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RESEARCH ARTICLE

Influence of Courtyard on the Behavioural, Cultural, Climatic and Spatial Characteristics in a Transformed Vernacular Courtyard House – A Case Study in Kumbakonam, Tamil Nadu

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Abstract

Background: Courtyard have been used in residential vernacular architecture for many decades. It was incorporated within the spatial design of a house for both its cultural and climatic significance. **Objectives:** To understand the significance of courtyard in modern-day context, this research aims to explore the behavioural, cultural, climatic and spatial characteristics of courtyard in a transformed vernacular house in Tamil Nadu. **Methods:** The vernacular house was documented. Unstructured interviews were conducted with the residents to understand the relationship of the courtyard and its surrounding spaces. A matrix of attributes was developed in the research. In-situ measurements were recorded in 2021 December (Winter) and 2022 May (Summer). A statistical analysis using ArcGIS software was carried out to evaluate the correlation between the attributes. **Findings:** Results indicated that the cultural links with climatic and spatial attributes have been either weakened or lost in a few cases after transformations. Cultural links with courtyard have been lost to a larger extent. The links between cultural attributes and spatio temporal activities have been lost in recent years. Spatio temporal activities are more linked to privacy in recent times. The relationship between courtyard and climatic attributes has been altered with the changes in spatial configuration. The links between the climatic and spatial attributes have become weak due to transformations but not lost. The courtyard is strongly linked to temperature compared to all other climatic attributes. Spatio temporal activities are more related to temperature and day lighting. These activities are associated with spatial attributes like size, enclosure and openings. Spatial attributes like enclosure and openings are more linked to courtyard. **Novelty:** The study establishes the relationship between the behavioural, cultural, climatic and spatial attributes of a residential courtyard.

Keywords: Courtyard; Culture; Climate; Activity pattern; Transformation

1 Introduction

Courtyard have been used in residential architecture from the Harappan civilization till date. It is functionally an outdoor space surrounded by walls. The necessity of a space exclusive for the community for various activities within the village was observed in the vernacular settlements of Madhya Pradesh [(1)]. The courtyard acted as a key element in all climatic types, by providing thermal comfort to its inhabitants. A comparative study of summer (courtyard without roof in dry and arid areas) and winter courtyard (courtyard with a roof at its top such as glasshouse and greenhouse) in Iranian cold climate emphasized the efficient functioning of winter courtyard in cold parts of Ardebil [(2)]. Two traditional Chinese shop houses were investigated and found that the indoor air temperatures in the spaces next to small courtyard were 5-6 °C lower than immediate outdoors [(3)]. Courtyard is one of the familiar elements in the regional architectural styles designed to use the sun's warmth and light. It was observed that the traditional courtyard houses of Lucknow, which are compact and self-shaded can limit the daytime indoor temperature rise during summer [(4)]. Results from quantitative evaluation carried out on the vernacular buildings of Bikaner, India revealed that natural and passive design systems provide comfortable indoor environment irrespective of the outdoor climatic conditions. Buildings with large thermal mass and light-colored walls are suitable for climates which require heating in winter and cooling in summer and can reduce the energy needed considerably [(5)]. When the thermal performance of a vernacular haveli was compared to a contemporary house in the city of Bikaner, it was seen that the vernacular haveli performed better among the two for the whole year providing comfort indoors in both extreme summer and winter. [(6)]

In warm humid climates, the internal courtyard not only minimized the temperature but also lowered the humidity level by increasing the airflow to the internal spaces. [(7)] Increased wind velocity was observed in a single storey courtyard house in warm humid climate, due to the upwind air funnel in the courtyard. [(8)] Appropriate proportion and height of courtyard, orientation and building materials of enclosures significantly impact the duration of exposure to solar radiation, day lighting and heat storage thereby affecting thermal comfort. [(9)] The courtyard cannot be replaced by any of its derivatives due to its various advantages. [(10)] The existing vernacular courtyard housing structure needs to be preserved to retain the local spirit of the place. [(11)] Spatial exploration of courtyard is quintessential since it can be seen as an urban feature which can be often mutated for natural, cultural and social environment, in modern horizontal and vertical developments. [(12)]

There has been substantial research on the relationship of either the cultural, or climatic aspects with the spatial use of courtyard in traditional houses. However, studies that explore the impact of courtyard on the behavioural, cultural, climatic and spatial factors within the dwelling and their interrelationships are found to be rare. Though courtyard are found to be beneficial in various ways, they are gradually disappearing in modern dwellings due to transformations. In this era of cultural identity crisis, climatic sustainability and rapid spatial transformations, it becomes essential to study the cultural and climatic importance of vernacular courtyard and their relationship with the built forms in improving the physical and psychological welfare of the inhabitants to maintain their fundamental attributes in the contemporary built forms. Therefore, the main objective of this study is to analyze the significance of courtyard in the transformed courtyard house and explore the invisible links that exists between the cultural factors, climatic factors and the spatio-temporal activities within the dwelling.

