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A COMPARATIVE ANALYSIS ABOUT THE INDOOR THERMAL ENVIRONMENT OF A ROOM WITH AND WITHOUT TRANSITIONAL SPACE OR THRESHOLD IN TRADITIONAL ROW HOUSES ADJACENT TO A NARROW ALLEY "*RUPCHAN LANE*" IN OLD DHAKA, BANGLADESH

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Abstract
Attaining appropriate thermal comfort conditions for users in built forms, located in a warm and humid sub-tropical climate is a complex phenomenon. Especially, when it is resided at a congested place like old Dhaka Bangladesh, the provision of giving cross ventilation and building with proper orientation is quite challenging. This paper aims to investigate about the indoor thermal environment of a room with and without transitional space or threshold in traditional row houses adjacent to a narrow alley of old Dhaka through field measurements. Transitional spaces are the part of buildings which are used for semi-outdoor household activities, social gathering and it is also proved to provide an indoor thermal effect. The field study has been conducted by collecting thermal data (Temperature, Humidity and Airflow) respectively, among the outdoor narrow alley, transitional space and adjacent indoor. This east west elongated alley has an average width of 2.13 meter (varies from 1.5 to 2.6 meter) holding row houses on both sides. Among different aspects of thermal environment the study of this paper is based on the analysis of temperature of corresponding cases. Other aspects and their variables were considered as constant (especially material) for accuracy and avoidance of confusion. This study focuses on the outcome that can ultimately contribute to the built form configuration of row houses with transitional spaces and in its relation to the adjacent outdoor space while achieving thermal comfort for the people inhabiting. This study will disclose scope for analysis on the thermal quality and performances of the socially interactive spaces like courtyard, veranda or transitional spaces.

Keywords: *Built- form, Old-Dhaka, Row Houses, Temperature, Thermal Comfort, Thresholds, Transitional Space*

1. Introduction

A row-house is one of a cluster of low-rise residential or shop house buildings that shares one or both side walls and a roofline with the structures next door [1]. A row house is typically just two to five stories in height and home to one or two families [1]. In old Dhaka, Bangladesh the traditional row houses are one of the fine examples of vernacular building. The origin of the Row houses can be traced back to the time of British reign(century), when there was a trend to build decorative double storied row houses or traditional palace like *Zaminder bari* or the house of Landlord. Traditional old houses with relatively large thermal mass, open courtyards, extended verandahs and rooflines can be defined as vernacular buildings. Meanwhile, it is said that these vernacular buildings have been delicately crafted over generations in response to experience of conditions and use [9]. Latest researchers, therefore, endeavored to extract traditional passive techniques active in and around the vernacular buildings for applying them to the modern houses.

1.1 ROW HOUSES IN RUPCHAN LANE

Rupchan Lane area is a part of Sutrapur Thana and group C of the Capital city Dhaka. This part of the traditional city of about 250 m length is more than 200 years old and at present has a predominantly colonial flavour. Most of the buildings of this area were erected on the either sides of a narrow, serpentine road, which are mostly two storied (Figure 01). Other historically significant areas like Shakhari Bazar, Tanti Bazar, Bahadur Shah Park, Ahsan Manzil, B K Das road are situated in the walking distance.

Figure 01: Row Houses around the narrow alley of Rupchan Lane

Adjacent to each other leaving almost no gap in between, these row houses contain courtyards varying from small to large for ventilation and daylight accommodation. The material of this houses are handmade bricks, thickness of wall varies from 0.3 to 0.45 meters. Adjacent to the road some row houses have verandas or small transitional spaces.

The row houses are situated with a narrow frontage of 5m and a long depth of 20 m. The façade of the houses are facing towards either south or north with a total floor area of 100 m2. These houses were originally constructed more than 100 to 150 years ago with a strong influence of Indo-saracenic architecture. These houses are currently used as residential blocks having changes in both functional arrangement and physical appearance. According to the users they are residing in these houses for more than three generations. One of the resident Mr. Kartik Ghosh (60) explained how his grandfather constructed this house using local material handmade brick, with timber joists at the roof acting as beams and some elements like iron columns supporting the roof of verandah at first floor, iron railing were imported from abroad.

