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Analyzing Vernacular Sustainable Design Principles- A Case Study of a Vernacular Dwelling in Godavari Region of Andhra Pradesh, India

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Abstract

Hundreds of years of experience, self-learning and traditional wisdom has led to the development of contextual based traditional architecture. Vernacular style of architecture developed using locally available material, so as to achieve the better living conditions which suits to the context. Use of local traditional design and construction techniques had eventually helped in building of social and cultural background in various regions of the country. Sensitivity in design as per the specific microclimatic aspects has been practiced since ages in the country. The main objective of this paper is to understand the design principles and strategies followed by the vernacular style of architecture which are energy efficient and climate responsive. Design principles such as form, proportion, spatial design aspects, construction materials etc.., have been documented and analyzed for a specific case example of an existing traditional building in Pippara village of West-Godavari district, Andhra Pradesh, India. Besides thermal performance, lighting analysis have been performed through IES-VE Analysis. This paper also sheds light on the transformation of courtyard spatial configuration as per the changing needs of users; this investigation is an attempt to demonstrate the adoption of good practices in transformation of traditional spatial design aspects of the dwelling. Simulation results has shown that the current case study has improved thermal performance upto 30% after the courtyard transformation, whereas natural lighting levels has drastically reduced upto 79% within the indoor sapces.

Keywords: *Vernacular Architecture, Traditional form, Design Principles, Appropriate technology, Climate Responsiveness.*

1. Introduction

Energy crisis in the new era is becoming more evident and substantial. There is an urge in change of building design philosophy, construction technology and management methods (*Zhiqiang (Jhon) Zhai, 2009*). In most of the developed countries architects and highly qualified professionals involve in the design and construction of new upcoming buildings. It has been observed that most of the buildings in developing countries and under developed countries buildings are mostly designed by the users. Oxford institute for sustainable development estimated that over 90% of current structures throughout the world has been designed by the users itself *(P.Oliver, 2003; Ramesh ,2016)* number of dwellings estimated according to this is about 800 million *(A.S Dill, 2010*). Vernacular architecture can be explained as a style of architecture where design decisions are influenced by tradition, cultural significance and climate responsiveness. Vernacular architecture varies from place to place according to the topography, local materials and technical knowhow *(P Jayasudha, 2014; Ramesh,2015*). However a lot of trial and error methods has been adopted in the evolution of traditional style of architecture, more over deeper analysis is essential to understand the unwritten information available regarding the traditional wisdom of particular locality (Building and Environment, May 2010).

Some of the significant works focusing on vernacular style of architecture are “Vernacular Reponses” of plethora cultures. “Pattern Language” (Alexander, 1977) draws a conclusion of salient architectural styles. Whereas the vernacular architecture derives conclusions from the previous user experience and reflects the culture and traditions. The strength of traditional architectural style helps in building the natural harmony with climate and built fabric (F. Wang, 2002).

This study has focused more on the traditional design principles and functions of a typical vernacular dwelling in state of Andhra Pradesh, India. This work attempts to assess the thermal performance and various spatial design considerations as per the local climate and context. A case study example has been identified, documented and analysed in one of the traditional settlements of Godavari region, Andhra Pradesh, India.

2. A Traditional Village of Pippara

Pippara is a traditional villages of Andhra Pradesh near Godavari River basin with a population of 7,719 (Census, 2011) which is located at the south eastern part of the country. It is 120 Km east from the capital region limits of Andhra Pradesh at 16.716N, 81.555E. This village is located almost at the geographical center of Andhra Pradesh state and possess rich culture and tradition. By virtue of its location one can observe the traditional aspects of design in most of the settlements within this region. The streets follow Grid-iron pattern as shown in the figure 1. The present study is unique in demonstrating the gradual transformation of previously existing plans as per the eventual needs of users in the dwelling. The effectiveness of thermal performance is explained on basis of building planning and orientation building components and activities of occupants (Manoj Kumar Singh, 2010).

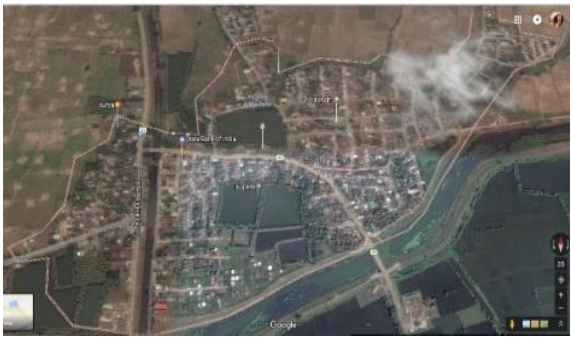

Figure 1 Map of Pippara Village with grid iron Street pattern.