1.1 Context of the Study

Kumbakonam is a temple city located in Thanjavur district in Tamil Nadu, India. It is located at 10.97°N and 79.42°E. The city is culturally significant not only for the numerous temples but also for its silk weaving. The tropical warm humid climate was conducive for weaving and related activities. Weaving of silk was carried out mainly by the Sourashtrian community in Kumbakonam. Their dwellings were designed with courtyard as the major spatial element. This study examines a transformed courtyard house of Sourashtrian community in Nadana Gopal Street near Ramasamy temple. The street has many traditional courtyard dwellings which are culturally significant and undergoing transformations. The selected sample dwelling is one of the oldest dwellings in the street. Figure 1 shows the location of the study area. Figure 2 shows the plan of the selected courtyard house. The dwelling is 75 years old and belongs to a Saurashtra (an Indo- Aryan ethno-linguistic Hindu Brahmin community of South India) family.

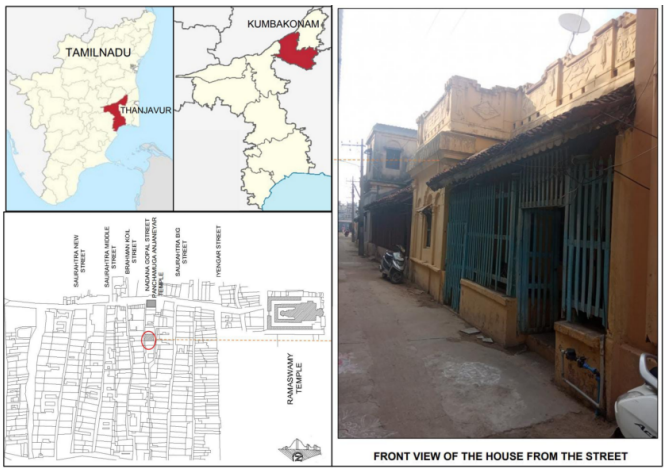


Fig 1. Location of site area

Fig 2. Floor plan of the transformed courtyard house

The entire house was initially occupied by a single joint family but is now divided into 2 dwelling units for convenience and to generate economy. The house has three courtyard, a front courtyard, a rear courtyard and a kitchen courtyard. The main and rear entrance of the house are aligned in an axis that passes through the front and rear courtyard. All habitable spaces like hall, bedrooms, kitchens and multifunctional space are arranged around the Courtyard. Front and rear courtyard are connected by a multifunctional space. The work-from-home concept is a notable example of how a more sustainable world can work. Nature and place of work has a major impact on our lives, economy and on global warming in the present scenario.[13] The

efficient planning and construction of these Saurashtrian courtyard houses were based on sustainably working home-based work concept. Initially, weaving was carried out within the house. These work homes are designed with workspaces combined with the courtyard. Dyeing and other activities related to weaving were initially carried out in the rear courtyard. At present, the residents have shifted to other jobs and are occasionally engaged in dyeing yarn. Women have shifted to small-scale catering and are performed within the house.

2 Methodology

The study attempts to explore the relationship between the behavioural, cultural, climatic aspects and spatial characteristics of courtyard in a traditional courtyard house and the performance of a semi-open transformed courtyard house is compared with that of a closed courtyard house to understand the significance of courtyard in residential architecture. Firstly, the selected vernacular house was documented through on-site observations and unstructured interviews were conducted with informed consent from the residents to understand the nature of the courtyard house from the residents' perspective. Further, the cultural, climatic and spatial relationship of courtyard and its surrounding spaces were analyzed through a matrix of relevant attributes identified through literature. Table 1 shows the matrix of identified attributes for the study. The data pertaining to the cultural attributes were derived from unstructured interviews conducted with the occupants. The data on climatic attributes were collected through in-situ measurements recorded between 7am to 7pm at an interval of two hours for one week in December 2021(winter) and May 2022 (summer). The instruments used for in-situ measurements include HTC digital indoor hygrometer thermometer with clock (Model no: 103 – CTH) to measure temperature and humidity; Ace Testo 405i thermal anemometer with smartphone to measure wind velocity; and HTC instrument – 1989 LX-101 A – Light meter to measure the daylight levels. Assessment of spatial attributes was done through spatio-temporal mapping of activities to investigate the impact of activity patterns within the spatial organization of spaces within the dwelling. A statistical analysis was carried out using spatial lag model through ArcGIS software to evaluate the correlation between all the considered attributes.

Table 1. Matrix of attributes used in the study for analysis

Behavioural attributes - Spatiotemporal mapping of activities		
Cultural attributes	**Climatic attributes**	**Spatial attributes**
Community	Air temperature	Form
Gender segregation	Relative humidity	Size
Gathering	Wind velocity	Orientation
Interaction	Solar radiation	Enclosure
Access	Day lighting	Openings

3 Results and Discussion

The functioning of the selected courtyard house was documented through on-site observations of the researcher and the data was analyzed with the perspective of the residents through unstructured interviews. Inferences were drawn based on the analysis in the research.

