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Methodology for Effective Daylighting in Courtyard Houses of Composite Climate

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Abstract*: Studies have shown the relevance of the courtyard houses and passive strategy that plays a significant role in energy reduction, providing thermal comfort and visual comfort. Generally, designing the courtyards was considered suitable for thermal comfort. North India lies in the composite climatic zone, and courtyard houses in this region have a distinctly vernacular style. Many studies all around the world were conducted to analyse courtyard houses and followed different methodologies. The aim of this paper is to uncover and formulate a research methodology to analyse effective daylighting in courtyard houses of composite climate; approximately forty research papers were reviewed to find out the research methodology. The year of publication, climate zone, sky models used, weather file, building type, verifying method, simulation tools, daylight matrices, and methodology adopted were studied in the reviewed literature to formulating the methodology. The study concludes that experimental models were commonly used for daylight analysis, moreover climate-based sky can be used for detailed simulation instead of the Daylight factor with overcast sky conditions.

***Keywords*: Calibration, Composite climate, Courtyard houses, Effective daylight, Methodology, Modelling, and Simulation**.

I. INTRODUCTION

The 21st century is the age of innovation. Rapid growth and development can be seen in the real estate market of the world in the last 50 years. The use of passive strategies to reduce the energy demand of the building was in trend in the past decade. Courtyards, as a feature of vernacular architecture, were used generally in the building of Hot-Dry climate. Courtyards were the important feature of the houses of composite climate. Generally, the composite climate is studied for energy and thermal comfort analysis. Passive daylighting plays a key role in achieving lighting energy reduction, thermal delight, and visual comfort in buildings.

The use of passive strategies was propagated in the building design to make the building more climate-responsive and energy-efficient. The research aims to formulate a research methodology for the analysis of effective daylighting in courtyard houses of composite climate. The main objective of the research was:-

- To study literature related to the courtyard analysis based on daylight, energy performance, thermal comfort, quality of space analysis.
- To study the year of publication, climatic zone, sky condition, building type, verifying method, simulation tools, daylight matrices, and methodology adopted for the study.

The energy requirement of a building is rapidly increasing day by day. In residential buildings, most energy is consumed in ventilation, cooling, and artificial lighting. The energy-efficient building that adopts passive daylighting is considered a useful strategy. The question of the research is, what will be the suitable methodology for the analysis of effective daylighting in courtyard houses of composite climate? The research was limited to the courtyard houses of composite climate, and the focus was oriented towards daylighting only. The study covers the background of the courtyard and daylight. The analysis covers the year of publication, climatic zone, sky condition, building type, verifying method, simulation tools, daylight matrices, and methodology adopted for the study in the reviewed literature.

II. RESEARCH BACKGROUND

A. Courtyard

A courtyard is a circumscribed space open to the sky, often surrounded by a building or a complex structure. In Western and Eastern building styles, courtyards serve as traditional architectural features and have been used as a space of multiple functions by both ancient and contemporary architects. Building material with high thermal mass, wind catchers, basement, verandah, and changes in sectional profiles were the key components of achieving thermal comfort in courtyard houses. According to the author, in the courtyard houses of the Hot-dry climate of Yazd, Iran, the inhabitants had to move horizontally and vertically in the Hot-humid climate of Bushehr, Iran. A symbiosis of the user and the courtyard's technical parameters is essential in achieving comfort [1].

Buildings in different climatic conditions require different strategies. For a deeper understanding, we require detailed simulation and analysis [2].

B. Daylight and daylighting

Daylight is the visible range on the electromagnetic spectrum, which is between 400nm to 700nm.

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Daylighting is the controlled emission of natural light in the interiors.

Direct solar illuminance should be ignored, and only sky illuminance shall be considered as daylighting of building interiors [3]. The Sky illuminance value depends on the spot, day, time, and geographic location.

III. LITERATURE STUDY

Literature study provides us the background knowledge, methodology adopted in the previous studies, and finding gaps in the research. A total of forty literature were reviewed, which can be seen in Tables 1 to 6. Twenty-six out of forty literature were based on the courtyard analysis, and the remaining fourteen were based on the daylight simulation tools and other parameters. Figure 1 depicts the number of the reviewed literature. A maximum of 41%, i.e., twenty-two were based on daylight [2, 4-24], 29%, i.e., sixteen were based on thermal comfort [1, 2, 11, 13, 18, 19, 25-34], and 15%, i.e., eight were based on energy-related topics [9, 10, 13, 14, 24, 35, 36]. Thus, it is evident from the study that daylight is the first choice of the present researchers for analyzing the built space.

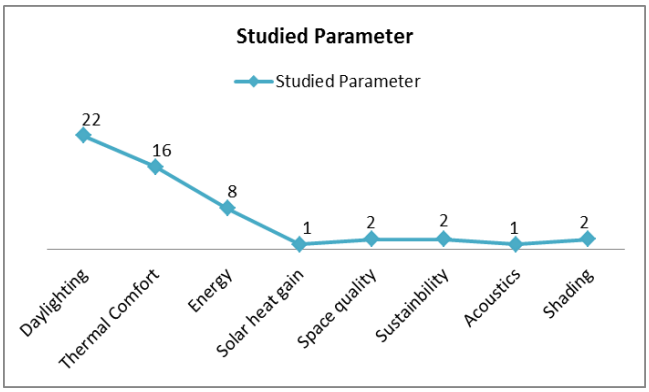

Fig. 1. Number of reviewed literature based on studied parameter.

A. Year of publication

Figure 2 shows the number of reviewed literature based on the year of publication. 73%, i.e., twenty-nine of the reviewed literature were published in the last five years (2016-2020) [1, 2, 9-14, 18-24, 28-34, 36-38], 18%, i.e., seven literature were published (2011-2015) [4, 5, 26, 27, 39-41]. The capabilities of new matrices were enhanced, because of the availability of a variety of simulation tools, due to which a number of researches have been seen in recent years.

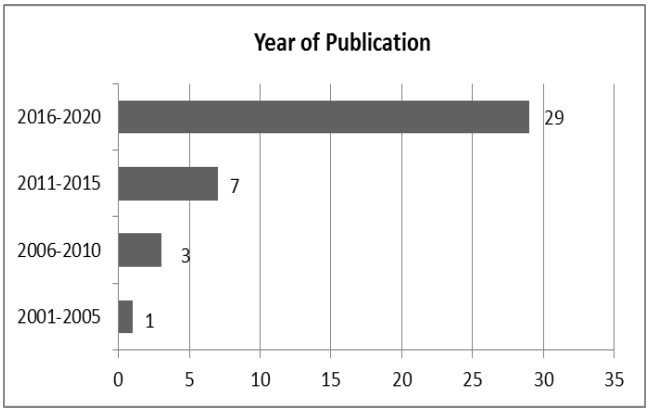

Fig. 2. Number of reviewed literature based on the year of publication.

B. Climatic zone

Indian standards recognize five climatic zones in India: Hot-dry, Warm-humid, Temperate, Cold, and Composite. "A climatic zone that does not have any season for more than six months may be called a Composite zone" [3]. In the overall reviewed literature, 26% of the literature belonged to the Composite climate [9, 10, 18, 22, 25-28, 30, 33, 35, 36], 24% to Hot-arid climate [1, 8, 11, 12, 14, 19, 22, 32, 34-36], 20% to Hot and humid climate [1, 6, 7, 22, 28, 29, 35, 36, 38] see Figure 3. Figures 4, 5, and 6 depict the percentage of different climate zones in the reviewed literature based on energy, daylight, and thermal comfort. The analysed charts show the Composite climate was studied in 36% of energy-based literature [9, 10, 35], 16 % of daylight-based literature [9, 10, 18, 22], and 41% of thermal comfort based literature [18, 25-28, 30, 33]. There was a significant gap in the study of the courtyards of Composite climate based on daylight.