3. Description of a typical dwelling

The selected building typology is about 100 years old dwelling which extents up to 982 Sq. M. with 47.65% of ground coverage. This dwelling belongs to an agro based family with the total number of occupants extending up to 30 people. Roof structure of the dwelling is treated with traditional terracotta tiles and the whole dwelling has a raised plinth of 0.8 meters above the natural ground level as shown in the figure 2. The whole dwelling has been dived into two separate structures i.e. 355 Sq.M and 110 Sq.M respectively, one is used for living and the other is dedicated to kitchen. The living area consists of 8 bedrooms, one private living area, one public living area and a guest room. The kitchen has been segregated into cooking, dining and storage areas.

Figure 2 Facade of the dwelling showing tiled roof and 0.8m raised plinth level above N.G.L.

Raised semi covered platform in front of the dwelling is known as 'arugu' which connects the exterior and interior, thus enhances interactions at family and community level. Front side of the building opens into a wide street where the main entrance exits to enter into the dwelling. Dwelling consists of a backyard of 142 Sq.M which caters space for cattle, toilets and bio-gas plant and eventually opens into a 4.5M wide road. Southern side of the dwelling is allocated for storing the agricultural equipment are the main salient features of a selected typology in the West-Godavari region of Andhra Pradesh, India as shown in the figure 3.

4. Analysis of the dwelling form

350mm thick external walls increase the thermal lag which effectively results in reducing the heat gain in summer and effective placement of the openings ensures the cross ventilation helps in attaining the thermal comfort. Further investigation of traditional design principles are discussed below.

Figure 3 Traditional Residence at Pippara, West Godavari District.

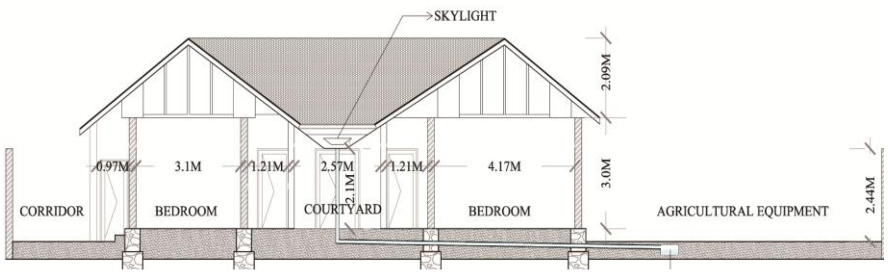

Figure 4 Section showing the designed rainwater harvesting technique

4.1 Planning and Orientation of built form

Climate of this region is warm and humid (Energy Conservation Building Code, 2007). Annual average temperature raises from 26^{O}C to 42^{O}C in summer and 20^{O}C to 34^{O}C in winter. Relative Humidity raises from 52% to 68%. By virtue of its location adjacent to the irrigation canal of River Godavari and location of water bodies at the center results in the increase of relative humidity affecting microclimate. The morphology of settlement shows a street layout of grid iron pattern, in which most of the dwellings are oriented towards east-west direction which reduces the solar heat gain in discomfort hours. The parallel streets are connected to each other more often which increases the porosity and reduces the rigidity of the street pattern. Only the shorter side of the built form are exposed to the direct solar beam radiation whereas longer side of the building is exposed to the diffused solar radiation. Existing vegetation in front and backyard of the built form reduces the additional heat gain.

4.2 Building Components

The present case study is a composite structure which has a combination of wooden columns and load bearing brick walls as shown in figure 4. All the external and internal walls possess an identical thickness of 350mm and are constructed by the burnt clay bricks (100mm x 55mm x 33mm) dressed with lime mortar which provides thermal insulation. The roof is made of Teak and Neem tree wood in which three layers of terracotta tiles have been placed to increase the thickness of the roof i.e. 300mm which increases the heat gain lag from the solar radiation. The incidence of the solar beam radiation on an angled surface of the pitched hip roof reduces its intensity due to the possessing roof angle of 35^{o}. Hip roof has a projection of 1.8 m externally which helps in shading the building from harsh east and west sun. The projection of rooms on either sides of the west façade prevents the laterally inclined solar beam radiation during thermal discomfort period of day. Total number of windows in the case study are 24 and similarly sized. (900mm X 1200mm). Out of 9 windows in east west axis 7 windows are completely shaded with the help of roof projections as shown in figure 4. 92% of windows allow diffused sun light into the structure where as 58% of widows ensures cross ventilation. Almost all windows were placed one behind the other in a linear way with window to wall ratio of 0.1 (10%).