3.1 Functioning of Courtyard House

In the morning, daily activities take place in the courtyard which are the major open spaces within the house. Due to its large size and North- South orientation, the rear courtyard is found thermally comfortable by the users in the early morning. Hence, activities like brushing, bathing, washing and drying clothes are carried out in the rear courtyard and are completed before 9am. Cooking activities are done mostly in the passage space near the front courtyard except between 7am and 9am which is performed in Kitchen 1. Semi-enclosed spaces surrounding the courtyard are preferred during the afternoon and hence activities like eating, sleeping, washing and drying vessels, watching tv, preparatory activities for cooking, casual interaction and dyeing occasionally are carried out here. This might be due to diffused light and shading received in the areas surrounding the courtyard. In the evening and at night semi-enclosed spaces away from the courtyard are preferred. During the night, enclosed rooms away from the courtyard are preferred during all seasons. This is due to the need for increased privacy during sleep. The front courtyard is not used for any activity due to its reduced size. There is no difference in the preference of space for any activity during summer and winter within the house. Table 2 shows the Spatio temporal activities that are carried out

within the sample building. Figure 3 depicts the activities that are carried out in the spaces adjacent to the courtyard.

Table 2. Spatio Temporal Activities within the sample building

Sl.no.	Space	Timings	Activities	User Gender
1	Hall	5pm to 7pm	Watching TV, Spinning yarn (rare)	Male and Female Unit 1
		7pm to 9pm	Watching TV, Dinner	
2	Bedroom 1	3pm to 5pm	Sleeping	Female Unit 1
		9pm to 7am	Sleeping	
3	Bedroom 2	11am to 1pm	Sleeping	Male - Unit 1
		1pm to 3pm		
		3pm to 5pm		
		9pm to 7am		
4	Kitchen 1	7am to 9am	Cooking	Female
5	Kitchen 2	3pm to 5pm	Tea	Male - Unit 2
6	Bedroom 3	9am to 1pm	Breakfast, Sleeping	Male - Unit 2
		1pm to 3pm	Lunch, Sleeping	
		9pm to 7am	Dinner, Sleeping	
7	Multifunctional space 1	Throughout the day	No activity Used as storeroom	Common to all members
8	Multifunctional space 2	Throughout the day	No activity Used as passage space	Common to all members
9	Front courtyard	Throughout the day	Used as passage space	Common to all members
10	Rear courtyard	7am to 9am	Brushing, Bathing, Washing & Drying Clothes	Female - Unit 1
			Brushing and Bathing	Male – Unit 1
			Brushing and Bathing	Male – Unit 2
11	Kitchen courtyard	-	No activity	-
12	Passage space near front courtyard	9am to 11am	Breakfast & Tea	Male and Female – Unit 1
			Cooking, Catering	Female Unit-1
		1pm to 3pm	Lunch	Male and Female Unit-1
		5pm to 7pm	Dyeing and Drying Yarn (rare)	Male Unit-1

From Table 2, it is observed that front courtyard, multifunctional space 1 and multifunctional space 2 are used throughout the day. On the other hand, it is noted that the space which holds maximum number of activities is passage space near courtyard in unit 1. Nearly 7 various activities are carried out in this space. It is used for 6 hours. The second most used space is Bedroom 3 in unit 2. It is observed that the front courtyard is used throughout the day, but it holds zero number of activities. It is used as a walkway and storage purposes.

(a) (b) (c) (d)

Fig 3. Activities in spaces adjacent to courtyard a) Dyeing activity in front courtyard, b) Tarpaulin sheet covering the front courtyard extension, c) Preparatory activities for cooking in passage 2, d) Washing and drying clothes in rear courtyard

3.1.1 Resident's Perspective

The surrounding spaces of the front courtyard are found to be thermally comfortable by the residents throughout the day during both summer and winter. In general, hall is found to have lower temperature. Often external mechanical devices like fan are required to maintain thermal comfort due to poor air circulation in internal spaces. Women expressed concern that due to increased humidity in winter, fungi formation occurs on the damp floors in the courtyard. It becomes difficult for them to clean it very often and maintain the same. The size of the courtyard house is found to be larger to be maintained with less family members. External light source is required during the day for spaces away from the courtyard due to a minimal number of windows. The irregular forms caused by transformation have led to the creation of dead spaces in both the courtyard which the residents feel can be modified and used when their economic conditions become better. The degree of enclosures has become more within the dwelling which leads to suffocation and thermal discomfort, and they feel comfortable to carry out activities near the vital openings of the house, the courtyard.

3.2 Analysis of attributes within the dwelling

3.2.1 Cultural Attributes

Weaving, which was traditionally the major occupation, is carried out as a leisure activity at present. A disconnection from the courtyard space was observed between the family members due to shift in occupation of the community. Use of space was not restricted to any specific gender within the house. Traditionally, the front courtyard of the house was visually connected to the main entrance and the entrance of the opposite house maintaining visual connectivity with neighbors. This ensured interaction between the houses. At present the entrance doors of individual houses are kept closed during most parts of the day for privacy. This reduced the chances for casual interactions between neighbors. Privacy is given increased priority in the family setting at present. The doors and courtyard along the major axis of the house were off centered in the plan of the house owing to privacy. With the increase in the use of cell phones and television in recent years, individual preferences have led to the use of enclosed spaces. Cultural significance is lost unobtrusively. A detailed study about the links between culture, social benefits, and courtyard in Kumbakonam region has been done by the authors [14].