The row houses are basically two storied with a threshold or transitional space at the front or some houses have direct access from road (Figure 02). The width of the transitional space varies in between 1-1.5 meter (Figure 03), approached by stair or while leveled with road, are accessed directly. Following the transitional space, a living hall or living room cum bed room is located. The indoors are mostly set with furniture (bed, sofa set, reading table, Television/television rack) sometimes over furnished because of the shortage of spaces. Windows are only located at the front side of the room and mostly remain closed due to security purpose at ground floor. Next to this room a bed room and toilet is located and this room contains the upstairs to go to the first floor. Following this room, a courtyard is located and which is common feature of this type of row houses to allow light and ventilation in indoor and provide thermal comfort (Figure 02). But unfortunately in most houses the configuration of courtyard have been changed, either they are largely occupied with room spaces or completely transformed into indoor spaces with wet constructions because of the scarcity of spaces and high demand of livable spaces to facilitate more users of different generations.

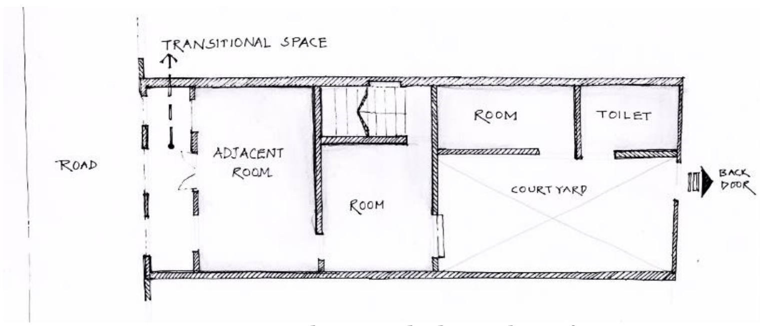


Figure 02: Typical Ground Floor Plan of a Row House

Figure 03: Row Houses with a transitional space at front side with the adjacent room

2. Climate of Bangladesh and Weather of Dhaka:

Bangladesh has a subtropical monsoon climate characterized by moderately warm temperature, high humidity and wide seasonal variations in rainfall. According to Atkinson's widely used classification it can be categorized as *warm-humid* (KoenigBerger et al, 1973). Meteorologically Bangladesh has four distinct seasons.

- *Winter,* from December to February (mean temperature between12^{0}C and 28^{0}C),
- *Pre-monsoon,* March to May (20^{0}C and 35^0 C),
- *Monsoon* from June to September (25^{0}C and 32^{0}C)
- *Post-monsoon* covers October and November (17^{0}C and 31^{0}C).

Dhaka is located in central Bangladesh at 23^0 42'0"N 90^0 22'30"E and experiences a hot, wet and humid tropical climate. The city has a distinct monsoonal season, with an annual average temperature of 25^{0}C and monthly means varying between 18^{0}c in January and 32^{0}C in May. Approximately 87% of annual average rainfall of 2,123 millimeters occurs between May and October [2, 3].

Climate data for Dhaka

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	26 (79)	30 (86)	34 (93)	36 (97)	35 (95)	34 (93)	33 (91)	33 (91)	33 (91)	32 (90)	30 (86)	27 (81)	31.9 (89.4)
Average low °C (°F)	14 (58)	19 (66)	23 (73)	26 (79)	28 (82)	29 (84)	28 (82)	27 (81)	27 (80)	25 (77)	21 (69)	17 (63)	23.6 (74.5)

Table 01: Climate Data for Dhaka [2.3]

3. Literature Review

The energy consumption for space cooling has been particularly rising in growing cities of Southeast Asia, where hot-humid conditions continue throughout the year. In this region, most of the modern urban houses are constructed of relatively large thermal mass materials such as brick and concrete. The use of large thermal mass materials along with the lack of natural ventilation in these urban houses often results in hot indoor conditions particularly during nighttime [4]. This leads to the excessive use of air-conditioning during the sleep at night. Therefore, application of passive cooling design is required wherever possible to improve the indoor thermal conditions in these modern urban houses for energy-saving. Meanwhile, it is said that vernacular buildings have been subtly crafted over generations in response to experience of conditions and use [2]. Recent researchers, therefore, attempted to extract traditional passive techniques employed in and around the vernacular buildings for applying them to the modern houses [4].

