi et al., 2023). A recent systematic review, however, reports substantial inconsistencies across semi-open-space studies (Vakilinezhad et al., 2026). Vegetation around government school buildings in Chennai alters daylight availability in ways that designers rarely quantify (Jayaram et al., 2025). Curvilinear and biophilic forms are mainly justified on psychological grounds. A virtual-reality experiment found that curved forms improved attention and creativity and reduced stress among high-school students (Li et al., 2025). Syntheses of biophilic school design report broad but heterogeneous evidence of wellbeing benefits (Browning et al., 2024; Fisher, 2024; Ghaziani et al., 2021).

1.3 Research gap

Two bodies of knowledge therefore exist side by side. One is a growing performance literature, largely international and simulation-based, that evaluates strategies one at a time. The other is a rich but evidentially thin body of Indian precedents that combine strategies holistically. Previous comparative studies of Indian educational buildings have described these precedents. To the authors' knowledge, none has coded them systematically, audited the evidential quality of their documentation, or mapped them against the performance literature. This study addresses that gap.

2. Methodology

2.1 Research design

The study adopts a qualitative multiple-case design with embedded quantitative coding (Yin, 2018), structured in four stages (Figure 1):

1. case selection;
2. coding of published documentation against a fixed codebook;
3. cross-case analysis of prevalence, co-occurrence and climate stratification;
4. mapping of each strategy against peer-reviewed evidence and translation into measurable parameters.

The unit of analysis is the school building as documented in professional publication sources. The study does not evaluate the buildings' actual performance, and it should not be read as doing so.

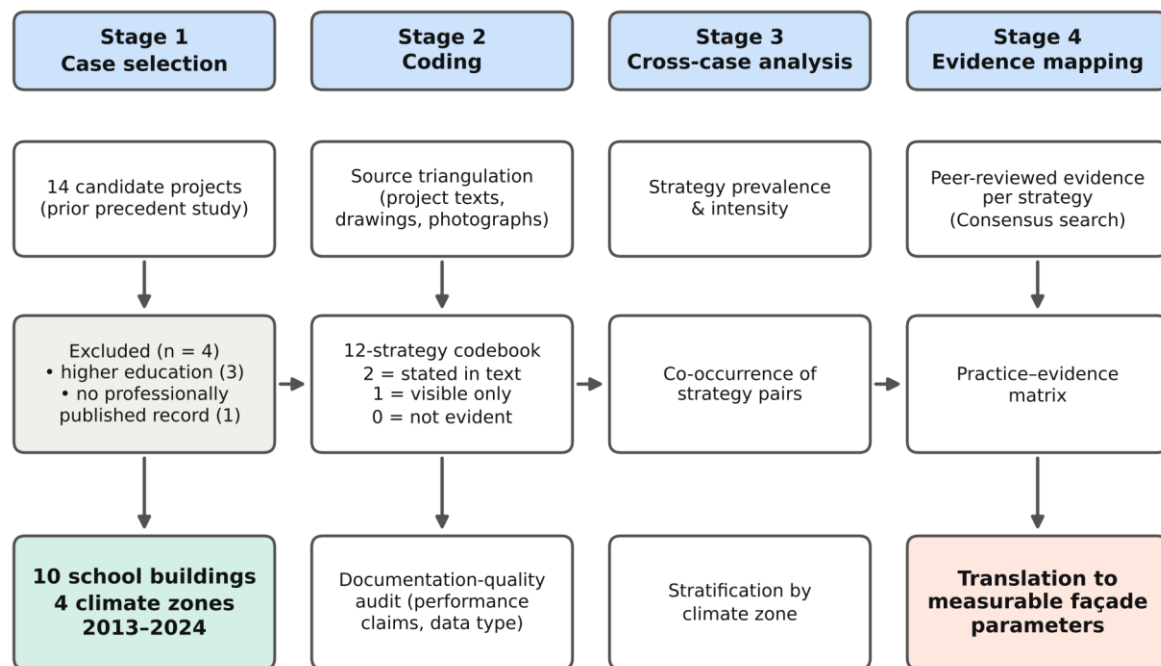


Figure 1. Four-stage research design. Stage 1 narrows 14 candidate projects to 10 school buildings; Stages 2-4 code, compare and evidence-map their façade strategies.

2.2 Case selection

Fourteen projects compiled in an earlier exploratory precedent study formed the candidate pool. Cases were retained if they met all four criteria:

- the building serves pre-school, primary, secondary or special-needs education;
- it was completed in India from 2010 onwards;
- its design is documented in at least one professionally published source (architectural journal, design media or the architect's own project page) containing photographs and a design narrative;
- climate-responsive intent is claimed or visible in the façade or envelope.

Four candidates were excluded. Three were higher-education buildings: the Indian Institute of Management Ahmedabad, a nursing college in Surat and a business school in Bolpur. Their occupancy, schedules and spatial typologies differ from schools. The fourth, a school in Bengaluru, was documented only by a student presentation on a document-sharing site. The final sample comprises ten buildings (Table 1).

Sampling was purposive and information-oriented rather than statistically representative. The sample therefore over-represents celebrated, design-led projects. This bias is intrinsic to the precedent literature that the study critiques, and it is discussed as a limitation in Section 4.8.

Each case was assigned a climate zone following the five-zone classification of the National Building Code of India (BIS, 2016), which is also

used by the Energy Conservation Building Code (BEE, 2017). Climate-zone boundaries in India are known to obscure substantial intra-zone

variation (Gupta et al., 2024). Zone assignment is therefore treated as an approximate stratification variable.