3.2.2 Climatic Attributes

Courtyard within the vernacular houses were designed to provide better microclimatic conditions and accommodate a variety of activities. The behavior of the inhabitants of the house is linked to the existing comfort conditions within the house. Table 3 shows the in-situ microclimatic observations recorded within the dwelling. Most of the activities like eating and related preparatory activities happen in and around passage 2, due to less heat with a temperature of 35.91°C during summer and warmer than rest of the spaces by 1°C (30.77°C) in winter. It is evident that the users feel comfortable using the surrounding space of courtyard during the forenoon in summer, as the courtyard helps to regulate the temperature in the surrounding spaces. The north south oriented rear courtyard helps in bringing cool air during early mornings. The temperature in the rear courtyard is 29.47°C between 7 and 9am in summer and rises by 5.1°C in the next two hours.

Table 3. In-Situ microclimatic observations during the activity within the dwelling

Sl. No.	Space	Time	Air temp. (°C)			Relative Humidity (%)			Wind velocity (m/s)	Day lighting (Lux)	
			Winter	Summer	Peak Summer	Winter	Summer	Peak Winter		Winter	Summer
1	Hall	5pm to 7pm	30.17	35.53	36.71	67.20	41.57	71.17	0.02	0	0
2	Bedroom 1	3pm to 5pm	29.87	36.44	36.73	69.00	37.57	77.00	0.00	0.00	0
3	Bedroom 2	11am to 1pm	35.02	34.87	36.73	73.86	41.86	77.50	0.00	97	180
		1pm to 3pm	30.40	36.73		65.43	35.43		0.00	78	230
		3pm to 5pm	29.91	36.46		68.86	37.71		0.00	32	162
4	Kitchen 1	7am to 9am	28.37	32.50	36.64	77.50	50.67	77.50	0.00	14	38
5	Kitchen 2	3pm to 5pm	30.06	36.54	36.60	69.00	37.71	77.83	0.00	17	27
6	Bedroom 3	9am to 11am	34.27	32.87	36.60	76.71	50.57	78.50	0.02	57	68
		1pm to 3pm	30.46	36.60		66.57	36.29		0.00	13.0	84
7	MFS*	-	35.30	-	36.60	-	50.50	78.50	0.01	99.0	140

Continued on next page

Table 3 continued

8	MFS 2*	-	35.90	-	36.79	-	50.50	77.33	0.00	290	427
9	Front court-yard*	-	35.78	-	35.81	-	54.14	78.83	0.02	9269	12500
10	Rear courtyard	7am to 9am	29.47	31.78	35.99	77.00	47.00	77.00	0.03	1000	2120
11	Kitchen courtyard *	-	35.42	-	36.01	-	54.43	78.00	0.00	3840	5400
12	Passage near -front courtyard	9am to 11am	34.73	32.80	35.91	74.43	53.57	77.67	0.00	3930	4980
		1pm to 3pm	30.77	35.91		65.29	39.71		0.03	3090	6200
		5pm to 7pm	30.41	35.90		64.80	44.80		0.00	54	96
13	Outdoor	1pm to 3pm	33.5	37.5	38.00	57.5	28.5	68.0	0.04	8943	9567

Note: (*) Time is not marked as these spaces did not have specific activity; MFS -Multi functional space; MFS 2- Multifunctional space 2

Relative humidity is as high as 77% between 7am and 9am in the rear courtyard and it decreases steadily throughout the day to reach 65% between 5pm and 7pm during winter. During summer, humidity decreases steadily from 47% in the early morning between 7am and 9am to 40% at 3pm and starts to increase to 44.71% between 5 and 7pm. Increasing the air movement can aid in dissipating the heat and create better microclimatic conditions in warm humid regions. The sloped roof helps to collect rainwater in the courtyard. At times, cans or vessels are kept in the courtyard to collect rainwater and used for household activities. The wind velocity in the rear courtyard is at an average speed of 0.03m/s between 7am and 9am, it gets reduced to an average speed of 0 to 0.1m/s during winter. During summer, the average wind velocity is at 0.1m/s between 7-9am and reaches still air condition by 9am. The activities in the rear courtyard are completed before 9am during winter and summer due to rise in temperature and reduced wind velocity after 9am. Due to increased solar radiation during the day in both courtyard, activities are carried out in the spaces surrounding the courtyard. Spatio-temporal activities carried out within the vernacular house are found adaptive to the existing microclimate condition. The daylight analysis revealed that spaces like bedroom 2 and multifunctional space 2 that are adjacent to the courtyard received sufficient daylight until 3pm. Though kitchen 1 is located adjacent to the kitchen courtyard, due to transformations, daylight received was not sufficient to carry out everyday activities. Dependency on artificial light is essential for cooking, especially during winter. Although kitchen 1 is large in area, all the preparatory activities for cooking take place near passage 2 and front courtyard extension between 9am to 3pm for want of daylight. Kitchen 2 received borrowed daylight from the front courtyard and diffused light through the skylight. Multifunctional space 1, though located away from the courtyard, had enough daylight to carry out activities since it had a window opening towards the rear courtyard. Hall and bedroom 1 had no daylight since they are located away from the courtyard.