Figure 5 Shaded windows with roof Projections

4.3 Transformation of structure (1909 to 2017).

The residential building typology under study is existing since 1909 and approximately having age of 107 years. It was consisting of a single big courtyard as shown in the figure-5. It is evident from the literature that the courtyard in traditional built up area is an open enclosed space and at central portion of building which is used as an component to draw light to the interior spaces of the building. It is further used as multifunctional space in day to day activities like washing and drying cloths, grinding grains, tot-lot for children and an interaction and relaxing space in the evening among the family members. This space is a semi open space which gives a sense of security for the users. Central courtyard has been fragmented into two spaces as living and private living spaces and space to draw light has been reduced to 1.2mx0.8m effecting the indoor lighting profile of the house. The intensity of ind-oor light has been analyzed further and discussed.

The Initial form of the building during the year 1909-1948 may be called as 'Original Form of Building' (OFB). Eventually the demand for space has been increased with the demand and need of occupants. Hence the additional space has been acquired from segregating the central courtyard into two more enclosed spaces namely living space and private living spaces as shown in the figure 6. This is the first transformation of building that took place during 1948-1969 which may be called as First-transformation of Original form of building (FT-OFB).

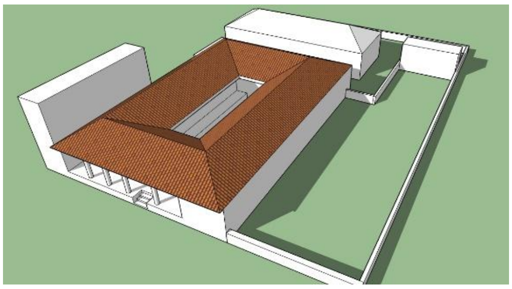

Figure 6 Original form of building (OFB); 1909-48.

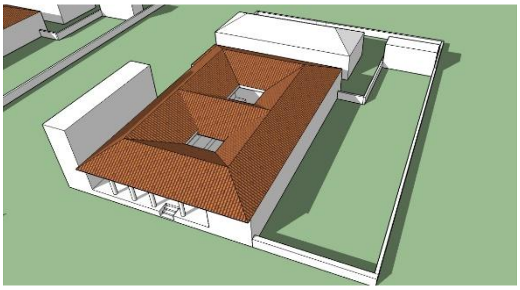

Figure 7 First transformation of original form of building (FT-OFB); 1948-69

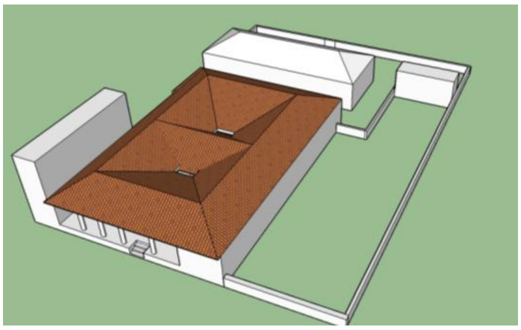

Figure 8 Second transformation of original form of building (ST-OFB) 1969-2017

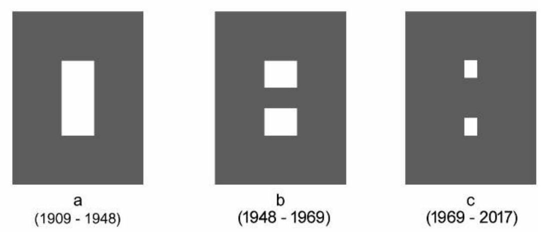

Figure 9 Ground of dwelling's roof showing the transformation of courtyard since OFB: 1909 (15mx5m) –FT-OFB: 1948 (5mx5m) – ST-OFB: 1969 (1.2mx0.8m)

After the first transformation the courtyard size was still more reduced to a size of 1.2M X 0.8M and covered by extending the tiled roof as shown in the figure 7. Also the floor level of the courtyard has been increased to the surface level of other rooms as shown in the figure 8. A funnel which is made of mild steel with fixed glazed fenestration on four sides connected with a storm water drainage channel of 150mm dia. at the bottom. This kind of funnel configuration is an interesting vernacular component related to rainwater harvesting which can be further studied to analyze in terms of harvesting and thermal configuration with and without funnel and its influence on the building. This took place during 1969-2017 which may be called as Second transformation of original form of building (ST-OFB). Figure 10 shows the Sky light at the courtyard center after transformation ST-OFB.