Table 1. Case sample. Years are as reported in the publication source; n.r. = not reported.

ID	School	Location	NBC zone	Type	Year	Architect
C1	The Rajasthan School	Ras, Rajasthan	Hot-dry†	Primary-secondary	2020	Sanjay Puri Architects
C2	Rajkumari Ratnavati Girls' School	Kanoi, Jaisalmer, Rajasthan	Hot-dry	Primary-secondary	2020	Diana Kellogg Architects
C3	Wockhardt Global School	Aurangabad, Maharashtra	Hot-dry†	Primary-secondary	2020	Mandviwala Qutub & Associates
C4	Contemporary Gurukul School	Morbi, Gujarat	Hot-dry†	Primary-secondary	2024	[Architect to be added]
C5	Healthy Planet School (Cocoon)	Noida, Uttar Pradesh	Composite	Pre-school	2023	Vir.Mueller Architects
C6	Bloomingdale International School, Cocoon pre-primary	Vijayawada, Andhra Pradesh	Warm-humid†	Pre-school	2024	andblack design studio
C7	Sai Kirupa Special School	Tiruppur, Tamil Nadu	Warm-humid†	Special needs	2023	Biome Environmental Solutions
C8	Yellow Train School	Coimbatore, Tamil Nadu	Warm-humid†	Primary-secondary	2013	Biome Environmental Solutions
C9	The Atelier	Bengaluru, Karnataka	Temperate	Pre-school	2016	Biome Environmental Solutions
C10	Mathru School for the Blind	Bengaluru, Karnataka	Temperate	Special needs	n.r.	Biome Environmental Solutions

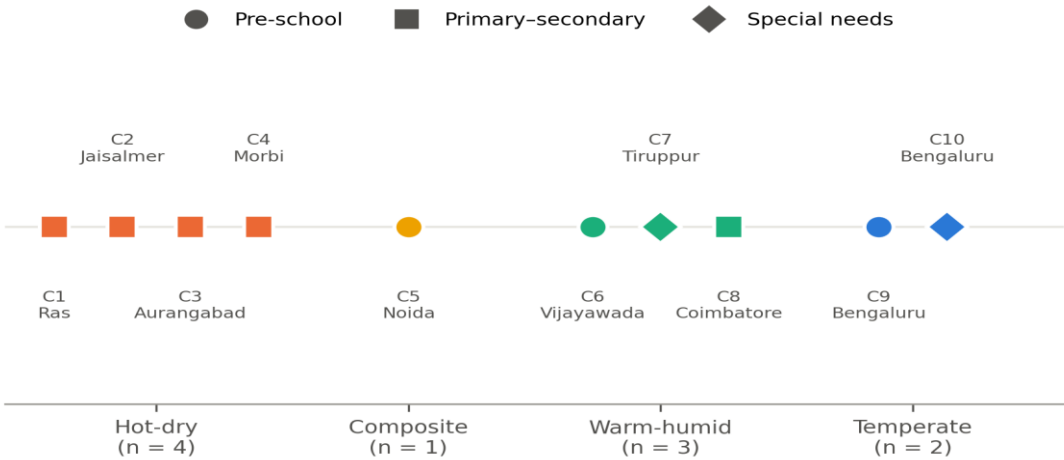


Figure 2. Distribution of the ten cases by climate zone and school type. The composite zone is represented by a single case (C5), which limits transfer of findings to composite-climate cities such as Delhi or Pune.

2.3 Data sources and codebook

For each case, all professionally published sources identified through the architect’s website and major architectural media were collected (Appendix A). Three types of evidence were extracted: design narratives (text), architectural drawings (plans, sections, elevations, where published) and photographs. A twelve-strategy codebook was developed deductively from the

passive-design literature (Koenigsberger et al., 2010) and the companion review (Junankar, 2026). It was refined inductively after a first reading of all cases (Table 2).

Each case-strategy pair received an evidence level:

- **2: stated.** The strategy is explicitly described in the project text as a design intention or climatic response.

- **1: visible only.** The strategy is identifiable in drawings or photographs but not mentioned in the text.
- **0: not evident.** The strategy cannot be identified in any source.

A strategy was coded as “present” at level 1 or 2. This two-tier scheme is the study’s main methodological device. It separates what designers claim from what an analyst infers, a distinction that conventional precedent analysis collapses.

Table 2. Façade and envelope strategy codebook.

Code	Strategy	Operational definition
O	Solar orientation of classrooms	Teaching spaces deliberately oriented to minimise east-west exposure or to exploit north light
ES	External shading devices	Overhangs, fins, louvres, chhajjas or sun-breakers projecting from the façade
R	Recessed openings	Windows set back within a deep wall, reveal or punched opening, providing self-shading
J	Jaali / perforated screen	Perforated masonry, stone, terracotta or metal screen in front of or replacing glazing
G	Restrained glazing	Deliberately limited or small glazed area, or glazing protected from direct sun
C	Courtyard	Open-to-sky space enclosed on three or more sides by the building
T	Semi-open transitional space	Verandahs, shaded corridors, loggias or covered play areas between interior and exterior
M	High-mass envelope	Load-bearing or thick brick, stone, rammed earth or compressed earth walls
SK	Skylights / roof apertures	Toplighting through skylights, clerestories or roof openings
V	Vegetation / landscape integration	Planting used to shade, buffer or cool façades, roofs or courtyards
L	Lightweight envelope	Steel, sheet-metal, fabric or other low-mass roof or wall systems
P	Curvilinear / soft geometry	Curved walls, organic plan forms or rounded volumes as a principal formal device

2.4 Documentation-quality audit

For each case, the documentation was audited for four attributes:

- the source type,
- the number of strategies stated versus identified,
- the presence of any quantitative performance claim (temperature, energy, daylight or comfort),
- whether the basis of that claim (measurement, simulation or anecdote) was disclosed.