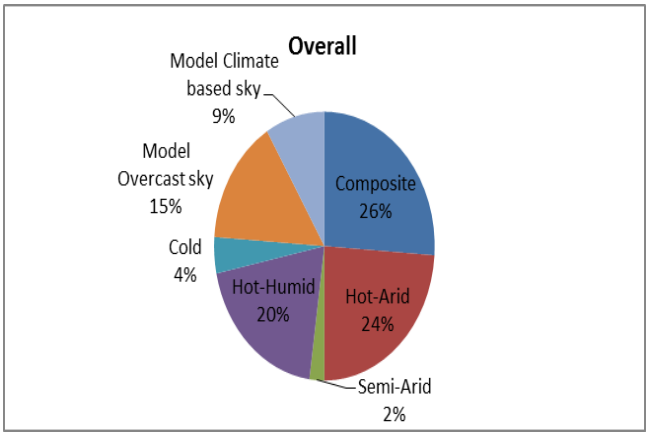

Fig. 3. Percentage of different climate zones in the reviewed literature.

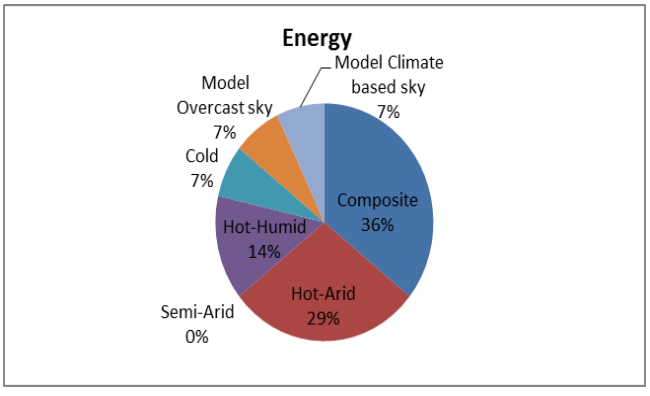

Fig. 4. Percentage of different climate zones in the reviewed literature based on energy.

Table-I. List of reviewed literature based on the courtyard.

Literature review of courtyard houses

Sl.no	Author and Year	Objective	Location and Climate	Type of Building	Courtyard Dimention	Caliberation	No. of Parameters Studied	Analysis Criteria	Methodology	Simulation tool	Conclusion
1	A and Gadi (2006)	The research focuses primarily on the impact of solar heat gain with differing proportions on the energy demand of the courtyard building shape.	The climate of Temprate, Rome, Italy	Residential building	The R1 ratio is taken to be the ratio of the the floor perimeters of the courtyard P to the height H of the form (P/H); The depth of the form is indicated.	NA	Solar heat gain, Thermal comfort	Analyzing effects solar heat gain on heating and cooling load of building.	Simulation based	IES-Radiance	Deeper courtyard forms were the most preferable for the purpose of reducing the cooling load in summer and heating load in winter.
2	Aldawoud et al. (2007)	The energy efficiency of a central atrium is investigated and contrasted with the energy output of a courtyard of the same geometric proportions.	Hot/dry climate. Phoenix, Arizona, Hot/humid climate. Miami, Florida, Temperate climate. Chicago, Illinois, Cold climate. Minneapolis, Minnesota	General Courtyard building Model	14.7m x14.7m 3.8 m Floor to Floor	NA	Energy analysis	Analyzed for different Glazing type, No. of floors, and glazings.	Simulation and experimental based artificial model generated in the software of both atrium and courtyard block and simulated in different cases.	DOE2.1E.	For shorter structures, the open courtyard building exhibits better energy efficiency.
3	Acosta et al. (2014)	The main aim of this article is to offer a quick and precise predictive method for calculating the daylight factor for different points on the floor of square courtyards under overcast sky conditions.	Overcast sky condition	General Courtyard building Model	Square courtyard, 3 m wide and with a height varying between 1 and 15 m. a height/ width ratio of 1/3 to 5/1 was used for all trials.	Data of physical and simulation model are validated.	Daylighting in the building	The daylight factors in the centre of the floorplan for each courtyard model, considering variable height and reflectance of walls. SC, DF, IRC, DV were checked.	Simulation and experimental manual collection of data from the sites.	Radience	The predictive methods developed in this research provide an approximation of the calculation of the daylight factors for characteristic points of a courtyard.
4	Eldien. H (2015)	In order to enhance the lighting and acoustical conditions, the research seeks to address the impacts of many courtyard shapes.	Overcast sky condition	Mixed use building	The circle, the rectangle (1:2), (1:3), the square, and the triangle.	NA	Daylighting and acoustical enviroment	DF is calculated in CIE overcast sky condition	Simulation based	SOLENE by CERMA laboratory and DISLAPYR (acoustics)	The courtyard surface is the key element deciding the degree of light rather than the difference of the heights of the adjacent masses in the lower layers.
5	Gulati et al. (2014)	The goal of the study was to evaluate the core urban courtyard houses, adapted colonial bungalows and semi-rural mud houses in Lucknow to determine which type(s) have reacted better than others to the prevailing climate and what factors or strategies can contribute to their improved efficiency.	Composite Climate	Residential building	NA	Data calibrated with actual site data	Thermal comfort	Study of all studies' on-site tracking data was undertaken with regard to the planned comfort bands	Simulation and experimental manual collection of data from the sites.	Ecotech	In the different seasons of the area, all the generic vernacular house styles of Lucknow were found to be thermally comfortable due to various multiple passive strategies embraced by them to fight the extremes of outdoor conditions.
6	Talaghani et. al. (2014)	The aim of this paper is its focus on heat mitigation strategies in urban courtyard blocks in the Netherlands.	Temprate climate, De Bilt (52 N, 4 E), Netherlands	Urban Courtyard	10 X10 m and 10 X50 m with steps of 10 m.	Data calibrated with actual site data	Thermal comfort	Analysis of different courtyard with climate change in 2050, albedo, waterbody, green space	Simulation and experimental manual collection of data from the sites.	ENVI-met	This research suggests using water pool and green areas are the most effective heat mitigation strategies for urban blocks in the Netherlands.
7	Ghasemi et al. (2015)	The goal of this analysis is to analyze the effect of atrium width and clerestory height on the sum of Average Daylight Factor (ADF) in different vertical top-lit atrium floors and to decide the acceptable degree of atrium width and clerestory height.	Hot and Humid, Malaysia	Office building	The model simulates four-storey, four-sided, rectangular atrium form with16m width, 48m length and 16m height.	Results of physical model and simulated model were calibrated.	Daylighting in the building	Examining the amount of Average Daylight Factor (ADF) in office space over the work plane.	Simulation and experimental, the physical model was made to the scale of 1:25.	IES-Radiance	It concluded that the minimum appropriate ratio of clerestory height(h) to atrium height(H) is h/H1/43/8 for the reasonable amount of ADF in neighboring atrium spaces.

Table-II. List of reviewed literature based on the courtyard (Continued).