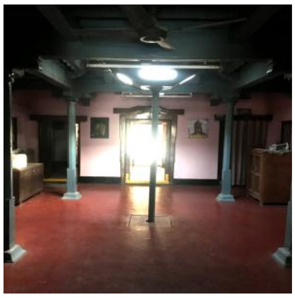

Figure 10 Showing skylight at the center of courtyard after transformation (1969)

4.4 Comparative analysis of OFB, FT-OFB and ST-OFB using IES-VE.

Thermal performance and Lighting analysis is performed using IES-VE. All the three transformations made for the current structure were analyzed and comparative analysis has been performed for both indoor thermal comfort and natural/daylight lighting levels.

4.4.1 Thermal Analysis:

The climatic character of the present context is warm and humid. May 15th has been identified as the average hottest day considering 10 years average temperature data which ranges from 34^{o}C to 44^{o}C. Thermal analysis of the present built form has been performed for the climatic data of Kakinada which closer to the present study area in absence of metrological data of current station. Discomfort hour range has been considered as per fig.12. Thermal analysis was performed for OFB and ST-OFB to compare the thermal comfort levels of before and after transformation.

All the rooms have been considered as individual zones to understand the thermal performance of each zone throughout the day. All the input parameters considered for performing simulations are given in the table 1. Thermal analysis has been carried out in Apache simulation engine in IES-VE platform. Thermal performances of each zone have been given in the figure 13 (OFB) so as to understand average thermal performance of all zones.

Table 1 Parameters considered for the thermal IEV-ES analysis

S.no	Building Component	Quantity	U-Value
1	External wall	350mm Thick	1.56 W/Sq.m
2	Internal wall	350mm Thick	1.56 W/Sq.m
3	Sloped roof with tiles (3 layer mud singles)	600mm Effective Thickness	1.26 W/Sq.m
4	Windows with no insulation	900mm x 1200mm	N/A
5	Doors	1200mm x 2100mm	N/A

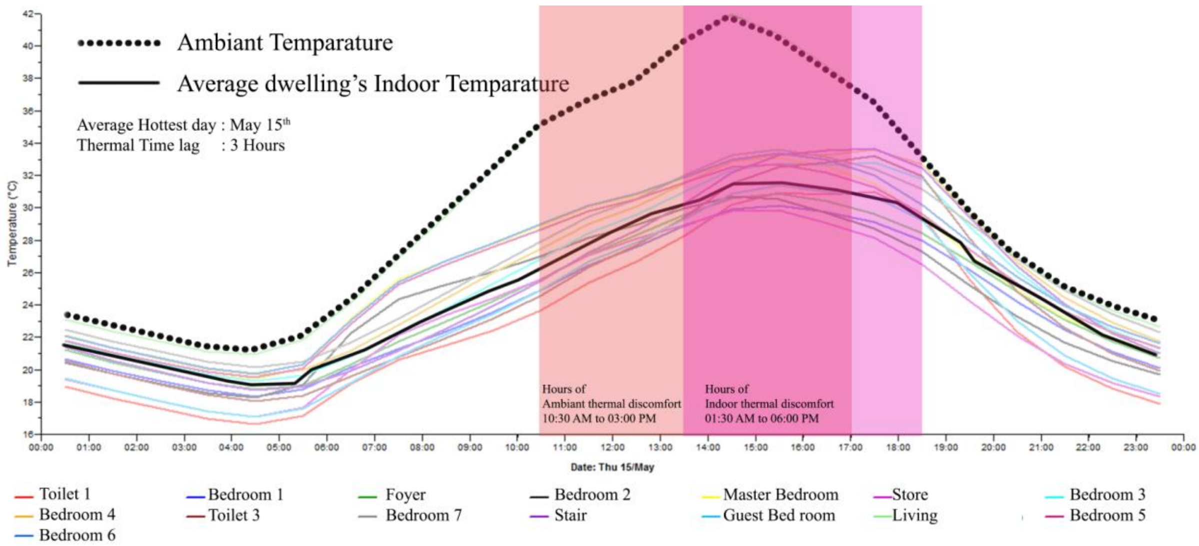

Figure 11 Thermal Performance Analysis of the dwelling during the hottest day (15th May) calculated through IES-VE Analysis-**Transformation OFB; 1909-1948.**