2.5 Cross-case analysis

Three analyses were performed:

- **Prevalence:** the number of cases in which each strategy is present, and the share of those occurrences that are stated.
- **Co-occurrence:** pairwise counts of strategies present together in the same case.
- **Climate stratification:** prevalence within each zone, with attention to strategies

whose climatic suitability is contested in the literature.

Given the small sample, the analysis is descriptive. No inferential statistics are reported, and counts are interpreted as patterns to be explained rather than effects to be generalised.

2.6 Evidence mapping and parameter translation

For each strategy, peer-reviewed evidence was retrieved through structured searches in Consensus, an AI-assisted academic search engine indexing Semantic Scholar, Scopus, PubMed and arXiv records, supplemented by citation chasing. Searches combined strategy terms with “school”, “classroom”, “educational building” and “India”, and prioritised 2015-2026 publications. Two ordinal ratings were assigned to each strategy:

- **General evidence:** 3 = strong (multiple consistent studies, including reviews); 2 = moderate (several studies with some inconsistency); 1 = limited (few or indirect studies).

- **Indian educational evidence:** 2 = several studies; 1 = a single study or closely related study in an Indian educational building; 0 = none identified.

The ratings indicate the existence and consistency of evidence, not its direction. For the lightweight envelope, for example, the strong general evidence points to overheating risk. Finally, each strategy was translated into geometric or material parameters that could be measured from drawings or on site, the performance metrics affected, and suitable evaluation methods.

3. Results

3.1 Sample profile

The ten cases comprise five primary-secondary schools, three pre-schools and two special-needs schools (Figure 2). Four cases lie in the hot-dry zone, three in the warm-humid zone, two in the temperate zone and one in the composite zone. Four of the ten were designed by a single practice, Biome Environmental Solutions. Seven were completed in or after 2020, so the sample reflects recent practice. The concentration of cases from one practice and the near-absence of composite-zone cases are themselves findings. Celebrated school precedents in Indian media cluster around a small number of design-led firms and around climates other than the composite zone, even though that zone covers more than 30% of India's land area (Khambadkone et al., 2017).

3.2 Strategy prevalence and articulation

Across the ten cases, 59 case-strategy instances were coded as present, an average of 5.9 strategies per building (range 4-8). Figure 3 shows the full coded matrix. The courtyard was the most prevalent strategy (8 of 10 cases), followed by jaali or perforated screens (7) and high-mass envelopes (7). External shading devices, recessed openings, vegetation and curvilinear geometry each appeared in five cases. Solar orientation and skylights appeared in four, and restrained glazing, semi-open transitional spaces and lightweight envelopes in three.

Articulation varied sharply. Of the 59 instances, 35 (59%) were stated in project texts and 24 (41%) were identifiable only from drawings or photographs. The most striking case is the recessed opening: deep reveals were visible in five buildings but were never mentioned as a climatic device. External shading was visible in five cases but stated in only one. Conversely, courtyards (6 of 8 stated), high-mass envelopes (5 of 7) and skylights (4 of 4) were usually articulated. Designers therefore narrate some strategies, typically those with strong spatial or material identity, much more readily than others. The less-narrated strategies, which govern solar control at the window, are the ones that matter most for classroom heat gain and glare.

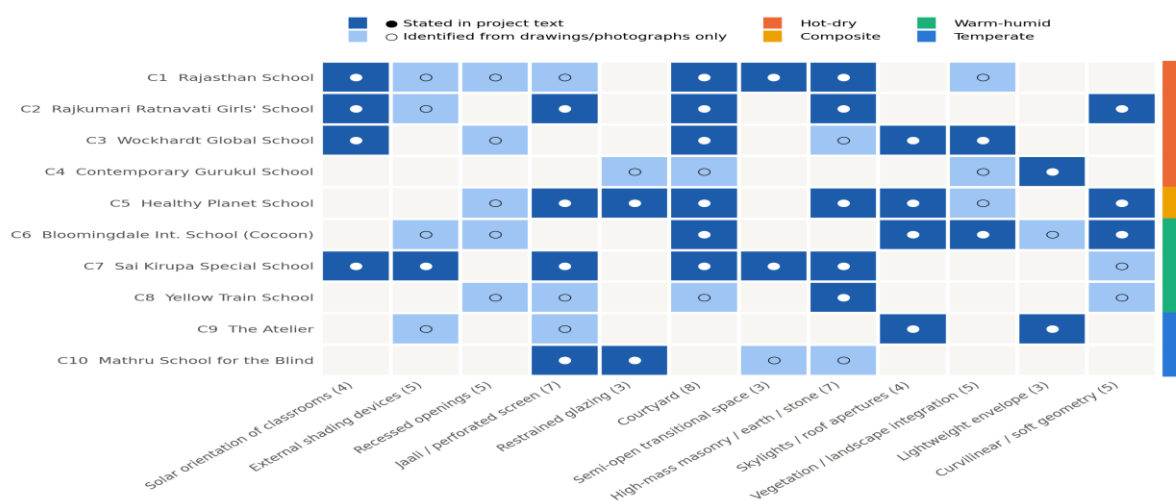


Figure 3. Coded case $\times$ strategy matrix. • = stated in project text (level 2); ○ = identifiable only in drawings or photographs (level 1); blank = not evident. Numbers in parentheses give the number of cases in which each strategy is present. The coloured bar on the right indicates climate zone.

