Building Orientation as the Primary Design Consideration for Climate Responsive Architecture in Urban Areas

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Abstract – Orientation is a design parameter that plays a major role in climate responsive architecture and helps achieve comfort within the built environment. However, it is difficult to achieve an ideal orientation, especially in urban context. The main aim of this paper is to develop alternate strategies to overcome the challenges faced in designing as per preferred orientation and then derive a set of tools that can help decide the orientation of a building on site both under normal and congested site conditions. Thereafter, the inferences from the paper can act as references for choosing an optimum orientation for placement of buildings in warm humid climate. It can act as a significant pedagogical guideline for students of architecture in deciphering solutions for a climate responsive design in a simplified manner. The results can also be utilised for future research in formulating similar tools for other climatic regions.

Keywords – building orientation, climate responsive architecture, lighting, solar radiation, thermal comfort, vegetation, ventilation, wind.

INTRODUCTION

Architectural design is a complex combination of various processes that integrate to create a functional, habitable, and comfortable built environment. These processes include site planning, form and massing, spatial layout within the structure, façade design and building services. A functional and habitable building is a combination of these factors implemented in the form of a design solution. However, a comfortable built environment is achieved with consideration of the local context and surroundings.

Warm humid climate zones are regions lying in the tropical belts where heat is the dominant problem. This climate experiences very little seasonal variation throughout the year. Air temperatures remain moderately high and the ranges are very narrow. Humidity remains high for most of the time, and so does precipitation [3]. Thus, this type of climate particularly requires sufficient air movement through the building, as it is the biggest source of comfort. However, wind speed in these regions is particularly low. Consequently, building design needs to consider orientation and cross ventilation solutions accordingly, ensuring sufficient breeze penetration into the indoor environment [6] (Table I).

According to Koenigsberger [3], ideal development in warm humid regions should be less dense than in hot-dry regions for three reasons:

- to allow free movement of air through buildings and through spaces between buildings;
- to provide privacy by distance, as walls and screens cannot be used for this purpose;
- many activities carried outdoors.

However, in contemporary scenario, this ideal development is not feasible due to lack of space and the economics associated with it.

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Table I

List of Recommended Design Solutions for a Warm Humid Climate (Inferred from Koenigsberger [3]) Highlighting the Factors which are Affected by Building Orientation

| Parameter | Recommended design features in warm humid regions |
|-----------|-----------------------------------------------|
| Form and planning | • Open Plans<br>• Elongated Building Forms<br>• Single-banked rooms (accessible from galleries<br>• Spread out layouts for multiple buildings<br>• Shading of vertical surfaces<br>• Broad overhangs<br>• Orientation – long axes in the East-West direction |
| Vegetation | • Groundcover preferred around the structure to avoid reflection<br>• Plantation to provide shade<br>• Pergolas and light framing with climbers preferred<br>• Plantation that can provide deflection of winds towards the openings<br>• Surrounding plants to protect the walls from direct radiation<br>• Deciduous trees can be used to provide shade in summer and sunlight in winters |
| Roof design | • Lightweight construction<br>• A reflective upper surface<br>• Double-roof construction can be preferred<br>• Low thermal capacity<br>• Good resistive insulation of the roof surface |
| Wall design | • Shaded walls: insulation not required<br>• Exposed wall/gable wall: good insulation needed to prevent increase of inner surface temperature above air temperature |
| Opening design | • Large and fully openable<br>• Free from the effect of external obstructions<br>• Air flow not to pass through hot surfaces (e.g., asphalt) before reaching the building<br>• Protection from driving rain, rodents, pests, odour and noise |

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Climate responsive architecture is a result of successful combination of various building design parameters utilized on an optimum scale to achieve comfortable living conditions within the built environment. Orientation is always the first criterion for placement of the building on site, which modifies the undesirable effects of natural climatic factors such as solar heat, illumination, ventilation, and even noise [8]. Orientation is an objective quantity (along with building form, shape, wind patterns, and indoor conditions), that behaves as one of the most important parameters of contextual design [12]. This type of design can be achieved in several forms, as site-oriented design or climate responsive design. Achieving a suitable orientation for any building in its preliminary design phase is an effective way to achieve passive cooling, rather than depending on the latter phases for the same. It represents the relationship between building elevations and the original geographic direction. Good orientation can effectively reduce the need for mechanical systems for heating, cooling, and ventilation. It controls the manner in which solar radiation is being received by the facade of a building, and thus alter its thermal load thereby affecting the thermal comfort of space [2]. While designing, building orientation is influenced by both natural as well as man-made surrounding conditions. Natural factors include solar radiation, prevailing winds and associated ventilation, and atmospheric humidity predominantly. However, the effects of ancillary factors like sky conditions and precipitation cannot be ignored. On the other hand, man-made conditions like vegetation, proximity and character of surrounding elements also play a significant role in finalizing a suitable orientation in building design.