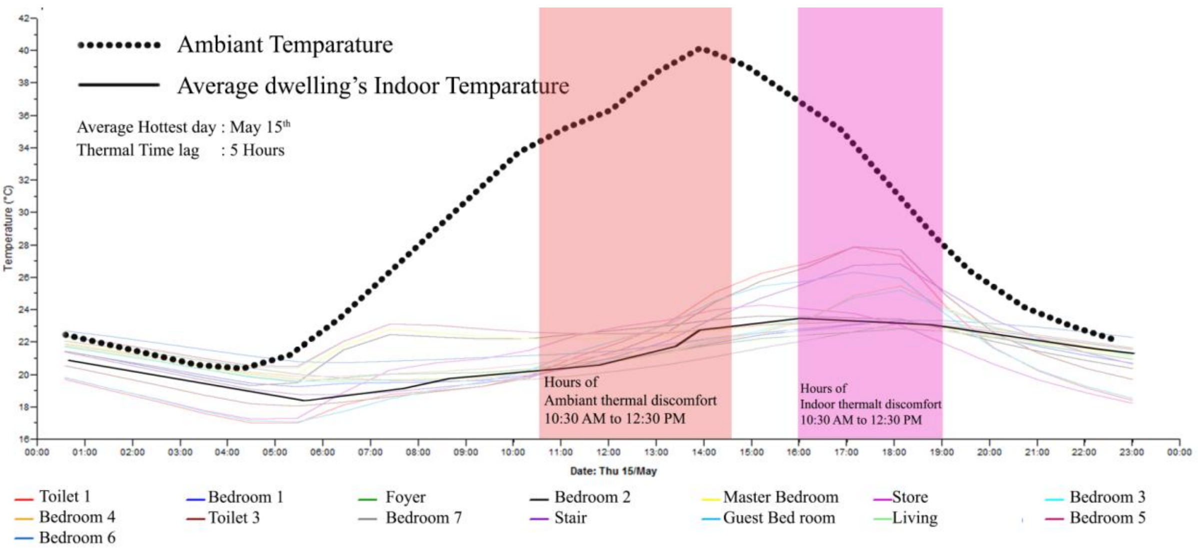

Figure 12 Thermal Performance Analysis of the dwelling during the hottest day (15th May) calculated through IES-VE Analysis-**Transformation ST-OFB; 1969-2017.**

4.5.2 Day Lighting Analysis

For analyzing indoor lighting levels IES-VE Radiance lighting simulation has been performed. For performing the lighting simulation external day light levels have been determined as 8700 Lux (Energy Conservation Building Code, 2007), India. The main building excluding kitchen and dining part has been analyzed. Enclosed floor space has been considered as analysis grid for each room individually as shown in the figure 13. Openings such as doors, windows and roof voids has been introduced as per existing conditions. Daylight simulation has been performed by Flucs-DL simulation engine in IES-VE platform. Daylighting simulation has been carried out on the average hottest day i.e. 15th May to analyze natural lighting levels in terms of day light factor for all the three transformations (OFB, FT-OFB and ST-OFB). Figure 15, 16 and 17 shows the results of the simulation and corresponding daylight factors.

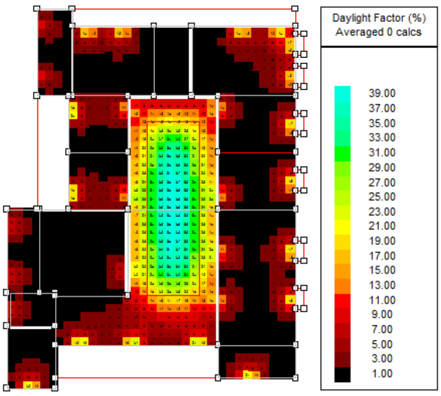

Figure 13 IES-VE Lighting analysis of dwelling OFB (1909-1948)