In the warm humid areas where ventilation is one of the two major issue for comfort [the other being shading], buildings of narrow depth usually promote comfort [5]. When arranged around a courtyard they also cast shadows in outdoor spaces and act as a cool sink [6, 7]. The buildings in traditional settlements of warm humid regions like Bangladesh usually have courtyards allowing air flow from outside to reach them [6, 7].

It has been proved that verandahs or transitional spaces almost act as elongated and wide shading devices in the south façade in the context of Bangladesh [8] .Fixed shading devices or verandah proved to be suitable in the context of Bangladesh climate, if properly designed and installed. The verandah or Transitional spaces also works as a *heat buffer zone* from the outside and keeps the indoor temperature cooler than outdoor. The temperature data shows a 3.5^{0}C temperature difference from out door to indoor in constant air change situation during the warmest part of the day. On the other hand temperature difference between indoor and outdoor having shading devices upon opening is 2.5^{0}C. This 1^{0}C cooler temperature difference indicates reduced energy consumption for thermal comfort. Therefore, for full height openings (up to lintel level) at south façade, it is recommended to use cantilever verandahs with required depth for shading [8].

4. Methodology

As this paper is being developed as a workshop term paper under M.Arch program of Bangladesh University of Engineering and Technology for Thermal Environment and Built Form (ARCH 6101) course, the submission time was in the late winter, specifically in last week of February, the data had to be collected in relatively lower ambient temperatures in relatively cooler environment comparatively with the warmest environment of summer season.

The field measurements were conducted in two-storey traditional row houses from 25th December to 31st December 2017.For Data handling convenience only the data of the warmest day which was December 30, 2017 is being presented among the seven days. The measurements were taken almost 2 hours apart in four houses, House A, House B, House C and House D at the adjacent room to the road or narrow alley (next to the transitional spaces). House A and House B are located at the Northern side of narrow alley (Rupchan Lane) having their frontage exposed to South; Whereas, House C and House D are located at the Southern side of the narrow alley having their frontage exposed to North. In these four houses house A and house C have a veranda or transitional space at the entry or frontal approach and House B and House D are directly approached from road (Figure 04 and Figure 05). Field measurements of temperature, Humidity and Airflow were taken using Hygrometer and Anemometer.

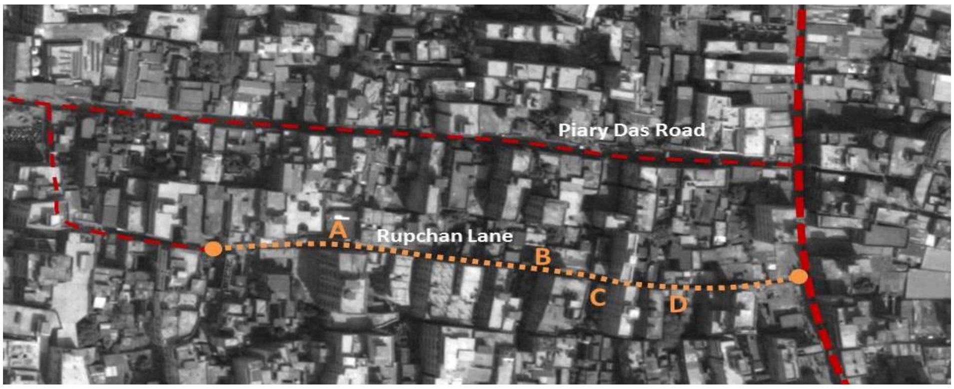


Figure 04: Location Map of "Rupchan Lane"