Vernacular dwellings are appropriate examples of green building concept. The design of these dwellings helps to connect the occupants to the environment with little or no impact on the nature of the site and its resources. The dwelling considered for this study has many green building characteristics. The dwelling is oriented towards the East. Openings on the eastern wall which faces the street are shaded by the parking space near the entrance. This reduces heat ingress into the interiors but provides daylight. Increased thermal mass of the exterior walls helps in thermal lag. Spatial organization has been planned carefully to provide flexibility in use of interior spaces. Locally available materials like country brick for walls, country wood for window frames and partitions, handmade clay tiles for roof were used. The presence of courtyard reduced dependency of mechanical and electrical systems. The front courtyard is oriented towards the East which takes advantage of the solar access during the day and provides natural light to all the habitable spaces of the dwelling. All openings of habitable rooms are oriented towards the courtyard. Openings towards the rear courtyard are minimized to prevent heat ingress into the internal spaces. Transformations made are limited to very few spaces when necessary.

3.2.3 Spatial Attributes

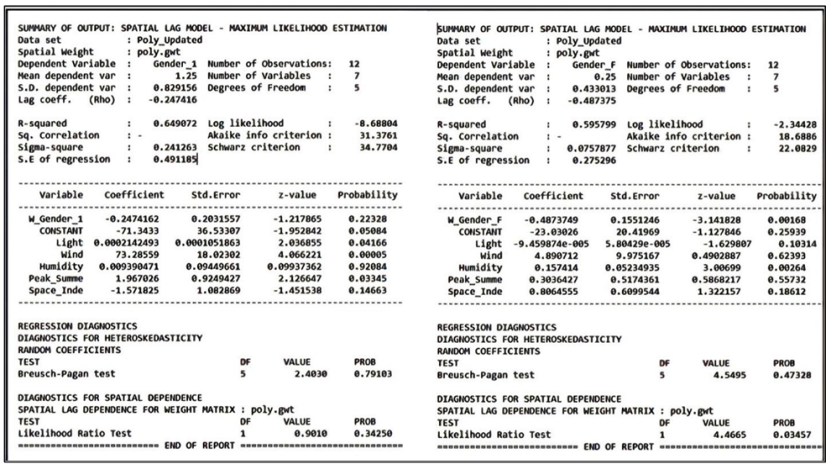
The spatial use and pattern of the activities within the dwelling changed with the change in the form of the courtyard. The form of the front courtyard has been modified after transformation. The form and size of the courtyard is a major deciding factor of the behavior of the users. Both daytime and nighttime activities in the front courtyard have shifted to the internal spaces due to its reduced size. Orientation of the courtyard is one of the main factors to create a comfortable microclimate to carry out activities. The N-S oriented rear courtyard is found thermally comfortable by the residents during early mornings. Enclosed spaces which are located away from the courtyard with no external openings affect the physical and mental well- being of the inhabitants. Courtyard with an increased degree of openness are the least preferred space by the younger generation due to the

increased preference towards individual privacy.

3.3 Links between Cultural, Climatic and Spatial Attributes

It is observed that the inhabitants shift their daily activities to different spaces within the house according to their cultural, climatic and spatial requirements. The change in form and reduction in size of the front courtyard led to a lack of space to hold gatherings within the dwelling. Hence, it may be said that change in the spatial attribute has led to change in the cultural attributes. The spatial hierarchy achieved in the design of the dwelling using courtyard is very well linked to the activities and behavior of the inmates of the house. Heterogeneity in the spatial organization has led to flexibility in spatial use based on the microclimatic preferences of the residents of the house.

To predict the relationship between the tangible attributes like climatic and spatial attributes further, a statistical analysis was done using ArcGIS software. Between the two regression models, the spatial lag regression model was used. Primary data from Tables 2 and 3 and spatial attributes was used to perform the spatial regression analysis. Figures 4, 5 and 6 show the results of the regression analysis.



SUMMARY OF OUTPUT: SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION

Data set	: Poly_Updated		
Spatial Weight	: poly.gwt		
Dependent Variable	: Gender_1	Number of Observations:	12
Mean dependent var	: 1.25	Number of Variables	: 7
S.D. dependent var	: 0.829156	Degrees of Freedom	: 5
Lag coeff. (Rho)	: -0.247416		
R-squared	: 0.649072	Log likelihood	: -8.68804
Sq. Correlation	: -	Akaike info criterion	: 31.3761
Sigma-square	: 0.241263	Schwarz criterion	: 34.7704
S.E of regression	: 0.491185		

Variable	Coefficient	Std.Error	z-value	Probability
W_Gender_1	-0.2474162	0.2031557	-1.217865	0.22328
CONSTANT	-71.3433	36.53307	-1.952842	0.05084
Light	0.0002142493	0.0001051863	2.036855	0.04166
Wind	73.28559	18.02302	4.066221	0.00005
Humidity	0.009390471	0.09449661	0.09937362	0.92084
Peak_Summe	1.967026	0.9249427	2.126647	0.03345
Space_Inde	-1.571825	1.082869	-1.451538	0.14663

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	5	2.4030	0.79103

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : poly.gwt

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	0.9010	0.34250

========== END OF REPORT ==========

(a)