Sl.no	Author and Year	Objective	Location and Climate	Type of Building	Courtyard Dimention	Caliberation	No. of Parameters Studied	Analysis Criteria	Methodology	Simulation tool	Conclusion
8	Mohsenin et al. (2015)	The goal is to assess and optimize atrium type and proportions to improve energy efficiency of atrium buildings.	Warm and Humid - U.S Climate Zone 3	Office building	Central, attached and semi-enclosed atrium types with an atrium of 27.43 x 27.43 m (90 x90 ft.), 27.43 x9.14 m (90 x30 ft.), and 22.86 x7.62 m (75 x25 ft.).	Data of physical and simulation model are validated.	Daylighting in the building	Investigates daylight metrics in central, attached and semi-enclosed atrium types with different proportions and roof aperture designs. ASE, sDA, UDI, DA, DF.	Simulation and experimental, using CBDM compaired with data collected from model.	DIVA and Rhino	This paper provides preliminary data for daylight in atrium buildings, which can be expanded as an online interface for architects.
9	Guedouh et al. (2015)	To investigate in daylighting efficiency of different building typologies under specific climate conditions of hot and arid regions.	Hot and Arid region with clear sky condition	Residential building	Mono block of size 15x20m with different typologies. With opening ratios of 0,25, 0,50 and 0,66	NA	Daylighting in the building	Analysis is done for Courtyard Building vs. Conventional Building and checked with different depths, orientation and opening ratios. DF.	Simulation and experimental, simulation run for 6 different typologies modeled in Design Builder and done a comparative analysis.	Design Builder	Courtyards regulate natural lighting. the control of the courtyard opening ratio helps to reach the annual illuminance levels desired, but the deep courtyard loses this privilege, more the courtyard is deep, less the interior spaces are illuminated.
10	Gangwar and Kaur (2016)	The objective is to investigate these works of architects after independence.	Various regions of India	General Courtyard building	NA	NA	Space quality	The aesthetic aspect will be analyzed on basis of scale, form, enclosures, surface treatment, colours etc, social and cultural aspect will be analyzed in terms of its utility as interactive space, the environmental aspect will be analyzed on the basis of its functioning as moderator of climate in particular climatic zone	Litrature review	NA	It is not necessary to imitate the indigenous courtyard system in similar fashion as these used in past, the essence on these courtyard systems could be used with changing needs of life style, social structure, cultural transformation and technological advancement.
11	Khajehzadeh et al.(2016)	This research aims to fill the information gap in the more familiar hot dry climate about the role of the central court house in a hot humid climate by contrasting its efficiency with a court house.	Iran (Yazd, hot and dry, and Bushehr, hot and humid)	Residential building	12.2x8.8x8.7 and 24.8x17.1x5.7m	NA	Thermal comfort by shading	Analyzing differing sizes, forms and dimensional ratios.	Courtyard's physical parameters and shading density on different facades of 10 houses of Yadz and 10 Houses of Bushehr were analyzed by mathmatical and simulation.	Archicad for shading analysis	Occupants have been forced to move (horizontally in Yazd and vertically in Bushehr)
12	Markus, B (2016)	To examin the design criteria for courtyard in different climatic zones.	NA	General Building	NA	NA	Thermal Comfort, Ventilation and Daylighting	Analyzing differing sizes, forms and dimensional ratios.	Litrature review	NA	The performance of air movement and daylighting in courtyard buildings depends on the design variants. The shape and scale of the courtyard have a direct influence on shade conditions and building ventilation and heating.
13	Martinelli and Matzarakis (2016)	The current research focuses on outdoor conditions, with the term "courtyard" referring specifically to the shared open space rather than the surrounding buildings.	Six cities of Italy- Aosta, Milano, Campobasso, Firenze, Lecce, Catania	Urban Courtyard	The study takes into account five courtyards of the same 20x20 m square shape and the various buildings 8 m, 12 m, 16 m, 20 m and 24 m in height, resulting in 5 different height-to-width ratios: Ratio: 2:5, 3:5, 4:5, 5:5 (1:1) and 6:5.	NA	Thermal comfort	The thermal comfort measurement is based on the estimation of the Physiologically Equivalent Temperature (PET) using the RayMan model.	Mathematical based, Five cities of different climatic zones were selected.	PET is calculated in the study using the RayMan model	As a general rule, for warmer climates, higher H/W ratios of 4:5 to 5:5 maybe advised to be carefully tested for each individual case, whereas for colder climates, lower-medium H/W ratios of 3:5 to 4:5 may be suitable.

Table-III. List of reviewed literature based on the courtyard (Continued).

Sl.no	Author and Year	Objective	Location and Climate	Type of Building	Courtyard Dimention	Caliberation	No. of Parameters Studied	Analysis Criteria	Methodology	Simulation tool	Conclusion
14	Tan et al. (2016)	Study evaluated the role of geometry factors - the atrium shape and the ratio of length to width - on building lighting energy performance in courtyard building.	Composite climate, Hubie, China	Residential building	NA	Caliberated with on site data	Daylighting and energy requirement in the building	Checking daylight factor (DF) in the surrounding rooms.	Simulation and experimental based.	Design Builder	Results show that courtyard which height to width ratio less than 1 have better lighting illuminance. No advantage was observed for height to width ratio more than 5.
15	Bulus et al. (2017)	The key objective of this analysis is to examine the central courtyard design as a passive cooling technique in Universiti Teknologi Malaysia (UTM) buildings to increase indoor thermal comfort.	Warm and Humid, Johor, Malaysia	Institute building	NA	NA	Thermal comfort	On surveying all the 46 courtyard cases quantitative analysis was done.	The approach of this research included creating a guideline for the field sample based on literature. Forty-six (46) courtyards in thirty-two (32) UTM buildings were surveyed, and the data was interpreted and analyzed using the statistical description process.	Theory and Litrature	The study shows that courtyards are common architectural components used in UTM structures. They are divided into shapes that are fully enclosed and semi-enclosed. The fully-enclosed rectangular courtyard is the most typical courtyard shape. Approximately 72% and 60% of the surveyed courtyard has overhangs and horizontal shading features.
16	Gupta et al., (2017)	Checking thermal comfor of the rural dwelling of composite climate.	Composite climate Jharkhand, India	Residential building	NA	Caliberated with on site data	Thermal comfort	The study cover three mud dwellings. Temprature and humidity were checked.	Data collection from the site and calibrated with simulation data.	Ecotech	All courtyard type dwellings do not necessarily show better thermal performance in summer and winter.
17	Kedissa el al. (2017)	By studying the effect of geometrical parameters on outdoor comfort levels, this research aims to describe different configurations of urban open spaces.	Constantine's Semi-Arid climate, Algeria	Urban courtyard	Forms were used for buildings ranging in scale. Length and width in increments of 15 m from 30 m to 135 m, with building heights ranging from 3 m to 72 m in increments of 3 m (one floor).	NA	Thermal comfort	This study uses the physiological equivalent temperature (PET), a thermal comfort index which takes into account all the environmental parameters which influence thermal comfort.	Numerical modelling is used in this study which concentrates on the relation between the microclimate of an open space on the H/W aspect ratio of the surrounding buildings.	TownScope 3.1, ENVI-met 3.1	The findings show that direct sunlight length, average radiant temperature and wind speed are affected by the urban shape and play a significant role in achieving optimum levels of thermal comfort.
18	Soflaei et. al. (2017)	In terms of geometric properties and orientation, the aim is to identify the best design model for courtyards in order to improve thermal comfort in modern desert houses.	Hot and Arid region, Iran	Residential building	Varying	NA	Shading performance, Thermal comfort	The study covers ten houses, models were generated and analyzed.	Simulation Based	Design Builder	In hot-dry climate, decreasing length to width ratio obtains greater shading index in the design of courtyards, which means that the courtyard of square shape performs better than rectangular shapes.
19	Acosta et al. (2018)	The purpose of this analysis is therefore to provide an easy and accurate method for the determination of the factor of daylight at different points in the rectangular courtyard or central atrium space, based on the variable geometry and reflectance of the	Temprate climate, Seville, Spain	Scale model with laser cutting in fiber board and a existing courtyard	30cm x 30cm in scale model	Scale model data is caliberated with site data.	Daylighting and the energy performance	In both cases DF was analyzed considering the sky component and reflected component.	Data collection from the scale model and existing courtyard and compairing it. Experimental method. (DF)	Methmatical and experimental method.	As expressed in the DFA (13), DFB (14) and DFC (15) equations, the predictive method defined in this study provides an accurate procedure for determining daylight factors at specific points in a space in the courtyard or central atrium.
20	Guedouh et al. (2018)	The present study aims to establish a dual relationship between thermal and luminous courtyard building environments in hot and arid regions.	Hot and Arid region	Different cases of Sample models with different Opening ratio, Aspect ratio, Shadow solar index, Glazed percentage.	Opening ratio - 0%, 11%, 18%, 21%	NA	Thermal Comfort and Daylighting	The models reflect various typologies (courtyard, traditional 1 and 2) that were analyzed on the basis of the following parameters, such as: number of stories, opening ratio of the courtyard, aspect ratio, percentage of openings (glazed surface) (Illumination- E)	The simulations were taken under clear sky condition under different seasons.	Design Builder	The Deep Courtyard building is the perfect model for solving this problem in hot and arid regions.

Table-IV. List of reviewed literature based on the courtyard (Continued).