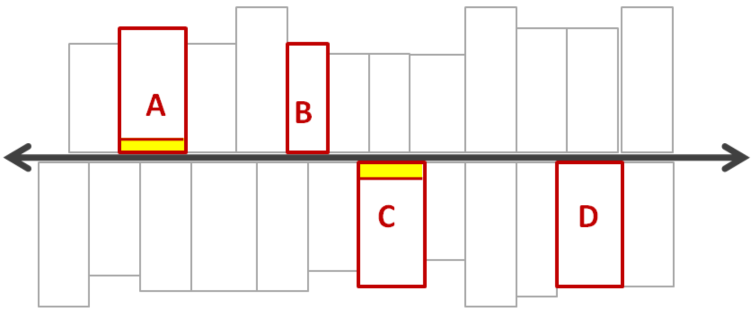


Figure 05: Conceptual diagram of the top view of "Rupchan Lane" with Row Houses

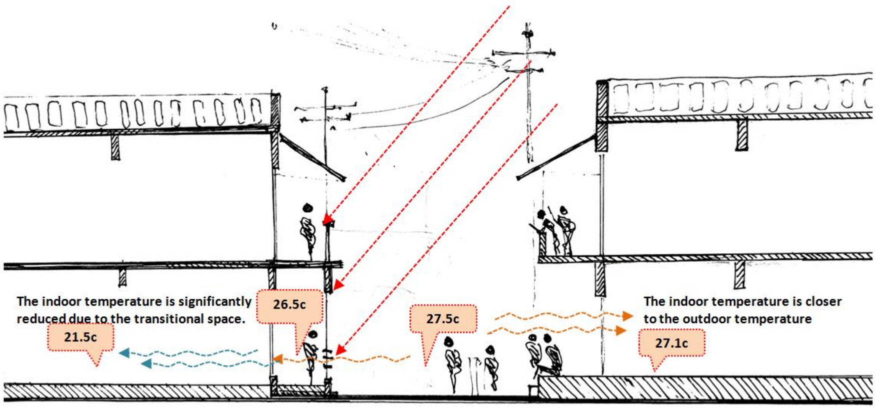
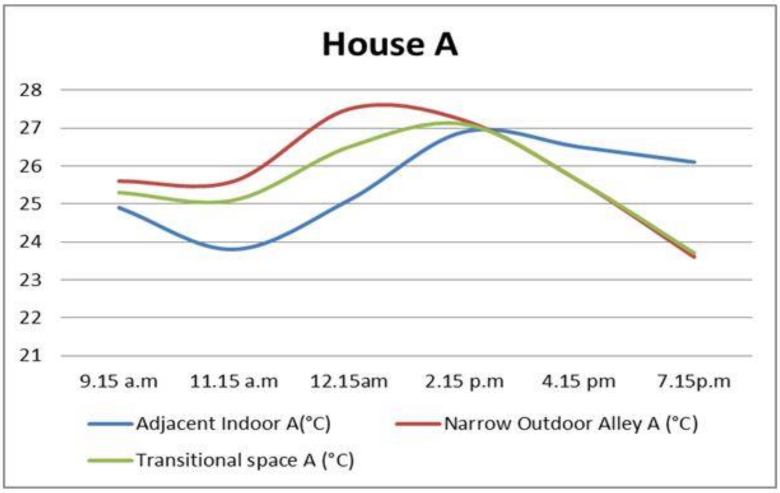


