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VERNACULAR COURTYARD AS A DESIGN STRATEGY FOR THERMAL PERFORMANCE IN HOT DRY CLIMATE WITH REFERENCE TO RESIDENTIAL BUILDINGS IN JAFFNA, SRI LANKA

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Abstract: This research study focuses on the impact of thermal performance on vernacular courtyard houses in Jaffna. Vernacular courtyards, known for their indigenous architectural style, exhibit sustainable, climate-responsive building design despite being considered primitive in construction techniques and material usage. The study comprises three phases: analyzing literature to assess courtyard house efficiency, identifying existing vernacular courtyard house typologies in Jaffna, and investigating the thermal performance of two selected courtyard houses from different typologies within the same climate zone. By comparing their thermal performance and efficiency, this study validates the effectiveness of using courtyards as a design strategy to enhance thermal performance. The research highlights the need to study the concept of "Vernacular courtyard typologies based on thermal performance" as a new area of study. This study helps architects, planners and designers to rethink sustainable building design strategies with emerging technologies.

Keywords: *Vernacular Courtyard Houses, Thermal Performance, Typologies, Dry Zone, Sri Lanka*

1. Introduction

Buildings have a significant impact on the environments of both occupants and the structures they surround. A courtyard, an unroofed space within a building, offers numerous benefits to both the structure and its occupants. They are transitional areas that change the environment around the structure, improving internal airflow and creating more comfortable thermal conditions (Alderwood, 2008). The courtyard is considered a passive component in architectural design, and its presence in early human settlements, such as Ur in Mesopotamia, Matmata in Tunisia, and Beijing in China, has contributed to its popularity.

The courtyard is common in residential buildings across all climates and can be square, rectangular, oval, semi-enclosed, fully enclosed, or formless. Its dimensions and proportions determine its contribution to thermal performance. In Sri Lanka, the courtyard is considered an important vernacular element, but modern residential buildings often do not include courtyards, resulting in lost passive cooling effects and increased energy usage in cooling. Understanding the effectiveness of courtyards is crucial for a sustainable building design.

Jaffna is experiencing increased population pressure and rapid construction of environmentally harmful residences, with low thermal mass materials and lack of apertures. The Jaffna peninsula has not been extensively researched on courtyard houses' thermal performance due to cultural factors and security concerns. To understand the performance of vernacular courtyard houses and their future functionality especially in a dry climate, it is crucial to study their thermal performance in the modern world. The study aims to identify existing typologies of vernacular courtyard houses in Jaffna and determine their thermal performance and efficiency by comparing two case studies.

2. Literature Review

Fundamentally defined, thermal performance is a component that has to do with how efficiently a building maintains heat. It relates to how well things holds heat or restricts its flow. This may make the difference between having a warm, comforting environment throughout the year or one that is bitterly uncomfortable. The satisfactory mind with the thermal environment is defined as the thermal comfort (Ferrari & Zanotto, 2012). Courtyards have long been a popular architectural element, particularly in residential architecture. (Das, 2016) identified the courtyard as the fundamental structural framework of architecture that has been modified to increase adaptability to the resolution of environmental factors arising from topographical and site constraints.

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People around the world must tackle lots of troubles with modern interventions and modern solutions for building construction, especially in economic aspects and recourses. Non-Renewable Energy depletion is one of the most severe problems in the world. It carries people to global warming and other climate-affective processes. Therefore, if people could transform sustainable design approaches, vernacular architecture provide the best solutions for them. Even though we have extensive research areas on vernacular architecture and its effectiveness, the analysis of courtyard houses based on their diverse characteristics and climatic context is lacking importance. This research highlights the importance of such study by analysing available literature sources.

2.1. VERNACULAR ARCHITECTURE AS A SUSTAINABLE SOLUTION

At present, the built environment has more responsibility in contributing the reduction of energy crisis thus supporting the global warming mitigation process. Many studies have been conducted in the fields of sustainability and vernacular architecture, ranging from historical passive and active methods to reduce the dependence of buildings on excessive energy. According to Alexander (1979), Knapp (1989), and Oliver (2001), the usage of vernacular characters, benefits both culture and the environment (2007). Foruzanmehr and Vellinga (2015); Hernandez and co-workers (2015); (2011), describe how climatically responsive structures, technology, and equipment have improved human comfort in traditional structures without the use of mechanical means. They demonstrate how historical structures can have thermally comfortable interiors by choosing the right orientation, materials, and technology.