Sl.no	Author and Year	Objective	Location and Climate	Type of Building	Courtyard Dimention	Caliberation	No. of Parameters Studied	Analysis Criteria	Methodology	Simulation tool	Conclusion
21	Freewan (2019)	The analysis explores how vertical surface geometries of courtyards could increase daylight in adjacent courtyard spaces.	Jordan, sub tropical Climate	General Courtyard building Model	5x5m or 4x4m	NA	Daylighting in the building	The study used Radiance to examine the influence that both daylight quantity and efficiency could have on vertical walls, inward sloping walls, outward sloping, staggered walls and double layer walls (Illumination-E)	Simulation Based	Radience	Courtyards with sloped inward, spaced inward and double layer walls have been found to maximize the quality of daylight and regulate the unnecessary amount of illumination, while sloped outward and staggered outward walls raise the level of daylight.
22	Sthapak et al. (2019)	The paper introduces vernacular architecture and defines thermal comfort and defines how vernacular houses respond to climate.	Chhatisghar, India	Residential building	NA	NA	Thermal comfort	Litrature and theory	NA	NA	Vernacular houses are more environment-friendly because they are evolved through a continuous process.
23	Ahmad et al. (2020)	The present study illustrates the use of different daylight efficiency measurement tools and its energy saving ability in energy-efficient building topologies.	Artificial simulation model	Office Building	NA	NA	Daylighting and energy requirement in the building	The study critically reviews and compares software used for energy simulation and daylighting in the building. (Illumination- E), DA.	Simulation and experimental, based results of all five software were compaired.	Simulation software such as MatLab, Energy Plus, Velux, Relux, DIALux, in the	The survey from this study showed that dimming-controlled daylighting resulted in 13 percent more energy sawngs than on/off management system in factory production. Through the case study, the value of daylight software in building energy saving is represented.
24	Asfour (2020)	This study investigates daylighting and the energy performance of courtyard and atrium office buildings.	Hot climate, Saudi Arabia	Office Building	The square courtyard and atrium in the center of this case are (10X10 m).	Calibrated with data of references cases	Daylighting and the energy performance	Considering different window-to-wall ratios (WWR) and checking sDA, ASE, UDI.	Comparative parametric analysis that employs computer simulation. Checked for three Reference Cases Courtyard Cases Atrium Cases	Energy analysis process.	Equivalent energy efficiency is reflected by both courtyard and atrium building configurations. With the use of shading equipment, a WWR value of 30 percent is the most effective for daylight efficiency.
25	Murti et al. (2020)	This paper discusses the effects of courtyards on indoor thermal environment in Indonesian contemporary boarding houses using field measurement.	Surabaya, East Java, Indonesia	Residential building	NA	Calibrated with site data	Thermal comfort	From 6 courtyard houses Taking Indoor and outdoor temprature and air movement data of every hours for 23 days	Experimental, Manual data collection	Using Digital data logger	Application of courtyards in contemporary boarding houses is one possible means of achieving sufficient cooling effects through full-day ventilation combined with courtyard and ventilated block.
26	Sofiael et al. (2020)	The purpose of this research is to conduct a parametric study to increase construction efficiency and provide simple-to-use rules in subtropical desert climates for the design of courtyard houses.	Hot and Arid region climate of Phoenix, Arizona	Residential building	Length 5-9m, Width 3-6 m, Height 3-9m	Calibrated with litrature study data	Thermal comfort	The paper explores the effect of the key architecture variables on the thermal comfort, including the orientation, Geometry, fabrics, proportions of windows and eccentricity in the courtyard.	Simulation and experimental based.	Grasshopper tool together with the environmental plugins Ladybug and Honeybee	The impact of width and length are not as powerful as height, direction, and form of wall material. For the three distinct wall material styles analyzed in this review, the best design model was defined and presented in order to optimize thermal comfort.

Table-V. List of reviewed literature based on methodology (Continued).

Sl.no	Author and Year	Methodology											Conclusion
		Objective	Location and Climate	Type of Building	Courtyard Dimention	Calibration	Parameters Studied	Analysis Criteria	Methodology	Simulation tool			
1	Reinhart et al. (2001)	To validate the Radiance based daylight simulation for a test office.	Different sky conditions	General office model	NA	Validated	Daylighting in the building	Analyzing the model in diffrent sky conditions and layouts with different shading. DA	Experimental and simulation	Radiance and DAYSIM			The treatment of direct sunlight influences the accuracy of the daylight coefficient method.
2	Nabil (2005)	This paper proposes a new model called 'useful daylight illuminance' or UDI, to test daylight in buildings.	Climate based sky	NA	NA	BRE-IDMP validation	Daylighting in the building	Analyzing the annual daylight illumination using weather file. UDI	Experimental and simulation	Radiance			Many of the interpretive flexibility of the popular daylight factor method is retained by the supportive daylight illuminance model.
3	Roudsari et al. (2013)	The main objective of the paper is to understand the use and validity of enviromental analysis tool for rhino and Grasshopper.	NA	NA	NA	NA	Sustainability	Litrature study	By Comparision with other similar enviromental analysis tool.	Litrature study			Ladybug shows best results on the basis of process and analysis of a building.
4	Zhai and McNeil (2013)	Roles of building simulation tools in sustainable building design	NA	NA	NA	NA	Sustainability	Building energy modeling, Computational fluid dynamics, Lighting modeling, Life cycle	Theory	Litrature study			Idea generation on sustainability.
5	Baghele et al. (2014)	The research examine the main factors of residential open space quality in related to design in approach to urban spatial organization.	Tehran, Iran	Residential Typologies	NA	NA	Quality of Open spaces	Reviewing the Theories of uraban spaces.	Theory	Litrature study			Lack of planning and design criteria of physical - spatial, in the construction of new urban areas can be substantial problems in housing and environment roles to be
6	Bellia et al. (2014)	The goal was to examine the effect on the forecast of daylight availability in an indoor area of the collection of one weather file or another.	Five European locations (Copenhagen, London, Milan, Nancy, Rome)	Office Building	NA	Weather data is caliberated with the Satel light archive.	Daylighting in the building	Results were analyzed both in terms of Annual and Monthly Light Exposures and dynamic daylight performance metrics. analysis of DA, DAcon and UDI	Simulation and experimental. The study is divided in three sections. At first global and diffuse irradiances were calculated for each weather file and for each city.	DAYSIM (version 3.1e)			The results recorded in this paper show that the use of weather files from IWEC, Meteonorm and Satel-Light for dynamic daylight simulations results in similar results for a north-oriented environment.
7	Sudan et al. (2016)	The research is to understand the total energy saving for the home, and can also be extended to other structures, by thermal as well as daylighting for composite climate.	Composite Climate, Varanasi	Office building	NA	Data caliberated with actual site data	Thermal and Daylighting energy	Hourly data recorded such as Hourly Lighting power, Luminious flux, daily and monthly energy saving, CO2 mitigation	Simulation and experimental.	NA			No requirement for artificial lighting during the day was needed. By using the daylighting principle in the building, annual energy savings of 3675.61 kW h have been reported.
8	Dogan et al. (2017)	This manuscript hence analyzes the significance of interior subdivisions on simulation results by thoroughly comparing the energy use intensity [EUI] levels for a representative set of floorplans against the ASHRAE-prescribed zoning scheme.	Cooling-dominated (Phoenix weather), heating-dominated (Anchorage weather) and a mixed climate (Boston weather)	General Building	NA	NA	Energy use Intensity EUI and its fours components: Lighting, electric, heating and cooling loads	Each case is samulated and analyzed with 10% of error. same repeated for three other climatic conditions.	It carries two main sections. The first section present a process of typological sorting for floor plans based on their exterior morphology and interior organization the second section these samples are translated into energy models	Archsim, Rhino, Grasshopper			This paper shows cases with significant inconsistencies in predicted energy use intensity for the ASHRAE 90.1 Appendix G thermal zoning when compared to actual floor plan layouts.

Table-VI. List of reviewed literature based on methodology (Continued).