Figure 06: Conceptual Section of Row Houses with and without Transitional Spaces

5. Result and Discussions

5.1 COMPARATIVE ANALYSIS BETWEEN HOUSE A AND HOUSE B

The narrow outdoor alley temperature at the starting time of temperature measurement in House A and House B is 25.6⁰C and 24.7⁰C respectively (Table 03, Table 04). The outdoor temperature rises at its peak at around 12.00 pm (Figure 06) and continues till 1.30 pm; it starts to fall from around 2.00 pm and a gradual temperature reduction can be seen towards evening around 7.15 pm. The Temperature in transitional space of House A changes and follow the curve of outdoor temperature, having its peak temperature around 1.30 pm and then tends to fall exactly with the fall of outdoor temperature. A significant difference can be seen in the measured temperature of indoor. The indoor temperature follows the curve of the temperature of outdoor and transitional space with a significant reduction. The indoor temperature raises its peak at around 3.00 pm which is remarkable; it can be caused due to the buffer zone of transitional space (Table 02). The transitional space or the thresholds helps to delayed indoor heating by providing shadow zone and eliminating heat radiation, conduction and convection directly. Whereas in the House B, the narrow outdoor alley temperature at the starting time is 24.7⁰C , tending to rise and has its peak 28.4⁰C at around 12.00 and tends to fall towards evening. A significant change can be found that the indoor temperature in House B starts with a higher degree in the morning. With the passing of time it continues to follow the curve of outdoor temperature and continues steadily from around 3.00 pm to 7.00 pm at evening. A significant point can be seen that the adjacent room in House A with transitional space maintains a comparatively higher temperature than the room of House B, although the temperature of narrow outdoor alley and transitional space tends to fall simultaneously (Table 02). So it can be concluded in the words that transitional space contributes in delaying heating in indoor temperature at day time, but from evening to night it kind of traps the heat from disbursing outside by creating a buffer and acts as a hollow thermal mass which delays the process of heat dissipation from indoor.



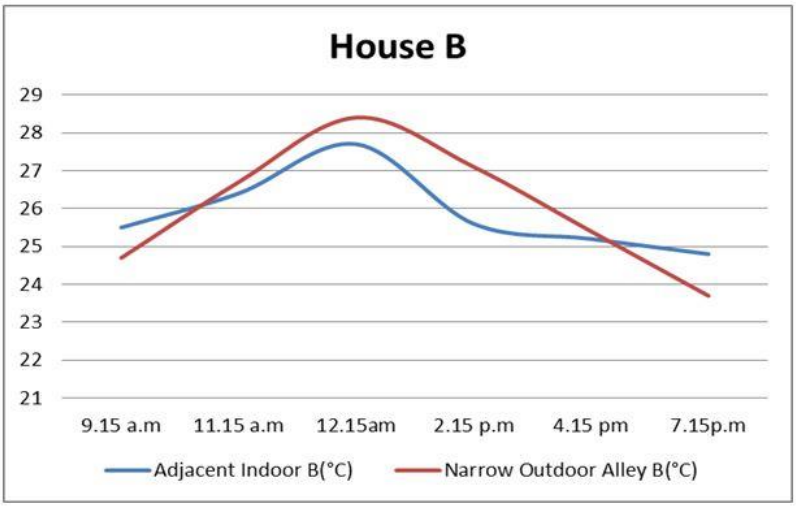


Table 02: Temporal Variations of the measured Air Temperature of House A and House B

HOUSE A 12, Rupchan Das Lane,Sutrapur.									
30.12.2017	temparature			Humidity			Airflow		
	Adjacent Indoor	Narrow Outdoor Alley	ansitional spa	Adjacent Indoor	Narrow Outdoor Alley	Transitional space	Adjacent Indoor	Narrow Outdoor Alley	Transitional space
9.45 a.m	24.9	25.6	25.3	57%	50%	40%	0	0	0
11.15 a.m	23.8	25.6	25.1	71%	70%	59%	0	0	0.1
12.00am	25.1	27.5	26.5	46%	47%	55%	0	0	0
2.30 p.m	26.9	27.2	27.4	55%	54%	52%	0	0	0
4.10 pm	25.7	25.6	25.6	58%	57%	5600%	0	0.1	0
7.00 p.m	24.4	23.9	23.7	62%	60%	59%	0	0.6	0