3.3 Strategy combinations

Pairwise co-occurrence reveals a dominant cluster as shown in Figure 4. The high-mass envelope co-occurred with jaali screens in six cases and with courtyards in six cases. Courtyards co-occurred with jaalis, recessed openings, vegetation and curvilinear geometry in five cases each. This mass-jaali-courtyard combination can be described as a “vernacular bundle”. It appears in hot-dry (C1, C2), composite (C5) and warm-humid (C7, C8) cases alike, which suggests that it

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operates as a design language as much as a climatic response.

Several pairs never co-occurred. The lightweight envelope never appeared with high mass, as expected. More notably, restrained glazing never co-occurred with external shading or solar orientation. The few cases that limit glazing do so instead of, not in addition to, solar-geometric strategies. No case documented the full set of window-scale solar-control strategies (orientation, external shading, recess and restrained glazing

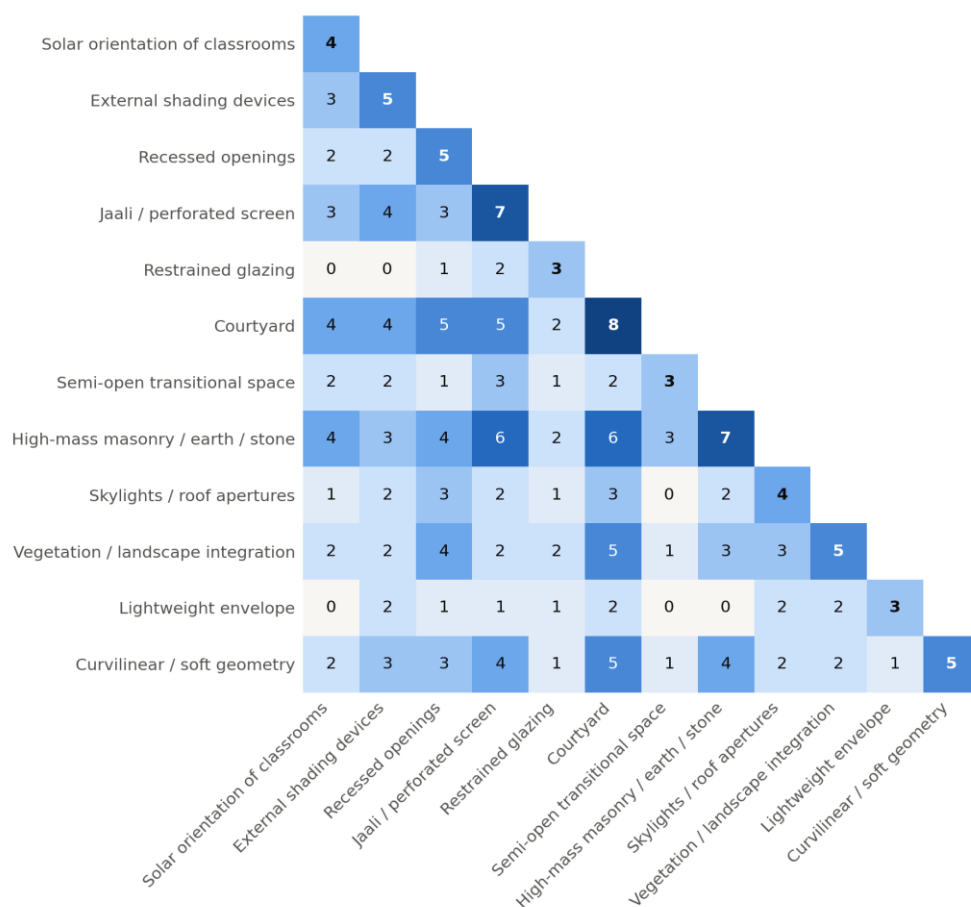


Figure 4. Co-occurrence of strategy pairs across the ten cases. Diagonal cells (bold) give the number of cases in which each strategy is present.

3.4 Climate stratification

In the hot-dry zone (C1-C4), courtyards were universal (4/4), and solar orientation (3/4), high mass (3/4) and vegetation (3/4) were common. The sole exception was C4, which uses a lightweight, colourful envelope with no high-mass walling and only image-level evidence of

courtyard and restrained glazing. In the warm-humid zone (C6-C8), all three cases used courtyards and curvilinear geometry. Two (C7, C8) used high-mass brick or earth walls and jaalis. In the temperate zone (C9, C10), both cases used perforated screens, neither used a courtyard, and toplighting or lightweight elements were more

prominent. The single composite-zone case (C5) combined eight strategies, including high mass, jaalis, restrained glazing, skylights and curvilinear walls.

Two patterns stand out against climatic design principles. First, the lightweight envelope in a hot-dry setting (C4) conflicts with the strong international evidence on overheating in low-mass classrooms. Second, the use of high-mass walling as a primary strategy in warm-humid settings (C7, C8) departs from the classic prescription of low-mass, highly ventilated envelopes for that climate (Koenigsberger et al., 2010). These cases are not necessarily poor buildings. Ventilation, shading and occupancy patterns may compensate. They are, however, precisely the cases in which unmeasured precedents are most likely to mislead.