Sl.no	Author and Year	Objective	Location and Climate	Type of Building	Courtyard Dimention	Calibration	Parameters Studied	Analysis Criteria	Methodology	Simulation tool	Conclusion
9	Hafith et al. (2017)	This thesis explores Concept Builder's capabilities in simulating the thermal behavior of the courtyard	Hot climate region, Bagdad, Saudi Arabia	General Arab courtyard model	NA	The results of the machine simulation were correlated with real life	Thermal and Daylighting energy	Hourly temprature analysis was performed.	This analysis suggests using alternative approaches to model the space of the courtyard. We modeled and tested six different configurations.	Design Builder	The findings indicate that the effects of the Concept Builder simulation are very different from the results measured, creating questions about the software's applicability in this particular case.
10	Mandala et al. (2018)	The research is to test the process of measuring five daylightings widely used in architectural study.	Hand calculation program use Uniform sky, simulation model use Overcast sky	A square model of a space measuring 8 x 8 x 4.5 meters with an opening on one side of it.	NA	The values of Hand calculation method caliberated with the simulation model results.	Daylighting in the building	This analysis would equate DF and CU (coff. of uniformity) estimates with five methods of estimation of daylighting.	Simulation and experimental.	SNI/DPMB method, BRE Daylighting Protractors, computer programs using Dialux and Velux lighting software	Get positive results, established similar results in different conditions with different methods.
11	Brembilla et al. (2019)	The main objective of the work was to compare some of the widely available Radiance-based CBDM methods, expressing their results in terms of annual daylight metrics.	Blended CE (for 4 component method) and Perez All-Weather model all other	Four classroom spaces are used to carryout an inter-model comparison between performance metrics.	NA	Inter-model comparison	Daylighting in the building	All the 5 methods were analyze ADF, UDI, DA, sDA, ASE for the space. and at last Sensitivity analysis done.	Simulation run for all five methods and inter model comparision is done.	4 Component method; DAYSIM; the 2-phase method; the 3-phase method and the 5-phase	Find 4 Phased is more efficient
12	Kumar and Kranthi (2019)	In this paper, the impact of daylighting in residential buildings was studied, and analyzed.	All climatic zones of India	Residential Typologies	NA	NA	Daylighting in the building	A review of literature was done to document and analyse the well-being in terms of user"s daylight comfort in the residential buildings.	The methodology includes a four stage cycle of identity, collect, classify and analyse. The first step was the identification of the key words.	Ecotect daylight tool and simulation is performed using Radiance Beta V2.0.	Factors such as location, weather condition and environmental built are directly dependent on the natural climatic and geographic conditions. Hence, the interior structure of residential building and window sizes are important for a daylight efficient design.
13	Kharvari (2020)	The purpose of this analysis is to determine the influence of Radiance parameters and model-related components on the accuracy of Radiance simulation results by comparing the results of field measurements and simulation.	Overcast sky	General model	NA	Validated	Daylighting in the building	Analysing DF at a point at different time.	Manual data collection and experimental and simulation based	Ladybug, Honeybee and Radiance	The findings suggest that with a bias below 15 percent, the suggested Radiance settings for reliable results are sufficiently accurate.
14	Nasrollahi (2020)	The key purpose of this paper is to provide applied solutions for the use of more natural lighting techniques as an alternative to artificial lighting, which aims to minimize the consumption of electrical energy while supplying consumers with visual comfort.	Overcast sky	General office model	NA	Validated	Daylighting, visual comfort, energy performance in the building	Analysing DF.	Experimental and simulation based	Relux software	The results obtained also suggest that the length-to-width ratio and height-to-width ratio are 6-to-5, while horizontal and vertical surfaces are ideal for testing purposes in close windows and in middle space along the longitudinal direction.

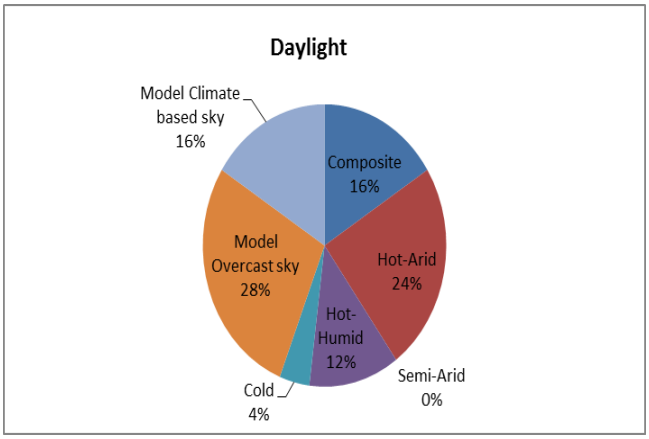

Fig. 5. Percentage of different climate zones in the reviewed literature based on daylight.

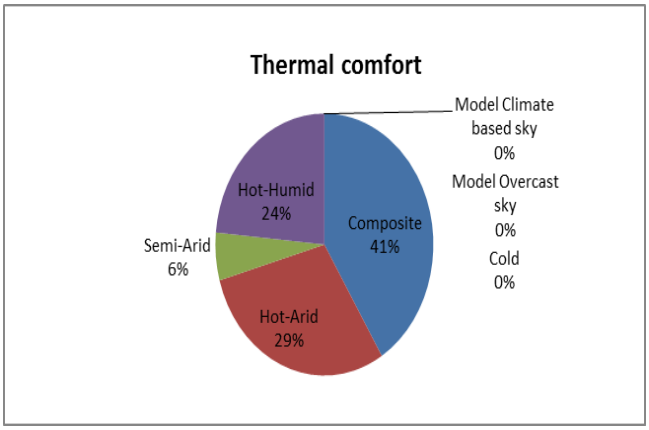

Fig. 6. Percentage of different climate zones in the reviewed literature based on thermal comfort.

C. Sky model

Sky condition plays a crucial role in the analysis of energy performance and daylighting. The daylight factor was one of the initial matrices that were used for the research based on overcast sky conditions. New daylight matrices use climate-based sky in the simulation, in which sun position varies with the location, day, and time. The climate-based sky gives more clear and accurate simulation results. Figures 4, 5, and 6 depict the percentage of different climate zones and sky conditions used in the reviewed literature based on energy, daylight, and thermal-comfort. Figure 5 shows that 44% of the reviewed literature based on daylight used experimental models, in which 28% used the overcast sky condition [4, 5, 15, 20-24] and 16% used the climate-based sky [13, 15-17]. No experimental model was used for the study of thermal comfort. It was found that experimental models were generally used for the analysis of energy and daylight. The overcast sky conditions were widely used for daylight analysis, which was not very specific. For the daylight analysis actual cases with climate-based sky were used in limited literature; it was a gap.

D. Weather file

Weather files were consolidated weather data of the overall year of a particular location, monitored and recorded by the local weather station. Weather files were very helpful in conducting modern-day research through simulation and analysing the building. For India, weather files related to all climatic zone are available on the ISHRAE website. ISHRAE "Typical Year" weather files can be used in the simulation program.

E. Building type

Various types of building typologies were analysed in the reviewed literature, such as Residential, Experimental models, Office, Mixed-use, Urban courtyard, Institute, and General building/ Standard building. Figure 7 shows the percentage of different building types in the overall reviewed literature, 29%, i.e., eleven have studied residential typology [8, 9, 22, 25, 26, 30, 32-34, 38, 41], 29%, i.e., eleven studied the experimental models [4, 10-12, 15, 19-21, 23, 24, 35]. Figure 8, 9, and 10 depicts the number of building types used in the reviewed literature based on energy, daylight, and thermal comfort. For the energy analysis, a maximum of 57%, i.e., four of the literature were experimental models [4, 10, 24, 35], 29%, i.e., two were office typology [13, 14], and 14%, i.e., one literature was residential typology [9]. Figure 9 depicts the number of different building types in the reviewed literature based on daylight. 43%, i.e., nine of the literature studied were experimental models [10-12, 15, 19-24], 29%, i.e., six were office typology [6, 7, 13, 14, 17, 18], 14%, i.e., three were residential typology [8, 9, 22], 5%, i.e., one mixed-use building [5], and 9%, i.e., two were general building [2, 17]. Figure 10 depicts the number of different building types in the reviewed literature based on thermal comfort. 43%, i.e., six of the studied literature were residential typology [13, 25, 26, 30, 32-34], 22%, i.e., three were urban courtyard [27, 28, 31], and 14%, i.e., two were experimental models [11, 18].