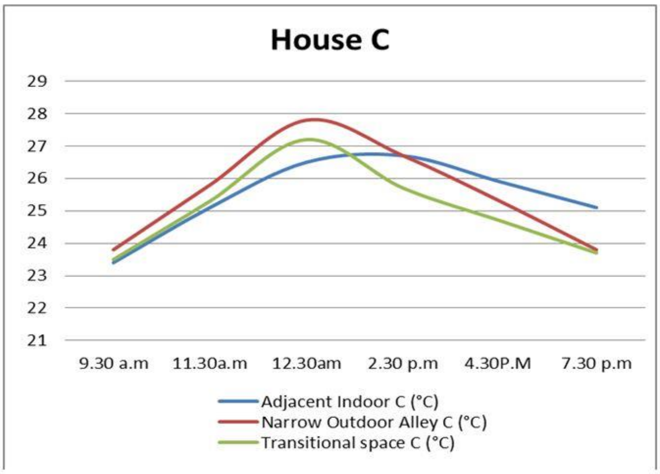
Table 03: Temporal Variations of the measured Air Temperature, Relative Humidity and Airflow of House A and House B.

HOUSE B 9, Rupchan Das Lane,Sutrapur.									
30.12.2017	temparature			Humidity			Airflow		
	Adjacent Indoor	Narrow Outdoor Alley	Transitional space	Adjacent Indoor	Narrow Outdoor Alley	Transitional space	Adjacent Indoor	Narrow Outdoor Alley	Transitional space
9.45 a.m	25.5	24.7	N/A	61%	48%	N/A	0	1.1	N/A
11.15 a.m	26.4	26.7	N/A	58%	62%	N/A	0	0.1	N/A
12.00am	27.7	28.4	N/A	51%	55%	N/A	0	0.3	N/A
2.30 p.m	25.6	27.1	N/A	54%	55%	N/A	0	0.1	N/A
4.10 pm	25.2	25.4	N/A	57%	56%	N/A	0	0.1	N/A
7.00 p.m	24.8	23.7	N/A	60%	58%	N/A	0	0.5	N/A

Table 04: Temporal Variations of the measured Air Temperature, Relative Humidity and Airflow of *House B and House B*

5.2 COMPARATIVE ANALYSIS BETWEEN HOUSE C AND HOUSE D

The narrow outdoor alley temperature at the starting time of temperature measurement in House C and D is 23.8^{0}C and 24.6^{0}C respectively (Table 06, Table 07), it is relatively lower comparing with the scenario of Outdoor temperature in front of House A and House B. It is may be due to the rooms orientation towards north and having no sun exposure. The outdoor temperature rises at its peak at around 12.00 pm and continue till 1.00 pm; it starts to fall from around 1.30 pm and a gradual temperature reduction can be seen towards evening around 7.15 pm. The Temperature in transitional space of House C changes and follows the curve of outdoor temperature, having its peak temperature around 1.00 pm and then tends to fall with the fall of outdoor temperature (Table 05). Similar to the scenario of House A and B, a significant difference can be seen in the measured temperature of indoor. The indoor temperature poorly follow the curve of the temperature of outdoor. In House C, the indoor temperature rises its peak at around 2.30 pm , it can be caused due to the buffer zone of transitional space(Table 05). The transitional space or the thresholds helps to delayed indoor heating by providing shadow zone and eliminating heat radiation, conduction and convection directly. But in House D , a difference can be identified that the outdoor temperature remains lower from morning to noon till 1.30 pm , it can be caused by a local airflow possibly resulted from the configuration of narrow alley. From noon the outdoor temperature rises till 2.30 pm and tends to low than indoor from evening around 4.10 pm. The same scenario after evening is also found in this case like the case of House A. The indoor air temperature continues to be higher than the outdoor temperature in House C as an effect of the heat trap due the transitional space and here the temperature is significantly higher than the indoor temperature of House D (Table 05). So it can also be concluded here that transitional space help in postponing heating in indoor temperature at day time, but from evening to night, it kind of traps the heat from distributing outside by creating a buffer and performs as a hollow thermal mass which suspends the process of heat dissipation from indoor.