3.5 Documentation quality

Table 3 summarises the documentation audit. All ten cases are documented through architectural media or the architect’s own website. None is documented in a peer-reviewed source, and none reports a monitoring campaign, simulation output or post-occupancy evaluation. Two cases include a quantitative performance claim. C5 is reported to maintain indoor temperatures of about 32-33 °C when outdoor temperatures exceed 45 °C. C2 is reported to remain comfortable when outdoor temperatures reach about 50 °C. Neither source discloses the measurement location, period, instrument or comparison basis. These claims should therefore be read as design narrative rather than evidence. The remaining eight cases make only qualitative claims, such as “cool”, “naturally lit” or “well ventilated”.

Table 3. Documentation-quality audit. “Stated / present” gives the number of strategies articulated in text over the number identified in any source.

Case	Primary source type	Stated / present	Quantitative performance claim	Basis disclosed
C1	Architectural media (ArchDaily)	4 / 8	None	-
C2	Architectural media (TheAPN)	5 / 6	Comfortable at ~50 °C outdoor	Not disclosed
C3	Architectural media (The Architects Diary)	4 / 6	None	-
C4	Trade media (Building Material Reporter)	1 / 4	None	-
C5	Architectural media (The Architects Diary; ArchDaily)	6 / 8	32-33 °C indoor vs >45 °C outdoor	Not disclosed
C6	Design media (designboom)	4 / 7	None	-
C7	Architectural media (The Architects Diary)	6 / 7	None	-
C8	Architectural media (ArchDaily)	1 / 5	None	-
C9	Architectural media (Architecture Lab)	2 / 4	None	-
C10	Architect’s website	2 / 4	None	-

Equally important is what the sources omit. No case reports window-to-wall ratio, glazing specification, reveal depth, jaali porosity, courtyard aspect ratio, wall U-value or roof construction. These are the variables on which the international evidence depends (Section 1.2). Published documentation therefore cannot, even in principle, be used to verify whether a precedent’s strategies are dimensioned within the ranges the literature associates with good performance.

3.6 Practice-evidence mapping

Table 4 maps each strategy to the evidence base, and Figure 5 plots prevalence in the sample against the depth of Indian educational evidence. The courtyard is the only strategy that is both highly prevalent and supported by evidence in Indian educational settings, through the Roorkee campus study and the Tiruchirappalli courtyard study (Parashar et al., 2025; Peter et al., 2024). Semi-open spaces, vegetation and lightweight envelopes each have a single Indian educational

study, although for the lightweight envelope that study documents a problem (Nagul et al., 2025). The two strategies that define the vernacular bundle, jaali screens and high-mass envelopes, appear in seven of ten cases but have no identified peer-reviewed evaluation in Indian

school buildings. Recessed openings, external shading and curvilinear geometry are similarly common in practice and unstudied in this context. No strategy reached the “several studies” level for Indian educational buildings.

Table 4. Evidence map for the twelve strategies.

Strategy	Cases	General evidence	Key international studies	Indian educational evidence
Courtyard	8	Strong	Salameh (2024); Salameh et al. (2024); Zhu et al. (2023); Alosan et al. (2025)	Parashar et al. (2025); Peter et al. (2024)
Jaali / perforated screen	7	Moderate	Wagdy et al. (2015); Gaber et al. (2025); Naik et al. (2022)	None in schools (non-school Indian studies: Chaudhary et al., 2026; Manu et al., 2021; Rehman et al., 2021)
High-mass envelope	7	Moderate (contested)	Selvaraj et al. (2021); Rajput et al. (2024); Maduabum et al. (2026); Hema et al. (2021)	None in schools (non-school: Kumar et al., 2017, 2018)
External shading	5	Strong	Lakhdari et al. (2021); Gaber et al. (2025)	None identified
Recessed openings	5	Moderate	Lionar et al. (2024); Zhang et al. (2024)	None identified
Vegetation	5	Moderate	Mahmoud et al. (2022)	Jayaram et al. (2025)
Curvilinear geometry	5	Limited (non-thermal)	Li et al. (2025); Fisher (2024); Browning et al. (2024)	None identified
Solar orientation	4	Strong	Grassie et al. (2022); Salameh et al. (2024)	None identified
Skylights / roof apertures	4	Limited	Lakhdari et al. (2021) (indirect)	None identified
Restrained glazing	3	Strong	Lakhdari et al. (2021); Alosan et al. (2025)	None identified
Semi-open space	3	Moderate	Acerio et al. (2022); Diz-Mellado et al. (2021); Vakilinezhad et al. (2026)	Devi et al. (2023)
Lightweight envelope	3	Strong (adverse)	Amankwaa et al. (2025); Manfren et al. (2026); Camacho-Montano et al. (2020)	Nagul et al. (2025); see also Garg et al. (2016)