An optimal building solution is an efficient amalgamation of site-oriented and climate responsive design both of which are heavily dependent on building orientation. A design is said to be site-oriented when most of its dominant characteristics are formulated out of considerations specific to the site provided and its surrounding conditions [5] (Table II).

| Primary factors | Secondary factors |
|-----------------|-------------------|
| Location        | Urban landscape   |
| Potential of existing landform | Weather and climate |
| Surroundings    |                   |
| Building orientation |               |

Climate responsive architecture incorporates design solutions that help reducing the energy load on active lighting and ventilation systems within a building. The concept revolves around implementing such features in the design that ensure efficient passive heating or cooling, and hence a comfortable built environment. A successful climate responsive design is complemented by spatial, economical, functional, and sustainable factors [7] (Table III).

### Table III

| SPATIAL                  | ECONOMICAL                      | FUNCTIONAL            | SUSTAINABLE         |
|--------------------------|---------------------------------|-----------------------|---------------------|
| • Availability of space for efficient design, planning, and internal layout | • Affordability for materials, installations | • Sufficient lighting and ventilation | • Maintenance |
| • Affordability for materials, installations | • Cost of maintenance and durability of design solutions | • Structurally feasible | |

### I. Methodology

This research designs a set of reference tools to be used for coming up with design considerations like building form and layout, solar shading devices, and site vegetation using parameters like solar angles and prevailing wind direction. These tools are manual and mainly intended for conditions when ideal orientation is not being achieved.

The tools are intend to be capable of developing design recommendations for a particular orientation in a particular type of climatic zone, since ideal orientation cannot be achieved all the time. Currently, the derivation of the tools is intended to be for warm humid climate specifically.

Fenestration design is not being taken into consideration, as it magnifies the scope of the research and can be used for further studies. Factors like obstructive elements are not being considered because in warm humid regions where shading is more important than direct sunlight these adjacent elements add to the comfort levels.

The tools worked upon are as follows:

- tool for orienting the building form as per solar and wind orientation;
- tool for designing an ideal shading device for different facades;
- tool for selecting the appropriate vegetation as per orientation.

### II. Orientation as a Building Design Factor

Building orientation refers to its positioning on a site and relatively the placement of its openings, typology of its roofs, and design of its shading devices. The intention of achieving an ideal building orientation is to control the manner in which solar radiation is being received by the facade of a building:

- to maximize thermal comfort within a built environment [14];
- to minimize energy loads on active systems of lighting, heating, cooling or ventilation [14].

Building orientation is influenced by both natural as well as man-made surrounding conditions. Natural factors include solar radiation, prevailing winds and associated ventilation, and atmospheric humidity predominantly. Man-made conditions like vegetation, proximity and character of surrounding elements
also play a significant role in finalizing a suitable orientation in building design [4].

The amount of solar radiation falling on sloped surfaces is determined by its orientation. It plays an important role in zon- ing spaces within a site based on their function [9]. Appropriate building orientation is the most significant aspect for achieving passive solar design.

Fig. 1. Percentage of solar radiation falling on different building surfaces. Photovoltaic GIS from EU Science Hub [16].

III. IDEAL ORIENTATION IN URBAN AREAS

In urban areas, the comfort level and thermal performance of buildings are affected by various elements in the surroundings that cast shadow, e.g., vegetation and adjacent buildings. Street layouts and forms of the surrounding structures, apart from orien- tation, influence the solar exposure of built structures. These obstructions put restriction on the amount of solar radiation entering a building through the openings on its skin.

The factors playing a key role in achieving comfort levels in urban areas can be classified into two categories:

- **URBAN PARAMETERS** – street width, building orientation;
- **ARCHITECTURAL PARAMETERS** – roof profile and form, envelope design (Table IV).

IV. TOOL FOR ORIENTING THE BUILDING FORM AS PER SOLAR AND WIND ORIENTATION

This tool has been designed keeping seven common building layout typologies into consideration, namely, rectangular, square, L-shaped, U-shaped, H-shaped, courtyard, and verandah layouts (Table V). As the solar orientations are fixed, the variations have been considered with respect to changing wind directions for each of these layouts.