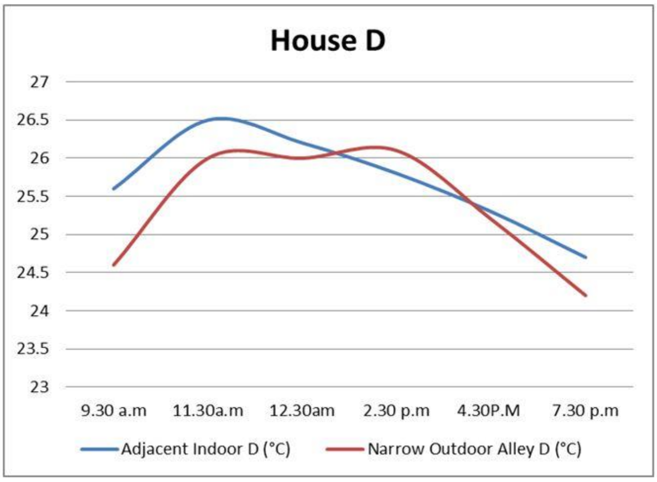


Table 05: Temporal Variations of the measured Air Temperature of House C and House D

HOUSE C 56, Rupchan Das Lane,Sutrapur.									
30.12.2017	temparature			Humidity			Airflow		
	Adjacent Indoor	Narrow Outdoor Alley	Transitional space	Adjacent Indoor	Narrow Outdoor Alley	Transition al space	Adjacent Indoor	Narrow Outdoor Alley	Transitional space
9.45 a.m	23.4	23.8	23.5	57%	50%	40%	0	0.4	0.1
11.15 a.m	25.1	25.8	25.3	60%	54%	59%	0	0	0
12.00am	26.5	27.8	27.2	53%	55%	55%	0	0.1	0
2.30 p.m	26.7	26.7	25.7	53%	53%	52%	0	0	0
4.10 P.M	25.7	25.3	24.7	56%	55%	56%	0	0.1	0.1
7.00 p.m	24.6	23.8	23.7	58%	57%	59%	0	0.3	0.2

Table 06: Temporal Variations of the measured Air Temperature, Relative Humidity and Airflow of House C

HOUSE D 59, Rupchan Das Lane,Sutrapur.									
	temparature			Humidity			Airflow		
30.12.2017	Adjacent Indoor	Narrow Outdoor Alley	Transitional space	Adjacent Indoor	Narrow Outdoor Alley	Transition al space	Adjacent Indoor	Narrow Outdoor Alley	Transitional space
9.45 a.m	25.6	24.6	N/A	65%	51%	N/A	0	0	N/A
11.15 a.m	26.5	26	N/A	57%	59%	N/A	0	0.1	N/A
12.00am	26.2	25.1	N/A	67%	64%	N/A	0	0	N/A
2.30 p.m	25.8	26.1	N/A	55%	55%	N/A	0	0	N/A
4.10 pm	25.3	25.2	N/A	58%	56%	N/A	0	0	N/A
7.00 p.m	24.7	24.2	N/A	56%	57%	N/A	0	0.4	N/A

Table 07: Temporal Variations of the measured Air Temperature, Relative Humidity and Airflow of House D

5.3 COMPARATIVE ANALYSIS BETWEEN HOUSE A AND HOUSE C

It can be seen in both House A and C in which the adjacent room with transitional space possesses lower indoor temperature than outdoor at daytime. The indoor temperature remains significantly reduced than outdoor and there remains a time gap of almost 2-3 hours in between the peak of maximum outdoor temperature and maximum indoor temperature, which indicates a significant delay in the process of heat gain through radiation, conduction and convection. In both cases towards evening the indoor temperature rises and become higher than the outdoor temperature, which indicates that the transitional space helps to confined the heat in indoor rather quickly remove it. This transitional space possibly act like a hollow thermal mass which hinder in quick reduction of indoor temperature by trapping heat inwards (Figure 07, Figure 08). In both cases outdoor temperature and the temperature of transitional space tends to fall down towards the time of evening, but indoor temperature remains steady and reduces very slowly comparative to the outdoor and transitional space temperature