The analysis provides us an idea that, generally, experimental models were considered for the study for daylighting and energy. While for thermal comfort, residential typologies were studied in maximum cases. There was a gap in the study of daylighting in courtyards of the residential typology.

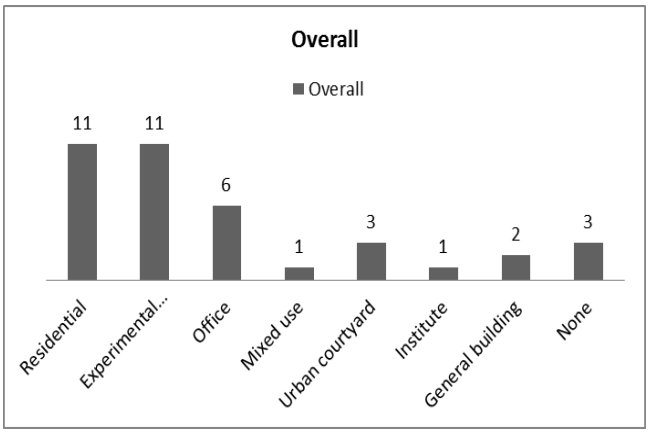

Fig. 7. Number of different building types in the reviewed literature.

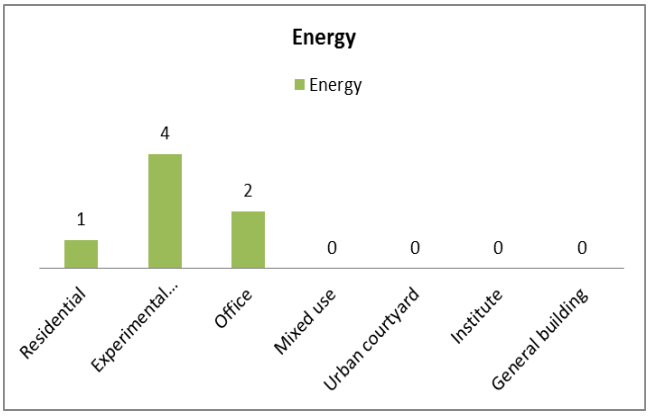

Fig. 8. Number of different building types in the reviewed literature based on energy.

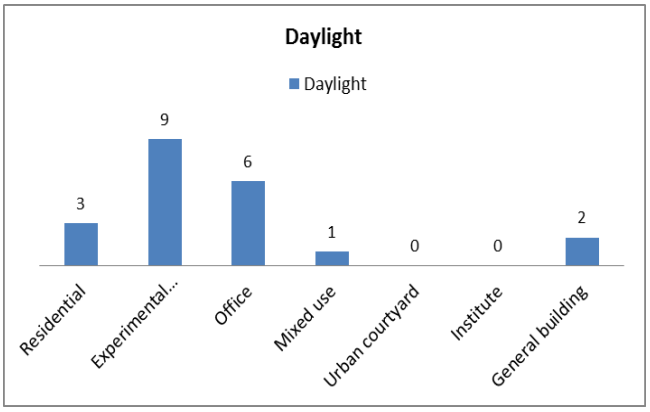

Fig. 9. Number of different building types in the reviewed literature based on daylight.

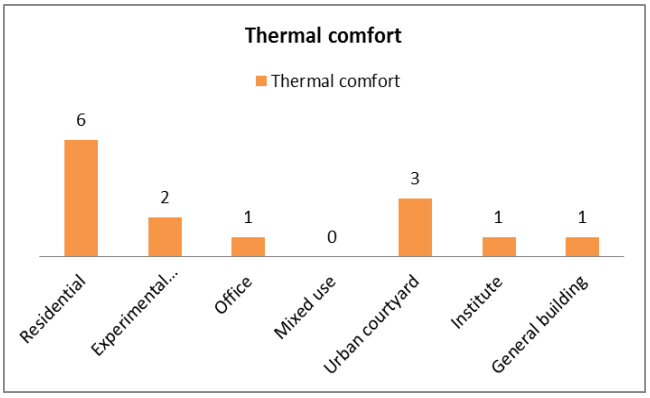

Fig. 10. Number of different building types in the reviewed literature based on thermal comfort.

F. Verifying method

Figure 11 shows the percentage of reviewed literature verified with calibration, validation, and not verified. 35% of the literature was calibrated, 15% were validated, and 50% of the literature was not calibrated or validated. Figure 12 shows the percentage of verifying methods used in the reviewed literature based on daylight. 45% of studies were calibrated [6, 9, 10, 14, 17-19, 21], and 20% were validated [4, 7, 9, 28] based on daylight. The study says that calibration and validation is the major step in the research based on daylight analysis.

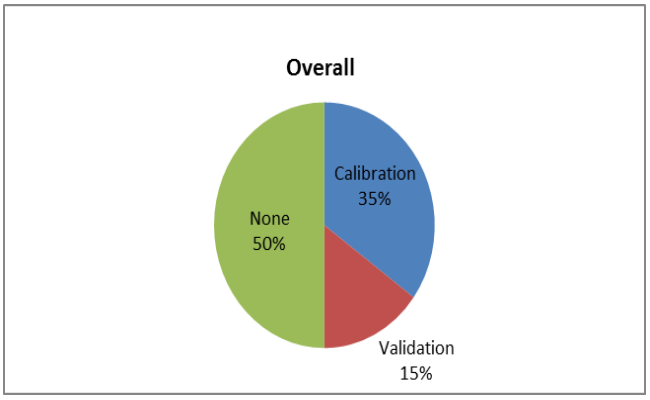

Fig. 11. Percentage of verifying methods used in the reviewed literature.

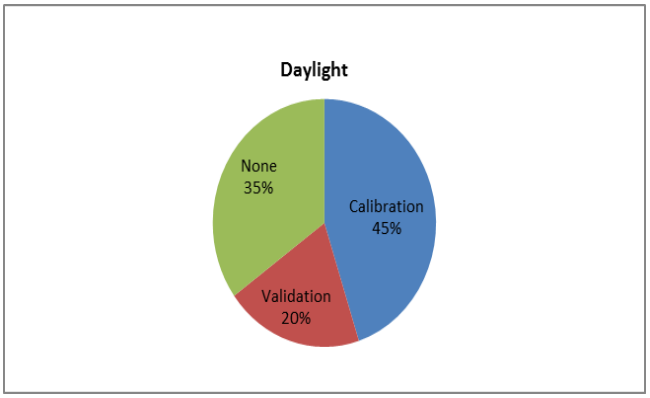

Fig. 12. Percentage of verifying methods used in the reviewed literature based on daylight.

G. Simulation tools used

Figure 13 illustrates the different state-of-the-art simulation tools which were used in the reviewed literature. Radiance was introduced in 1994; it is a command-line-based- program. Radiance doesn't have any user interface, which is a negative point, but it is very accurate in calculating the daylight in both overcast and climate-based sky conditions. In the overall reviewed literature, Radiance was used in the maximum, i.e., six [4, 12, 15, 16, 22, 23], Design builder was used in five [8, 9, 11, 19, 32], and Velux-Relux were used in five [13, 20, 24]. In the reviewed literature which talked about the energy analysis, Velux-Relux was used in two [20], Design builder was used in one [19], DOE2.1E. was used in one [35], and Archsim was used in one [7] of the reviewed literature; see Figure 14. Figure 15 illustrates the number of reviewed literature that discussed daylight; Radiance was used in six [4, 12, 15, 16, 22, 23] of the reviewed literature, Velux-Relux was used in three [13, 24], and Design builder was used in three [8, 9, 11], and DAYSIM was used in three [15, 17, 21]. Figure 16 illustrates the number of reviewed literature based on thermal comfort, majorly Designbuilder were used in two [11, 32], Ecotect was used in two [26, 30], and ENVI-Met were used in two [27, 31], of the reviewed literature. Honeybee-ladybug was used in 5%, i.e., one literature based on daylight [23].