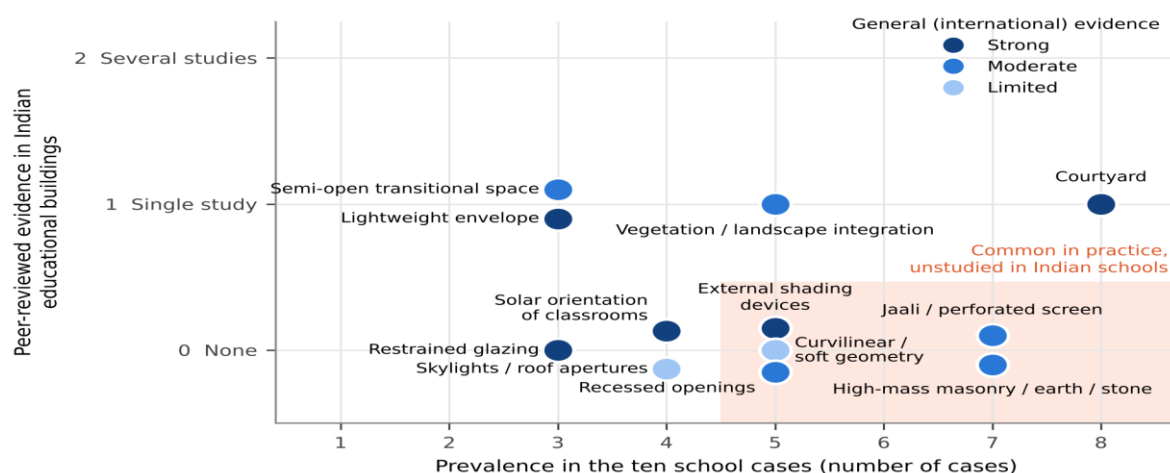


Figure 5. Practice-evidence matrix. Horizontal axis: number of cases (of 10) using the strategy. Vertical axis: depth of peer-reviewed evidence in Indian educational buildings. Bubble shade: strength of general (international) evidence. Small vertical offsets separate overlapping points and carry no meaning. The shaded zone marks strategies common in practice but unstudied in Indian schools.

4. Discussion

4.1 *Precedents are hypotheses, not evidence*

The central finding is the asymmetry between what precedents communicate and what they can establish. Contemporary Indian school precedents communicate a coherent and attractive design language: courtyards, jaalis, massive walls, shaded thresholds and, in pre-schools, soft curvilinear forms. They do not establish that these strategies deliver comfortable or well-lit classrooms. No case reports measured data, and the two numerical claims cannot be verified. This matters because the performance-gap literature shows that buildings designed with explicit calculation still diverge substantially from their predicted performance (de Menezes et al., 2012; Geng et al., 2019; van Dronkelaar et al., 2016). It also matters because Indian monitoring of climate-responsive buildings has found that strategies perform very differently once occupied (Manu et al., 2019).

It would be wrong to conclude that the precedents are therefore ineffective. The correct conclusion is narrower. Their effectiveness is unknown, and the way they are documented makes it unknowable without new data. Precedents should therefore be treated as well-formed hypotheses about what might work in a given climate, and they should be tested before being transferred.

4.2 *The vernacular bundle: coherent language, uneven evidence*

The mass-jaali-courtyard combination is the dominant pattern in the sample. Its components rest on very different evidential footings.

Courtyards are the best-supported component. However, the international evidence makes their benefit conditional on geometry: orientation, an aspect ratio typically above 2 in hot climates, and shading within the courtyard (Mahmoud et al., 2022; Parashar et al., 2025; Zhu et al., 2023). None of the eight courtyard cases publishes the dimensions needed to check these conditions. Alosan et al. (2025) add a sharper caution: courtyard dimensions explained under 3% of the variance in cooling demand and discomfort,

against over 40% for window-to-wall ratio and insulation. A courtyard is thus not a substitute for a well-designed classroom envelope. In a precedent narrative, however, it can easily be presented as one.

Jaali screens have a plausible mechanism and supportive simulation evidence for daylight and solar control (Gaber et al., 2025; Wagdy et al., 2015). Indian jaali studies, though, concern generic rooms or residential and office settings (Chaudhary et al., 2026; Manu et al., 2021; Rehman et al., 2021). Classroom tasks impose specific demands, including uniform illuminance on desks, low glare on boards and screens, and views. These may conflict with dense perforation. Porosity, depth and screen-to-glass distance determine whether a jaali improves or degrades a classroom, and none of the seven jaali cases reports them.

High-mass envelopes are the most contested component. In the composite and hot-dry zones, Indian monitoring supports thermal mass within a defined bioclimatic envelope (Kumar et al., 2017, 2018), particularly with night ventilation (Bhamare et al., 2020). Schools have a further, rarely noted, advantage: occupancy ends in mid-afternoon, so the time lag of a massive wall can shift peak heat release into unoccupied hours. That advantage depends on effective night-time purging, which is difficult in schools that are locked overnight. In warm-humid climates, where diurnal ranges are small, the case for mass weakens. Numerical studies in warm Indian climates favour low-conductivity walling (Selvaraj et al., 2021), and classroom simulations attribute most cooling to ventilation rather than mass (Maduabum et al., 2026). Long-term monitoring of naturally ventilated buildings in warm-humid Pondicherry and Auroville found cavity walls, night ventilation and optimised building form to be the most effective strategies (Doctor-Pingel et al., 2019). The high-mass, brick- or earth-walled warm-humid cases (C7, C8) therefore warrant monitoring rather than imitation. Embodied energy adds another dimension. Burnt clay brick carries high embodied energy (Jain et al., 2024), whereas stabilised earth carries the lowest (Sen et

al., 2021). “Exposed brick” is not by itself a sustainability credential.