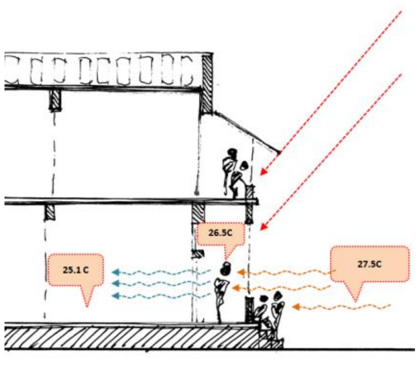


Figure 07: conceptual section of House A (Room towards south

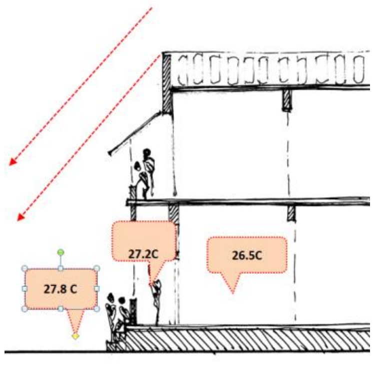


Figure 08: conceptual section of House C (Room towards North)

5.4 SUMMERY

Comparing the temperature of day time at peak outdoor temperature, it can be seen that House A performs better than other three houses (Table 08), the temperature difference between outdoor and indoor is 2.4°C (positive) which indicates a sufficient reduction in indoor heat, causing by the transitional space; whereas the temperature difference is only 0.7°C between indoor and outdoor of House B at same time at same direction.

Comparing the temperature of night-time, at around 7.00 pm, it can be identified that House A and House D performs better than House B and C (Table 09). The negative temperature value indicates a rise in indoor temperature than outdoor. House C and B with transitional space have larger negative value, but a possible airflow (Table 03) in outdoor and transitional space (0.6 and 0.4 respectively) probably increase heat dissipation by moving the stuck heat from transitional space and allowing heat exchange from indoor to transitional space then finally towards outdoor.

	Day time	Adjacent Indoor	Narrow Outdoor Alley	Transitional space	Temperature Difference	
HOUSE C	12.00pm	26.5	27.8	27.2	1.3	
HOUSE A	12.00pm	25.1	27.5	26.5	2.4	Performing BEST
HOUSE D	2.30 p.m	25.8	26.1	N/A	0.3	
HOUSE B	12.00am	27.7	28.4	N/A	0.7	

Table 08: Comparative analysis of temperature at peak outdoor temperature (Day time)

	Night time	Adjacent Indoor	Narrow Outdoor Aley	Transtional space	Temperature Difference	
HOUSE C	7.00 pm	24.6	23.8	23.7	-0.8	
HOUSE A	7.00 pm	24.4	23.9	23.7	-0.5	Performing BEST
HOUSE D	7.00 p.m	24.7	24.2	N/A	-0.5	Performing BEST
HOUSE B	7.00 p.m	24.8	23.7	N/A	-1.1	

Table 09: Comparative analysis of temperature at peak outdoor temperature (Night time)

6. Conclusion

This paper indicates that the transitional space of traditional row houses not only act as a space for social interaction but also contributes in achieving thermal comfort of the users, varying with time. Results from the study reveal a correlation between thermal comfort conditions and configuration of traditional row house. Transitional spaces contribute in delaying heating up process at day time but the indoor temperature tends to be confined due to the buffer created by transitional spaces at night time. It also reveals that with a good airflow and exposed towards south, the adjacent room can performs better even at night time. These conclusions have implications on climate design. Thus, the use of transitional spaces for passive cooling in tropical climates is possible by effective building design. Further research for other climatic extremes would be useful.

7. Acknowledgements

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