It is a plugin software of Grasshopper that uses Radiance and DAYSIM for daylight analysis. The software carries user friendly format and free accessibility to the user. It is suggested to use Honeybee-ladybug in the research based on parametric environmental analysis.

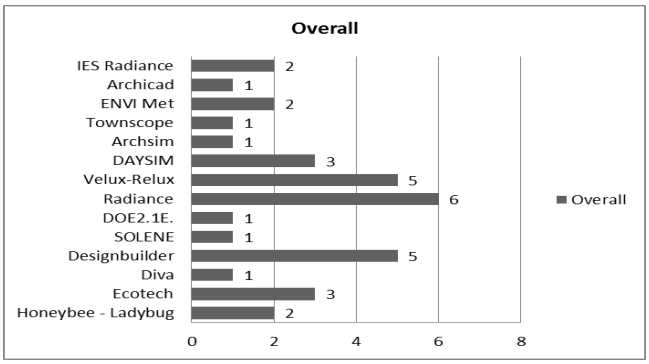

Fig. 13. Number of different simulation tools used in the overall reviewed literature.

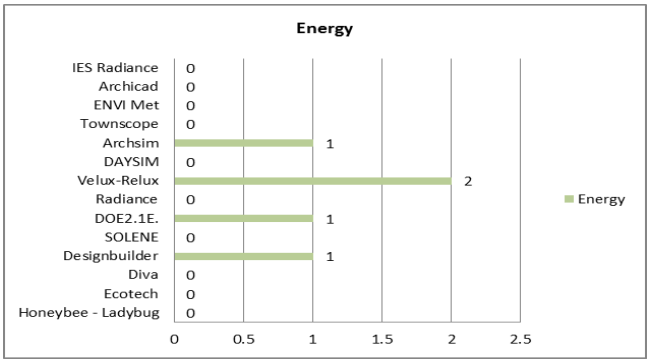

Fig. 14. Number of different simulation tools used in the reviewed literature based on energy.

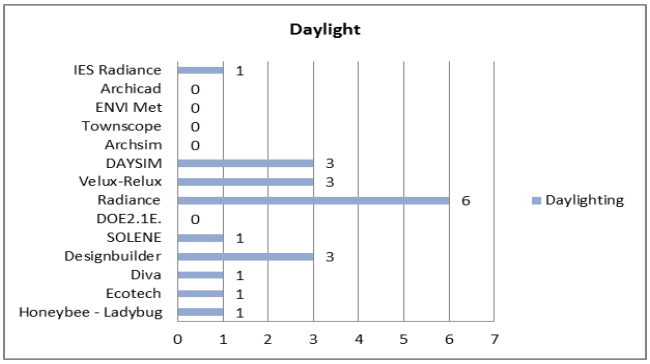

Fig. 15. Number of different simulation used in the reviewed literature based on daylight.

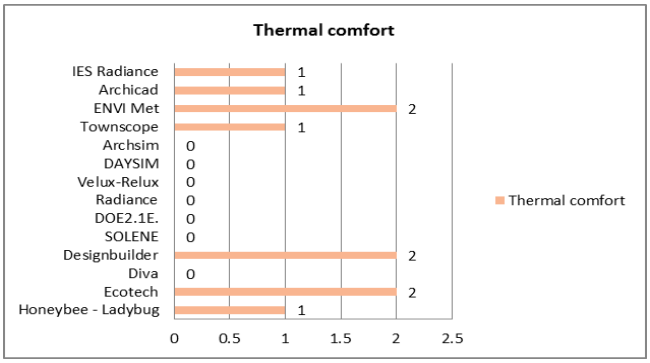

Fig. 16. Number of different simulations used in the reviewed literature based on thermal comfort.

H. Daylight matrices adopted

Figure 17 depicts the number of different daylight matrices used in the reviewed literature based on daylight. Maximum 35% i.e. eleven of literature used DF (Daylight Factor) [4-10, 20-24], 19% i.e. six used UDI (Useful Daylight Illuminance) [7, 14, 16, 17, 21, 22], 19% i.e. six used DA (Daylight Autonomy) [7, 13, 15, 17, 21, 22], 9% i.e. three used sDA Spatial Daylight Autonomy [7, 14, 21], 10% i.e. three used ASE (Annual sunlight exposure) [7, 14, 21], and 9% i.e. three used E (Illumination) [8, 12, 13]. DF was analysed in the overcast sky conditions, and all other matrices were analysed in climate-based sky conditions that define the detailed analysis of the building. Illumination (E) was used in a few of the literature, which defines the amount of light at a point on a particular day at a specific time. It was a gap in the reviewed literature to consider illumination level analysis for the existing case.

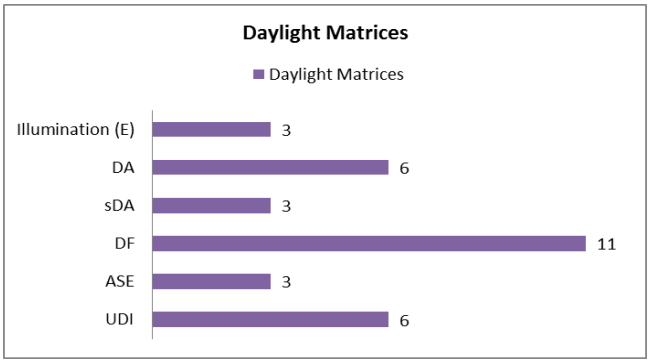

Fig. 17. Number of different daylight matrices used in the reviewed literature.

I. Methodology adopted

The reviewed literature was categorized as per the methodology adopted in the studies. In the overall analysis, 50%, i.e., nineteen of the literature were adopted the experimental-simulation methods in which collected site data were calibrated or validated with the simulation data [4, 6-9, 13, 16-20, 23, 24, 26, 27, 32, 35], or physical models were analysed in different conditions to achieve the results. 21%, i.e., eight of the literature were based on the simulation methodology, in which direct simulation was carried to achieve the results [5, 12, 21, 22, 25, 32, 36]. 10%, i.e., four of the literature used mathematical methodology [10, 28, 29, 38], 5%, i.e., two of the literature used mathematical-simulation [1,31], 3% i.e., one of the literature used parametric [14], 8%, i.e., three of the literature used theoretical [39,40], and 3%, i.e., one of the literature used experimental methodology [10] see Figure 18.

Figure 19 depicts the number of the reviewed literature based on the methodology adopted for energy analysis. 50%, i.e., two of the literature adopted experimental-simulation methodology [9, 35], 25%, i.e., one used simulation methodology [36], and 25%, i.e., one used parametric methodologies [14]. Figure 20 shows the number of the reviewed literature based on the methodology adopted for daylight analysis.

The Experimental-simulation methodology was used in 64%, i.e., fourteen of the reviewed literature [4, 6-9, 13, 15-20, 24], and 23%, i.e., four of literature adopted simulation methodology [5, 11, 12, 21, 23]. Figure 21 shows the number of the reviewed literature based on the methodology adopted for thermal comfort analysis. The experimental-simulation methodology was used in 41%, i.e., five of the literature [26, 27, 30, 34]. 25%, i.e., three used simulation [11, 25, 32], and 17%, i.e., two of the literature used mathematical methodology [1, 31]. It can be seen that experimental-simulation methodology was used in maximum numbers of the reviewed literature. For any research work based on daylighting, calibration or validation were important for verification of the data; together with these verifications, the experimental-simulation methodology should be adopted.

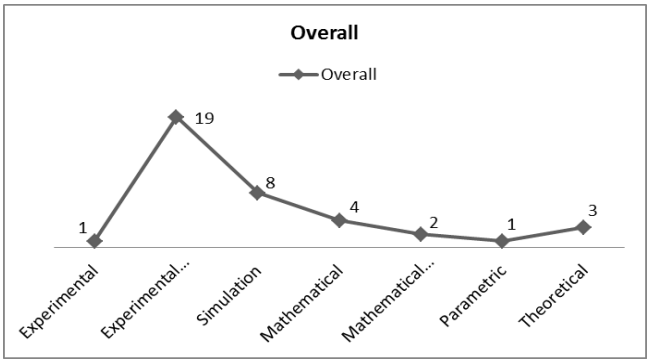

Fig. 18. Number of the Overall reviewed literature based on the methodology adopted.