4.3 The unspoken façade: recess, shading and glazing

The window wall is the least articulated part of the documentation. Recessed openings appear in five cases and are never stated. External shading is stated once in five occurrences. Restrained glazing appears in only three cases, and window-to-wall ratio is reported nowhere. Yet these are the variables that the evidence identifies as dominant for classroom heat gain, daylight and glare (Aloshan et al., 2025; Lakhdari et al., 2021; Lionar et al., 2024). This produces an inverted hierarchy: the strategies most visible in precedent narratives are not those with the greatest influence on classroom performance.

One interpretation is that Indian architects shade windows through massing and wall depth, a self-shading logic inherited from load-bearing traditions, without conceptualising it as a separate strategy. If so, the knowledge is embedded in practice but tacit. Making it explicit requires a measurement step that precedent publications do not provide. Reveal depth relative to window height, orientation and glazing ratio must be extracted from drawings or surveyed on site. This is the first task of the next research phase (Section 4.6).

4.4 Climate misfits and the limits of transfer

Two apparent misfits were identified. The lightweight, colourful envelope of C4 in a hot-dry setting runs against consistent evidence that low-mass classrooms, and metal roofs in particular, overheat. Examples include 39.8 °C peaks and 72.5% of occupied hours overheated in Accra (Amankwaa et al., 2025), and 70.6% user dissatisfaction in an Indian composite-climate school with mild-steel roofing (Nagul et al., 2025). Roof insulation or reflective finishes can mitigate the problem (Garg et al., 2016; Nagul et al., 2025). Whether C4 incorporates such measures is not documented. The warm-humid, high-mass cases raise the opposite question, as discussed in Section 4.2.

The climate distribution of the sample has a wider implication for composite-climate cities such as Delhi, Lucknow and Pune, whose classification is itself debated. Only one case lies in the composite zone, so composite-zone schools are designed from precedents conceived for other climates. The composite climate demands seasonal flexibility: solar exclusion in the hot-dry summer, ventilation during the humid monsoon, and some solar admission in winter. A static vernacular bundle transplanted from Rajasthan or Tamil Nadu may serve one season and fail another. The companion review identifies this seasonal tension as the central design problem for composite-zone schools (Junankar, 2026). The present analysis shows that Indian precedents do not yet address it explicitly.

4.5 Pre-school and special-needs cases: form beyond climate

Curvilinear geometry appears in five cases, concentrated in pre-schools and special-needs schools. Its rationale is primarily developmental and experiential: safety, wayfinding, enclosure and a child-scaled, non-institutional character. There is emerging evidence that curved forms can reduce stress and support attention in learning environments (Li et al., 2025), within a broader but heterogeneous biophilic literature (Browning et al., 2024; Fisher, 2024; Ghaziani et al., 2021). Where curved walls are also presented as climatic devices, however, no supporting thermal evidence was identified. The appropriate stance is to credit these forms for what they are designed to do and not to transfer climatic claims to them. Special-needs schools (C7, C10) also deserve attention as a distinct performance category. Occupants with visual or sensory impairments may be more sensitive to glare, acoustic reflection and thermal stress, and these interactions are absent from the façade literature.

4.6 From precedent to performance: a translation framework

To make precedents testable, each recurring strategy must be expressed as measurable parameters, linked to performance metrics, and evaluated by appropriate methods. Figure 6 sets

out this translation for the five strategies that dominate the sample.