This tool can direct a designer towards choosing an ideal orientation for their building, as per its basic layout in a warm humid climate, and then plan its spaces within accordingly. It needs to be noted that ancillary factors may affect the reliability of this tool and hence they should not be neglected in this process.

In case the building does not achieve an ideal orientation (as per this tool) due to space constraints or other contextual site conditions, the following tools can be used. They can help in passive solar design and enhance thermal comfort levels within the building.

| Design parameter               | Detail considerations                                                                 | Challenges in implementation                              |
|--------------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------|
| Building form and layout       | • Layout type: compact or spread-out                                                  | • Space constraints                                        |
|                                | • Zoning w.r.t thermal comfort                                                       |                                                            |
|                                | • Buffer zones                                                                       |                                                            |
| Site planning                  | • Solar angles                                                                       | • Shading from surrounding elements and vegetation         |
|                                | • Prevailing wind direction                                                          | • Cooling potential of shaded areas and nearby water bodies |
|                                | • Obstructive elements                                                               |                                                            |
|                                | • Vegetation (existing and planned)                                                   | • Availability of space to achieve ideal orientation        |
| Building envelope              | • Insulation levels                                                                  |                                                            |
|                                | • Material selection                                                                 |                                                            |
|                                | • Permeability                                                                       |                                                            |
|                                | • Opening design                                                                     |                                                            |
|                                |                                                                                      |                                                            |
|                                | • Cost                                                                                |                                                            |
|                                | • Functionality                                                                       |                                                            |
|                                | • Structural stability                                                                |                                                            |

V. TOOL FOR DESIGNING AN APPROPRIATE SHADING DEVICE FOR DIFFERENT FACADES FOR OVERHEATED AND UNDERCOOLED PERIOD

Any design condition, which cannot provide the ideal building orientation, can achieve comfort levels with fenestration design [1]. Again, depending on solar radiation and wind direction, fenestration design has the following components:

- opening orientation;
- opening size;
- energy transmission factor/ solar factor (G-value) (Table VI):

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G-value = \frac{\text{Total Solar Heat Gain}}{\text{Incident Solar Radiation}}
\]

It is a factor used to evaluate the levels of solar energy input. It determines how much of the collected solar energy on the surface envelope is transmitted towards the interior. This factor always has a value between 0 and 1, with 0 indicating no solar heat gain and 1 indicating maximum solar heat gain [13]. In warm humid climate, the lower the g-value of a surface the better it performs thermally.
When it is difficult to obtain ideal orientation in urban scenarios, window design + shading design = effective thermal performance in warm humid climate.

As fenestration design is an extremely elaborate subject in itself, it has not been taken into consideration for this research. It can be a further scope for this study.

The design of shading devices depends on:

- site location;
- orientation of openings.

These devices should be designed in such a way that the solar radiation is blocked only at those times of the year when overheating is a concern [11].

An exercise was conducted taking an example of Kolkata (a warm humid region), and the overheated and undercooled periods were mapped on the sun path diagram for the city. Further, it was analysed with respect to horizontal and vertical solar angles, and shading devices were proposed. This is an efficient manual method for understanding the required specifications for shading device design and can be helpful in practice as well as pedagogy.
Table VII

Mean Ambient Hourly Temperature (in degree Celsius) demarking the Overheated and Undercooled Periods [Author of the Article]

|       | 0600h | 0700h | 0800h | 0900h | 1000h | 1100h | 1200h | 1300h | 1400h | 1500h | 1600h | 1700h | 1800h |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| J     | 14    | 15    | 16    | 18    | 19    | 22    | 24    | 25    | 26    | 27    | 26    | 26    | 24    |
| F     | 17    | 17    | 19    | 20    | 22    | 24    | 27    | 28    | 29    | 30    | 29    | 28    | 27    |
| M     | 22    | 22    | 24    | 25    | 27    | 29    | 31    | 33    | 34    | 34    | 34    | 33    | 32    |
| A     | 25    | 26    | 27    | 28    | 30    | 32    | 34    | 35    | 36    | 36    | 35    | 34    | 33    |
| J     | 27    | 27    | 28    | 29    | 31    | 32    | 34    | 35    | 36    | 36    | 35    | 34    | 33    |
| J     | 26    | 27    | 28    | 29    | 30    | 31    | 32    | 32    | 32    | 32    | 31    | 31    | 31    |
| A     | 26    | 27    | 28    | 29    | 30    | 31    | 31    | 32    | 32    | 32    | 31    | 31    | 31    |
| S     | 26    | 27    | 28    | 29    | 30    | 31    | 32    | 32    | 32    | 32    | 31    | 31    | 31    |
| O     | 24    | 25    | 26    | 27    | 29    | 30    | 31    | 32    | 32    | 32    | 31    | 31    | 31    |
| N     | 19    | 20    | 22    | 23    | 25    | 27    | 28    | 29    | 30    | 29    | 28    | 27    | 27    |
| D     | 15    | 15    | 16    | 18    | 20    | 22    | 24    | 26    | 27    | 27    | 26    | 26    | 24    |