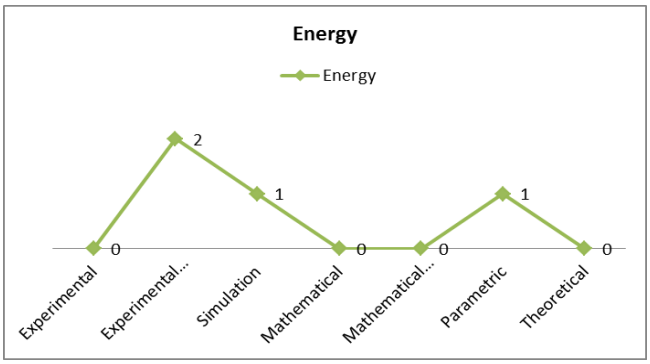

Fig. 19. Number of the reviewed literature based on the methodology adopted for energy analysis.

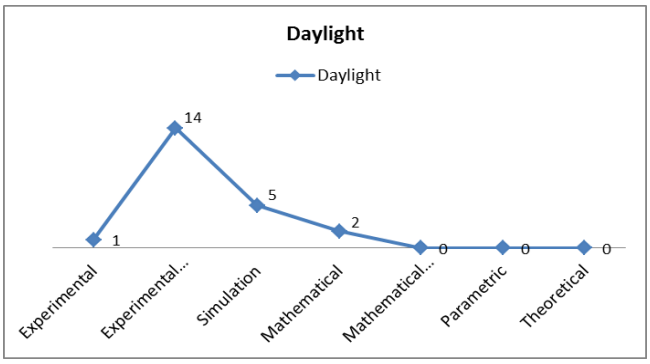

Fig. 20. Number of the reviewed literature based on the methodology adopted for daylight analysis.

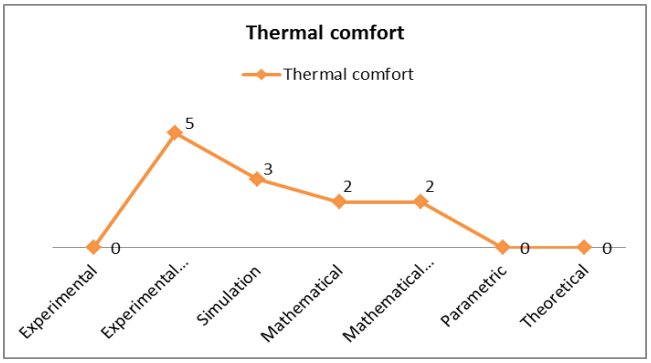

Fig. 21. Number of the reviewed literature based on the methodology adopted for thermal comfort analysis.

J. Methodology framed

The research begins with reviewing the literature of the associated field. The study of literature was divided into two parts.

- Part 1 carries the literature associated with the courtyards, courtyard houses of Composite climate, daylighting in courtyards, parameters related to courtyards, and daylighting.
- Part 2 carries the literature associated with the methodology, which covers simulation technics, associated software, weather files, sky conditions, calibration, and analysis of data.

Analysis of the literature review was done to find out the study gap to formulate the methodology.

The second stage was selecting the case studies. The criteria for determining the cases were based on the age of the houses, type of courtyards, type of placement of courtyards, climatic zones, and collection of the data from the site.

Collecting the illumination data with a certified Lux meter. The analysis of courtyard parameters was done that plays a key role in achieving adequate daylight in the courtyard with the help of plans and sections.

The third stage carries the modeling cases on the software, as precise as the actual site condition. Models of all the cases can be replicated on Sketch Up 2017, then simulation of all the case studies can be carried out on the parametric daylighting analysis software. Honeybee-Ladybug based on Radiance is recommended for the simulation. Grid-based illumination analysis to be done with fixed radiance parameters and weather file. Calibrating the site data with the simulation data for the same time and dates. Further simulation to be done on the standard days of the year, such as equinox and solstice. Comparing and analyzing all cases to find the results. Figure 22 illustrates the methodology framed for the study of effective daylighting in the courtyard houses of composite climate.

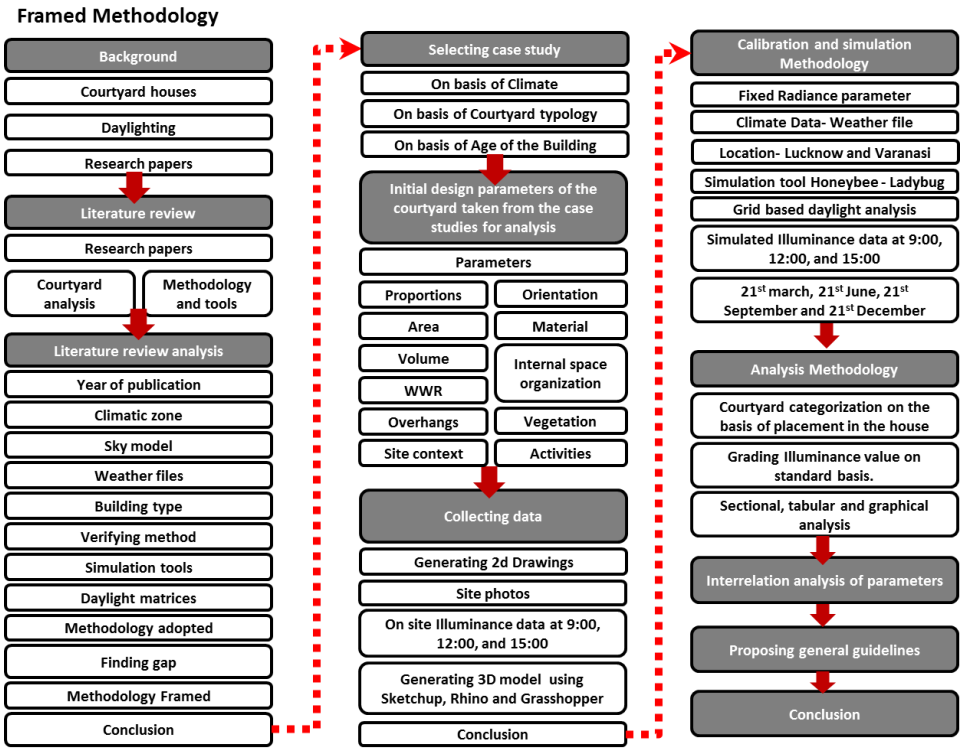

Figure 22. Methodology framed for the research.

IV. CONCLUSION

The paper fulfills the aim of the research to formulate a research methodology for the analysis of effective daylighting in courtyard houses of composite climate. Studying the publication year, climate zone, sky model, weather file, building type, verifying method, simulation tools, daylight matrices, and methodology adopted of the reviewed literature framed the methodology Figure 22. Moreover, this research paper gives the following outcomes.

- From the study, it is evident that daylight is the first choice of the present researchers for analyzing the built space.
- It will be helpful to refer to the latest literature study for the research work. The capabilities of new matrices were enhanced because of the availability of a variety of simulation tools.
- Courtyard houses of Composite climate were generally studied for thermal comfort in major cases. The study of the courtyard houses in Composite climate for daylighting purposes was minimal; it is required to fill the gap.
- The experimental model's based research studied in the reviewed literature used overcast sky conditions for the Daylight factor in significant cases. Studies using climate based sky condition seems in limited cases, future researches can be done using climate based sky for detailed analysis.
- For the daylighting analysis, the researchers prefer the experimental model instead of actual residential typology; on the other hand, real cases were used in the major reviewed literature for thermal comfort analysis. It is advised to use actual residential typology for future daylighting study.
- Various simulation tools were used in the reviewed literature; their maximum was based on energy plus and radiation. Honeybee-Ladybug is suggested for the parametric environmental study.
- New daylight matrices based on climate-based files can be used for achieving detailed results.
- For any research work based on daylighting, calibration or validation were important for verification together with experimental and simulation methodology can be adopted.

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