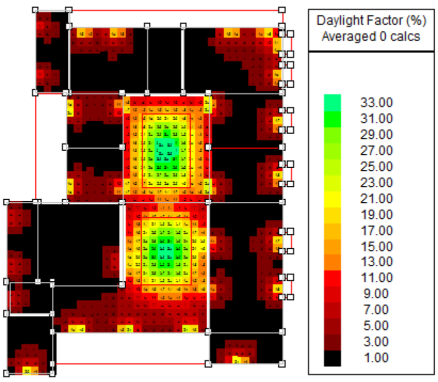

Figure 14 IES-VE Lighting Analysis of dwelling FT-OFB (1948-69)

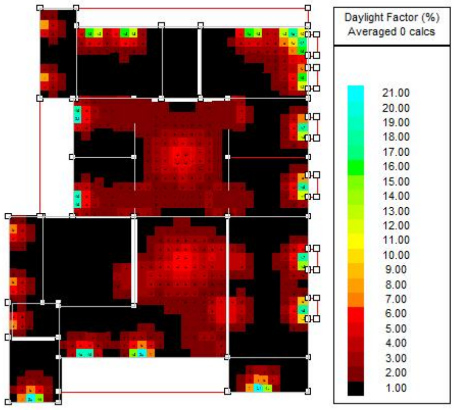

Figure 15 IES-VE Lighting analysis of dwelling ST-OFB (1969-2017)

5. Results and Discussion

The Present study has been conducted to investigate the extent of thermal performance and indoor natural lighting levels of a vernacular style of dwelling. From the analysis it is evident that OFB has a significant 7^{o} to 9^{o} C temperature difference between indoor and ambient air temperature levels during discomfort hours of average hottest day (May 15th). Whereas ST-OFB has achieved a temperature difference of 9^{o} to 14^{o} C. By comparing both the cases (OFB and ST-OFB) there is a significant 33% improvement of thermal performance by attaining 5^{o}C reduction in indoor temperature during discomfort hours i.e. as per fig. 12. It has been found that pitched roof and 350mm thick wall resulted in improving the thermal time lag of the whole structure up to 5 hours.

Results of Lighting simulation on the other hand has shown that natural indoor lighting levels has been reduced up to 54% from OFB to ST-OFB. Courtyard transformation cuts down the amount of natural light entering into the dwelling. Table 2 describes overall transformations and correspond-ding maximum attained daylight factor. From results it is evident that OFB having wide courtyard has shown maximum daylight factor as compared to other transformations. Table 3 emphasizes percentage of indoor floor space recorded. wide courtyard under natural lighting into high, medium and low based on daylight factor for all the three stages of transformation.

Table 2 IES-VE simulation results of indoor day light factor

S.no	Stage of Transformation	Max. Day light factor
1	OFB	39
2	FT-OFB	33
3	ST-OFB	6

Table 3 % of dwelling's Indoor floor space under natural lighting

S.no	Stage of Transformation	% of indoor floor space under natural lighting		
		High (>25 Day light factor)	*Medium (10 to 25 Day light Factor)*	*Low (<10 Day light Factor)*
1	OFB	21%	28%	51%
2	FT-OFB	13%	41%	51%
3	ST-OFB	0%	6%	94%

6. Conclusion

Apart from revealing architectural style of a particular region vernacular architecture also gives deeper understanding regarding the local context, material sensitivity and cultural bondage. In this work IES-VE simulations have been performed to analyze and the indoor thermal and natural lighting levels of typical vernacular house in Andhra Pradesh.

Results of thermal performance analysis has determined that indoor temperature has a difference of 7^{o}C to 9^{o}C. After the courtyard transformation ST-OFB (1948-1969) indoor thermal comfort has been increased up to 30% with the temperature difference of 9^{o}C to 14 ^{o}C between ambient and indoor temperature. Whereas on the other hand indoor lighting levels has been deceased drastically by 79% after the courtyard transformation of dwelling from Original form of Building (OFB) 1909 to Second Transformation of original form of building 1969. Hence the courtyard transformation procedure of the current case study has a positive impact on thermal comfort levels but has a negative impact on indoor lighting levels of the dwelling. As per our observation the lighting levels depending upon the functional utility of the floor spaces it has to be enhanced by the artificial lighting or with a support of PV panels for conservation of energy.

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