SUMMARY OF OUTPUT: SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION

Data set	: Poly_Updated		
Spatial Weight	: poly.gwt		
Dependent Variable	: Gender_F	Number of Observations:	12
Mean dependent var	: 0.25	Number of Variables	: 7
S.D. dependent var	: 0.433013	Degrees of Freedom	: 5
Lag coeff. (Rho)	: -0.487375		
R-squared	: 0.595799	Log likelihood	: -2.34428
Sq. Correlation	: -	Akaike info criterion	: 18.6886
Sigma-square	: 0.0757877	Schwarz criterion	: 22.0829
S.E of regression	: 0.275296		

Variable	Coefficient	Std.Error	z-value	Probability
W_Gender_F	-0.4073749	0.1551246	-3.141828	0.00168
CONSTANT	-23.03026	20.41969	-1.127846	0.25939
Light	-9.459874e-005	5.80429e-005	-1.629807	0.10314
Wind	4.890712	9.975167	0.4902887	0.62393
Humidity	0.157414	0.05234935	3.00699	0.00264
Peak_Summe	0.3036427	0.5174361	0.5868217	0.55732
Space_Inde	0.8064555	0.6099544	1.322157	0.18612

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	5	4.5495	0.47328

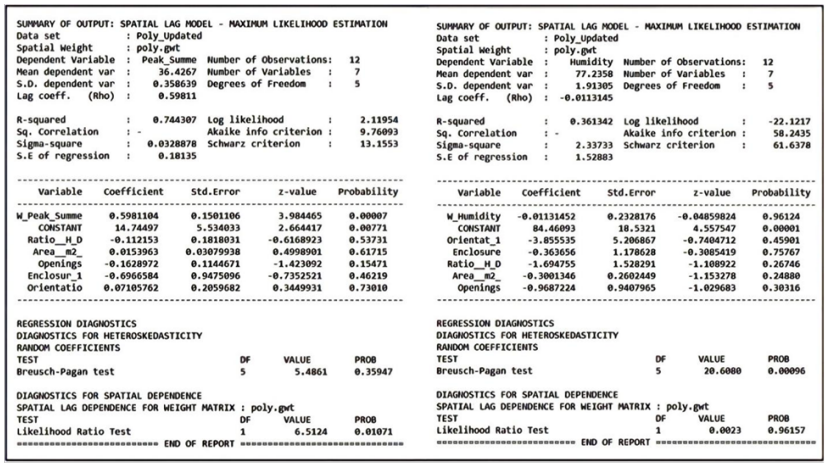
DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : poly.gwt

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	4.4665	0.03457

========== END OF REPORT ==========

(b)

Fig 4. Results of Spatial regression analysis – (a) Male gender Vs Climatic attributes, (b) Female gender Vs Climatic attributes



SUMMARY OF OUTPUT: SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION

Data set	: Poly_Updated		
Spatial Weight	: poly.gwt		
Dependent Variable	: Peak_Summe	Number of Observations:	12
Mean dependent var	: 36.4267	Number of Variables	: 7
S.D. dependent var	: 0.358639	Degrees of Freedom	: 5
Lag coeff. (Rho)	: 0.59811		
R-squared	: 0.744307	Log likelihood	: 2.11954
Sq. Correlation	: -	Akaike info criterion	: 9.76093
Sigma-square	: 0.0328878	Schwarz criterion	: 13.1553
S.E of regression	: 0.18135		

Variable	Coefficient	Std.Error	z-value	Probability
W_Peak_Summe	0.5981104	0.1501106	3.984465	0.00007
CONSTANT	14.74497	5.534033	2.664417	0.00771
Ratio__H_D	-0.112153	0.1818031	-0.6168923	0.53731
Area__m2_	0.0153963	0.03079938	0.4998901	0.61715
Openings	-0.1628972	0.1144671	-1.423092	0.15471
Enclosur_1	-0.6966584	0.9475096	-0.7352521	0.46219
Orientatio	0.07105762	0.2059682	0.3449931	0.73010

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	5	5.4861	0.35947

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : poly.gwt

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	6.5124	0.01071

========== END OF REPORT ==========

(a)

SUMMARY OF OUTPUT: SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION

Data set	: Poly_Updated		
Spatial Weight	: poly.gwt		
Dependent Variable	: Humidity	Number of Observations:	12
Mean dependent var	: 77.2358	Number of Variables	: 7
S.D. dependent var	: 1.91305	Degrees of Freedom	: 5
Lag coeff. (Rho)	: -0.0113145		
R-squared	: 0.361342	Log likelihood	: -22.1217
Sq. Correlation	: -	Akaike info criterion	: 58.2435
Sigma-square	: 2.33733	Schwarz criterion	: 61.6378
S.E of regression	: 1.52883		

Variable	Coefficient	Std.Error	z-value	Probability
W_Humidity	-0.01131452	0.2328176	-0.04859824	0.96124
CONSTANT	84.46093	18.5321	4.557547	0.00001
Orientat_1	-3.855535	5.206867	-0.7404712	0.45901
Enclosure	-0.363656	1.178628	-0.3085419	0.75767
Ratio__H_D	-1.694755	1.528291	-1.108922	0.26746
Area__m2_	-0.3001346	0.2602449	-1.153278	0.24880
Openings	-0.9687224	0.9407905	-1.029683	0.30316