Fig. 2. Stereographic Sun path diagram of Kolkata [Figure: Author of the Article].

Table VIII

Solar Shading Device Design [Author of the Article]

| Wall facing | Solar mask | Shape of SM | Type of shading device required | Wall azimuth | Horizontal solar angle | Vertical solar angle | Design of shading device |
|-------------|------------|-------------|--------------------------------|--------------|------------------------|----------------------|--------------------------|
| N           | Radial     | Vertical    | Vertical                      | 0°           | + 63.5°                | -63.5°               | tan δ = w/d               |
|             |            |             |                               |              |                        |                      | tan 63.5° = w/d           |
|             |            |             |                               |              |                        |                      | 2.005 = w/d               |
|             |            |             |                               |              |                        |                      | Thus, d = 0.5w            |
| Wall facing | Solar mask | Shape of SM | Type of shading device required | Wall azimuth | Horizontal solar angle $\delta_1$ | Vertical solar angle $\delta_2$ | Design of shading device |
|-------------|-----------|-------------|-------------------------------|--------------|----------------------------------|-----------------------------|--------------------------|
| NE          | Radial + Crescent | Vertical and Horizontal | 45° | + 56° | - | 85° | For Vertical Device (only right side), $\tan \delta = \frac{w}{d}$, $\tan 56^\circ = \frac{w}{d}$, $1.48 = \frac{w}{d}$, Thus, $d = 0.67w$ For Horizontal Device, $\tan \alpha = \frac{h}{D}$, $\tan 85^\circ = \frac{h}{D}$, $11.4 = \frac{h}{D}$, Thus, $D = 0.09h$, which is negligible. Hence, it can be dealt with an internal shading device. |
| E           | Radial + Crescent | Vertical and Horizontal | 90° | + 56° | -23° | 55° | For Vertical Device, $\tan \delta_1 = \frac{w}{d_1}$, $\tan 56^\circ = \frac{w}{d_1}$, $1.48 = \frac{w}{d_1}$, Thus, $d_1 = 0.67w$, $\tan \delta_2 = \frac{w}{d_2}$, $\tan 23^\circ = \frac{w}{d_2}$, $0.42 = \frac{w}{d_2}$, Thus, $d_2 = 2.35w$, which is difficult to design, hence multiple fins can be provided. Alternatively, another design solution is to provide a cantilever or balcony on top of this opening. For Horizontal Device, $\tan \alpha = \frac{h}{D}$, $\tan 55^\circ = \frac{h}{D}$, $1.43 = \frac{h}{D}$, Thus, $D = 0.7h$. |
| SE          | Radial + Crescent | Vertical and Horizontal | 135° | - | -72° | 40° | For Vertical Device, $\tan \delta_1 = \frac{w}{d_1}$, $\tan 72^\circ = \frac{w}{d_1}$, $3.003 = \frac{w}{d_1}$, Thus, $d_1 = 0.33w$. For Horizontal Device, $\tan \alpha = \frac{h}{D}$, $\tan 40^\circ = \frac{h}{D}$, $0.84 = \frac{h}{D}$, Thus, $D = 1.2h$, which is difficult to design, hence multiple fins can be provided. Alternatively, another design solution is to provide a cantilever or balcony on top of this opening. |
| S           | Crescent      | Horizontal           | 180° | - | - | 42° | For Horizontal Device, $\tan \alpha = \frac{h}{D}$, $\tan 42^\circ = \frac{h}{D}$, $0.9 = \frac{h}{D}$, Thus, $D = 1.1h$, which is difficult to design, hence multiple fins can be provided. Alternatively, another design solution is to provide a cantilever or balcony on top of this opening. |
| Wall facing | Solar mask | Shape of SM | Type of shading device required | Wall azimuth | Horizontal solar angle | Vertical solar angle | Design of shading device |
|-------------|------------|-------------|-------------------------------|--------------|------------------------|----------------------|--------------------------|
| SW          | Radial + Crescent | Vertical and Horizontal | 225° | +70° | - | 55° | For Vertical Device, tan δ₁ = w/d₁, tan 70° = w/d₂, 2.75 = w/d₂. Thus, d₂ = 0.36w. For Horizontal Device, tan α = h/D tan 55° = h/D 1.43 = h/D. Thus, D = 0.7h. |
| W           | Radial | Vertical | 270° | +22° | -28° | - | For Vertical Device (only left side), tan δ₁ = w/d₁, tan 28° = w/d₁, 0.53 = w/d₁. Thus, d₁ = 1.88w, tan δ₂ = w/d₂, tan 22° = w/d₂, 0.40 = w/d₂. Thus, d₂ = 2.5w for which the best solution is to provide an egg-crate device, like a jaali, providing openings from perpendicular sides. Alternatively, another design solution is to provide a cantilever or balcony on top of this opening. |
| NW          | Radial | Vertical | 360° | - | -60° | - | For Vertical Device (only left side), tan δ₁ = w/d, tan 60° = w/d 1.73 = w/d. Thus, d₁ = 0.58w |
VI. Tool For Selecting The Appropriate Vegetation As Per Orientation In Urban Areas Under Warm Humid Climate