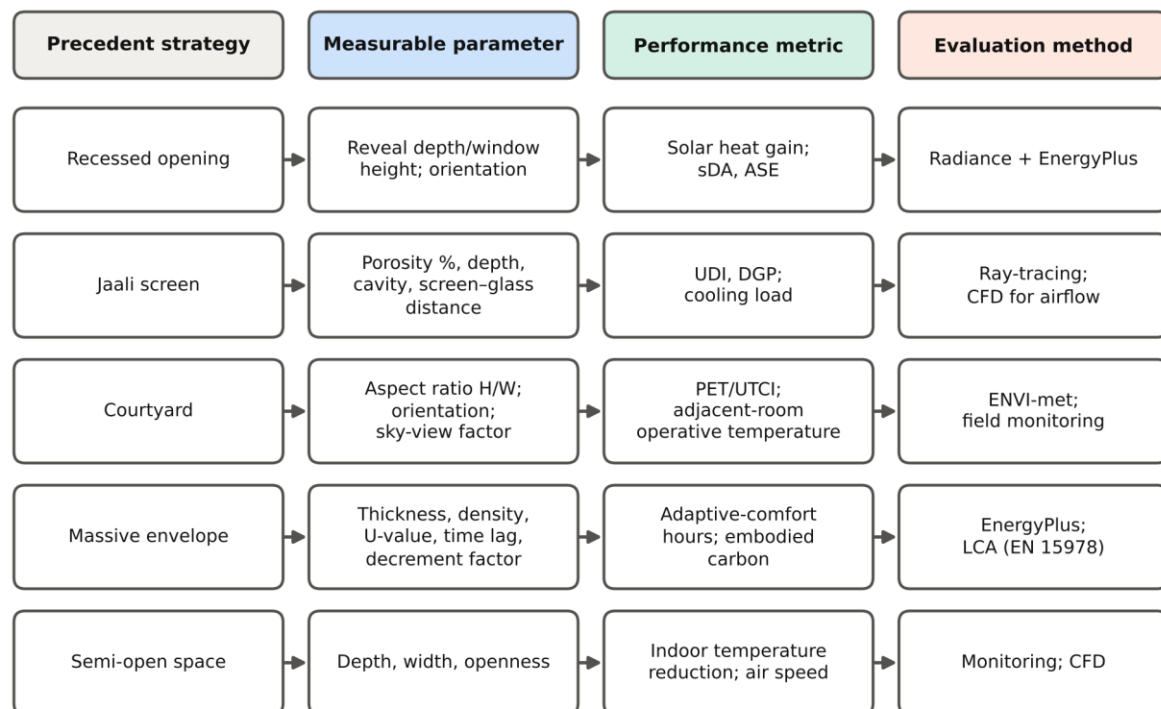


Figure 6. Translation framework from precedent strategy to measurable parameter, performance metric and evaluation method. sDA = spatial daylight autonomy; ASE = annual sunlight exposure; UDI = useful daylight illuminance; DGP = daylight glare probability; PET/UTCI = physiological equivalent temperature / universal thermal climate index; LCA = life-cycle assessment.

The framework implies a three-step research agenda:

- 1. Measurement from drawings.** Window-to-wall ratio, reveal depth relative to window height, jaali porosity and courtyard aspect ratio should be extracted from published or architect-supplied drawings of the ten cases. This tests whether practice falls within the ranges the literature associates with good performance.
- 2. Calibrated simulation.** Two or three representative cases per climate should be modelled using climate-based daylight metrics (sDA, ASE, UDI, DGP) and adaptive thermal comfort for Indian classrooms (Jindal, 2018; Rawal et al., 2022).
- 3. Field monitoring and post-occupancy evaluation.** At least one composite-zone school should be monitored through a full school year using the Indian building performance evaluation framework (Gupta et al.,

2019), extended to embodied carbon under EN 15978 (CEN, 2011).

Such a programme would convert the most celebrated Indian school precedents from illustrations into evidence.

4.7 Implications for practice and pedagogy

Three implications follow for practitioners, educators and publishers:

- 1. Façade parameters should be published:** Window-to-wall ratio, reveal depth, glazing specification and screen porosity should be reported alongside photographs. Media platforms and award juries could request these as standard project data.
- 2. Climate claims should be qualified:** Any quantitative claim should state whether it derives from measurement, simulation or expectation, and under what conditions.
- 3. Precedent studies should be taught as hypothesis generation:** Students should code precedents, identify the parameters missing

from them, and test those parameters through simple simulation before adopting a strategy.

4.8 Limitations

The study has the following limitations:

- **Secondary documentation:** The analysis relies on published documentation. Strategies that are present but neither photographed nor described would be missed, and visual coding is constrained by photographic framing. The level-1 code partly mitigates this but cannot eliminate it.
- **Single coder:** Coding was performed by one researcher. To support replication, the full codebook and case-by-strategy matrix are provided (Table 2; Supplementary Material S1).
- **Sample size and bias:** The sample is small, purposive and biased towards award-winning, design-led projects, and four cases come from a single practice. The findings describe the precedent discourse rather than the Indian school stock, most of which comprises standardised government buildings.
- **Climate classification:** Zone assignments for six locations require verification, and the five-zone classification masks intra-zone variation.
- **Ordinal evidence ratings:** The evidence ratings are ordinal judgements informed by a structured but non-exhaustive search. They indicate relative evidential depth rather than a formal systematic-review grading.

5. Conclusion

This study coded ten contemporary Indian school buildings against a twelve-strategy façade codebook and mapped the results against peer-reviewed evidence. Five conclusions follow:

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1. Indian school precedents share a recognisable climate-responsive language. A mass-jaali-courtyard bundle appears in most cases and across climates, which suggests that it functions as cultural identity as well as climatic response.

2. Two-fifths of identified strategies are visible but unarticulated. Recessed openings are never named, and window-scale solar control is the least documented layer of the façade, although it is the most influential for classroom performance.

3. No case documents measured performance, and the published sources omit the parameters needed to judge whether strategies are appropriately dimensioned.

4. The most prevalent strategies, jaalis and massive envelopes, lack peer-reviewed evaluation in Indian schools. Courtyards are the only common strategy with Indian educational evidence, and that evidence makes their benefit conditional on geometry.

5. Two climate misfits, a lightweight envelope in a hot-dry zone and high mass in warm-humid zones, show that precedents cannot be transferred safely without testing. The composite zone is almost absent from the precedent record.

Precedents remain valuable as sources of design hypotheses. The translation framework proposed here offers a route from precedent to performance: measure the parameters, simulate them against Indian comfort models, and monitor representative schools in use. Until that route is followed, claims that a celebrated school building is “climate-responsive” should be understood as statements of intent rather than findings.

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8. Author Declaration

Originality. The authors confirm that this manuscript is original work, has not been published previously, and is not under consideration for publication elsewhere.

Conflict of interest. The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper. The authors have no professional affiliation with any of the architectural practices whose projects are analysed.

Data availability. The coded case-by-strategy matrix, codebook and evidence-rating table are provided as Supplementary Material S1. The project documentation analysed is publicly available from the sources listed in Appendix A.

Declaration of generative AI and AI-assisted technologies in the writing process. During the preparation of this work the authors used Consensus (an AI-assisted academic search engine) to identify peer-reviewed literature, and Claude (Anthropic) to assist with structuring the analysis, generating the figures from the authors' coded data and drafting and editing the manuscript text. After using these tools, the authors reviewed and edited all content, verified every cited source and take full responsibility for the content of the publication.