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	5	20.6080	0.00096

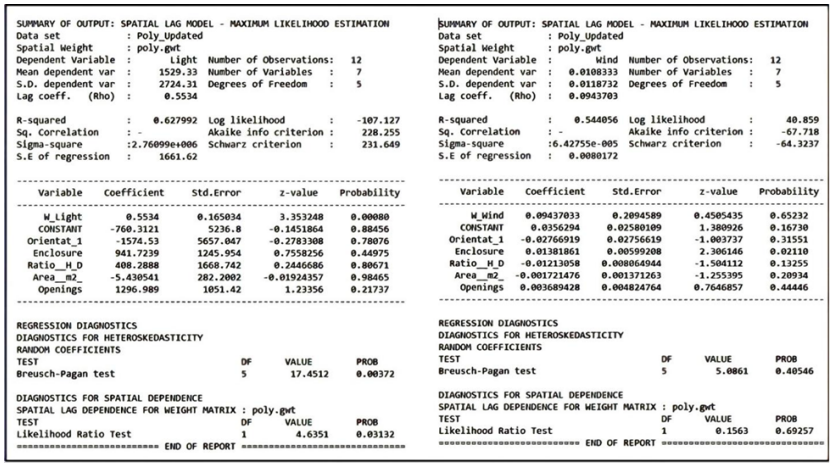
DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : poly.gwt

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	0.0023	0.96157

========== END OF REPORT ==========

(b)

Fig 5. Results of Spatial regression analysis – (a) Temperature Vs Spatial attributes, (b) Humidity Vs Spatial attributes



SUMMARY OF OUTPUT: SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION
Data set : Poly_Updated
Spatial Weight : poly.gwt
Dependent Variable : Light Number of Observations: 12
Mean dependent var : 1529.33 Number of Variables : 7
S.D. dependent var : 2724.31 Degrees of Freedom : 5
Lag coeff. (Rho) : 0.5534

R-squared : 0.627992 Log likelihood : -107.127
Sq. Correlation : - Akaike info criterion : 228.255
Sigma-square :2.76099e+006 Schwarz criterion : 231.649
S.E of regression : 1661.62

Variable	Coefficient	Std.Error	z-value	Probability
W_Light	0.5534	0.165034	3.353248	0.00080
CONSTANT	-760.3121	5236.8	-0.1451864	0.88456
Orientat_1	-1574.53	5657.047	-0.2783308	0.78076
Enclosure	941.7239	1245.954	0.7558256	0.44975
Ratio__H_D	408.2888	1668.742	0.2446686	0.80671
Area__m2_	-5.430541	282.2002	-0.01924357	0.98465
Openings	1296.989	1051.42	1.23356	0.21737

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	5	17.4512	0.00372

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : poly.gwt

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	4.6351	0.03132

========== END OF REPORT ==========

(a)

SUMMARY OF OUTPUT: SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION
Data set : Poly_Updated
Spatial Weight : poly.gwt
Dependent Variable : Wind Number of Observations: 12
Mean dependent var : 0.0108333 Number of Variables : 7
S.D. dependent var : 0.0118732 Degrees of Freedom : 5
Lag coeff. (Rho) : 0.0943703

R-squared : 0.544056 Log likelihood : 40.859
Sq. Correlation : - Akaike info criterion : -67.718
Sigma-square :6.42755e-005 Schwarz criterion : -64.3237
S.E of regression : 0.0080172

Variable	Coefficient	Std.Error	z-value	Probability
W_Wind	0.09437033	0.2094589	0.4505435	0.65232
CONSTANT	0.0356294	0.02580109	1.380926	0.16730
Orientat_1	-0.02766919	0.02756619	-1.003737	0.31551
Enclosure	0.01381861	0.00599208	2.306146	0.02110
Ratio__H_D	-0.01213058	0.008064944	-1.504112	0.13255
Area__m2_	-0.001721476	0.001371263	-1.255395	0.20934
Openings	0.003689428	0.004824764	0.7646857	0.44446

REGRESSION DIAGNOSTICS
DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	5	5.0861	0.40546

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL LAG DEPENDENCE FOR WEIGHT MATRIX : poly.gwt

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	0.1563	0.69257

========== END OF REPORT ==========

(b)

Fig 6. Results of Spatial regression analysis – (a) Light Vs Spatial attributes, (b) Wind Vs Spatial attributes

R-Square in the above result is considered to validate the reliability of the best fitted model. Since most of the predicted R-square values in the spatial regression analysis are in the range of 0.5 to 0.7, it can be said that the results are in the acceptable range. From Figures 4, 5 and 6, the following results can be observed.

Temperature is significantly related to the considered parameters in the order of openings, enclosure, H/D ratio, area, orientation. Design of openings is very crucial when compared to other factors with respect to temperature. Temperature is directly proportional to area. Temperature is inversely proportional to H/D Ratio, Openings, Enclosure. Humidity is substantially related to the examined parameters in the order of H/D ratio, area, openings, orientation, enclosure.