Vegetation is a design parameter that can be utilized and monitored by design [10]. It has a huge impact on the comfort levels of a building. This tool has been designed to select the most functional type of vegetation that can be planted in the direction of a particular façade. The variations have been shown with respect to the prevailing wind directions, as in warm humid climate it is extremely essential to ensure satisfactory air movement for passive cooling (Table IX).

Table IX

| Wind direction | N | NE | E | SE | S | SW | W | NW |
|----------------|---|----|---|----|---|----|---|----|
| N              |   |    |   |    |   |    |   |    |
| NE             |   |    |   |    |   |    |   |    |
| E              |   |    |   |    |   |    |   |    |
| SE             |   |    |   |    |   |    |   |    |
| S              |   |    |   |    |   |    |   |    |
| SW             |   |    |   |    |   |    |   |    |
| W              |   |    |   |    |   |    |   |    |
| NW             |   |    |   |    |   |    |   |    |

As observed, the three tools function best when they are used in a combination so that they complement each other. However, they are not completely dependent on each other for their validity, and can give design recommendations to create a comfortable built environment as discrete tools themselves.

These can be beneficial for academicians, students and researchers in framing architectural solutions for this climate zone, with respect to the context of their design problem and the site associated with it. They can act as a quick reference while designing buildings, spaces, sites, and shading devices. Additionally, they can also be used as a pedagogical tool for students of architecture to understand climate responsive architecture better, which is an essential component of designing sustainable buildings.

Conclusions

Inferring from this research, three manual tools were designed to suit warm humid climatic conditions. These tools have certain challenges and opportunities, which are discussed further (Table X).
The following subjects could not be effectively dealt with in this study and provide a relevant scope for future research:

- fenestration design under warm humid climate;
- role of building materials and their response with respect to orientation;
- similar simplified tools for other climatic zones.

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### Table X: Challenges and Opportunities of the Designed Tools [Author of the Article]

| Tool | Challenges | Opportunities |
|------|------------|--------------|
| Tool for orienting the building form as per solar and wind orientation | • In case the building form is beyond these seven predominant types explored, the designer needs to understand the workability. • Functional zoning within the building may not coincide with the climatic zoning recommended by the tool. | • Provides guidelines to the architect on placing the building on site. • Can be used for any height of building in warm humid climate. • Works best when the shading devices and vegetation around correspond to recommendations. |
| Tool for designing an ideal shading device for different facades | • It is important to obtain the correct stereographic sun path diagram for the given latitude. • In cases where the openings are large, there may be a need to customize the shading device design based on the conditions. | • Provides guidelines to the architect in designing and proposes appropriate direction-specific shading devices. • Works best when the building form, orientation, and surrounding vegetation correspond to recommendations. |
| Tool for selecting appropriate vegetation as per orientation | • A detailed study of the soil type, climate, and the species suitable for those conditions is needed to achieve specific results. • A botanical study of the local plant species can strengthen the validity of the tool. • The workability of the recommendations by this tool may be affected by surrounding elements and conditions, which have not been considered here; it has been assumed that there is no obstruction/element surrounding the built structure. | • Helps in appropriate site planning that is sensitive to climate, site, and surroundings. • Works best when the shading devices and building form correspond to recommendations. |

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