Humidity is inversely proportional to enclosure, H/D ratio, area, openings. Daylight is remarkably related to the studied parameters in the order of openings, enclosure, orientation, H/D ratio and Area. Design of openings are more significant as compared to other factors when daylight is considered. Light is directly proportional to enclosure, H/D ratio and openings. Though the degree of enclosure is more, the amount of daylight is higher due to the presence of courtyard and skylights within the house. Wind is significantly related to the considered parameters in the order of enclosure, H/D ratio, area, orientation, openings. Enclosure, H/D ratio and area are equally significant factors related to wind.

Male gender is notably related to the considered parameters in the order of wind, temperature, light. H/D ratio and area are equally significant factors related to male gender. Wind is the most important factor related to male gender. Male members use the space where there is increased wind, temperature and light. Male gender does not use the space with increased enclosure and openings. Female gender significantly related to humidity and light.

Female gender is more related to humidity than light. This can be related to the fact that the women of the house do more household chores that are related to humidity like washing vessels and clothes. Women use the spaces around the courtyard with more daylight, for carrying out their daily activities. Female gender's presence is directly proportional to the presence of wind, temperature, humidity. Female gender's presence is inversely proportional to the presence of light. Female members use the space when there is more wind and temperature even when there is no or less light in some cases.

In Saudi Arabia, traditional courtyard houses combine the indoors and outdoors while allowing access and privacy. The courtyard dwelling also acts as an interaction space with better light and ventilation.[15] Though courtyard in Xiaojiapo village, China are narrow and long, they can satisfy people's needs.[16] Recent research related to traditional courtyard houses in various regions show that these houses possess numerous advantages despite their variation in size, position, location etc. This study highlights that there are missing links between the various characteristics and their level of significance in order within the courtyard houses that are undergoing transformations. This will assist in understanding the links better and aid in revitalizing the courtyard and its surrounding spaces in residential courtyard design.

Figure 7 depict the links between the cultural, climatic and spatial attributes after transformations that were derived from the established link between climatic and spatial attributes from Figures 4, 5 and 6; and the links observed between the onsite investigation of cultural attributes and the spatio temporal activities of residents.

From Figure 7, it is observed that cultural links with climatic and spatial attributes have been either weakened or lost in few cases after transformations. Cultural links with courtyard have been lost to a larger extent because of the change in nature of work of the residents and modifications made to courtyard spaces within the dwelling. The strong links between cultural attributes and

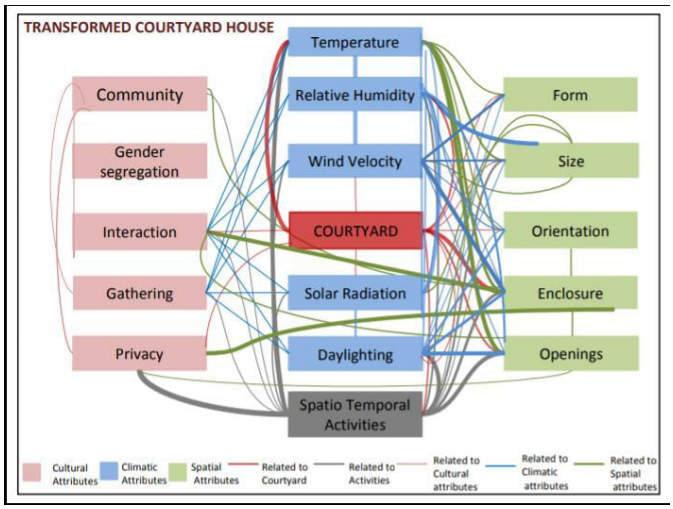


Fig 7. Links between cultural, climatic and spatial attributes after transformation

spatio temporal activities that existed prior to transformations have been lost in recent years. Of all the cultural attributes, spatio temporal activities are more linked to privacy in recent times. The relationship between courtyard and climatic attributes has been altered with the changes in spatial configuration. The links between the climatic and spatial attributes have become weak due to transformations but not lost. The courtyard is strongly linked to temperature compared to all other climatic attributes. Spatio temporal activities are more related to temperature and day lighting. Spatial attributes like enclosure and openings are more linked to courtyard when compared with other attributes like form, size and orientation in recent years. Spatio temporal activities are associated with spatial attributes like size, enclosure and openings.

4 Conclusion

Courtyard in vernacular houses are undergoing transformations. Changes in occupational pattern, changing climatic and spatial requirements are the major causes of these transformations. This study established the relationship between behavioural, cultural, climatic and spatial characteristics of a vernacular courtyard house. It signifies the importance of courtyard in modern day context. Spatio temporal activities are more linked to the considered attributes like privacy, temperature, day lighting, enclosure and openings at present when compared to other attributes in the study. It is evident that the courtyard is closely associated with the temperature of its surrounding spaces and activities carried out in these spaces. Increased air movement along with a lower temperature of the space is the deciding factor for both the genders to carry out their daily activities. In future study, innovative ways can be formulated to maintain a strong relation between these attributes using courtyard as the key element in both vernacular and modern residences. While vernacular architecture is receiving renewed attention, green building concepts can be incorporated into the design of modern buildings to provide better thermal comfort conditions to the inhabitants with energy efficiency.

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