Application of a universal solution that is accessible to everyone is crucial (Fathy, 1976). Therefore, the sustainable design techniques will be the best solution. It is much clear that the vernacular architecture characteristics are indeed effective as they are built considering different environment characters (Zhang et al., 2017b). The vernacular architecture is design to be passive and a great way to get around weather limitations.

2.2. INTRODUCTION TO COURTYARD HOUSES

Courtyards are a fundamental aspect of domestic architecture, dating back to the Indus Valley Civilization and influencing various regions worldwide. They have been used for thousands of years and have evolved over time, with courtyards being an integral part of Indian homes as a fundamental approach to home building. During the Magadha and Chola dynasties, small squares in residential areas were expanded into numerous courtyards, which served as focal links between interior and outdoor areas. Courtyards are now more common in public spaces, shrines, mosques, and gardens.

They provide a secure, sufficient, and private outdoor space, enabling natural ventilation and reducing the need for air conditioning or heating. Families enjoyed spending time in the courtyard gardens since they were the focus of activity all day long and served a variety of functions. Courtyards in architecture include decorative features that link interior and outdoor areas, offering a multipurpose living space in busy metropolises. Ancient writings and architectural designs have emphasized the value of courtyards as a source of uplifting vibration and energy in the centre of the house. In medieval cathedrals and monasteries, courtyards are a recurring pattern in household architecture worldwide. In temperate and tropical climes, courtyard buildings are used for heating purposes.

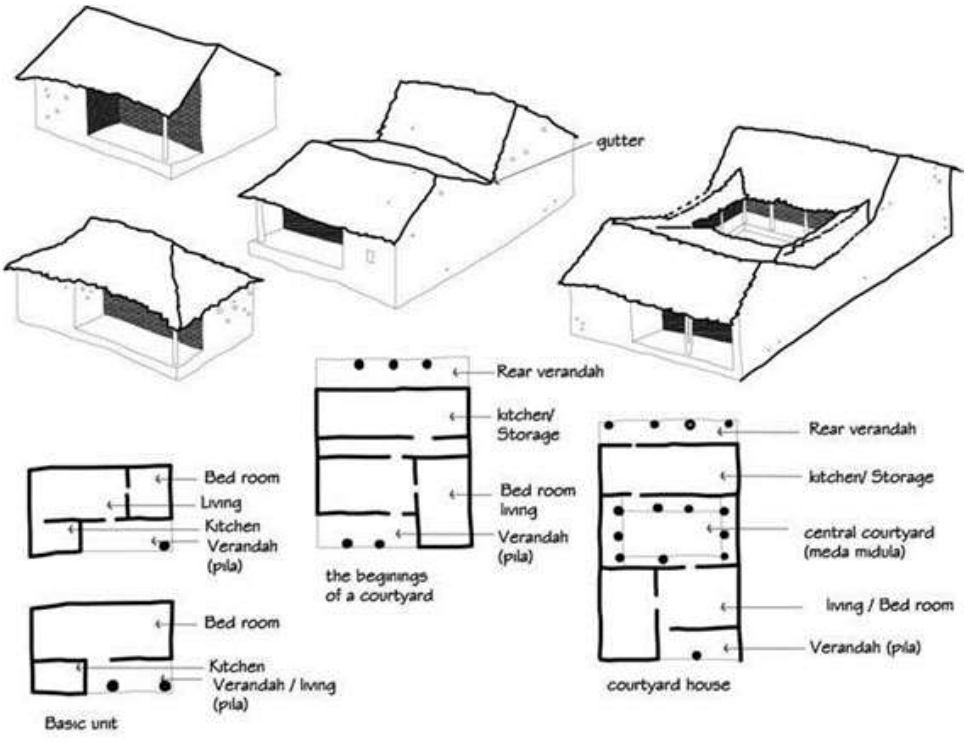


Figure 1: Evolution of a courtyard house (*Source: de Vos (1988)*)

2.3. SIGNIFICANCE OF THE COURTYARD HOUSES

The energy advantages of courtyards emphasize the importance of strategically placing them in the middle of a building or urban fabric. They can also significantly impact the climate, enhancing both physiological and mental senses. Courtyards are a fundamental structural framework of architecture that can be classified into two basic categories: fully enclosed (4 sides) and partially enclosed (3 sides) (Department of Energy, 2004). They can be shaped into various shapes, such as square, rectangular, round, or curved, depending on the location.

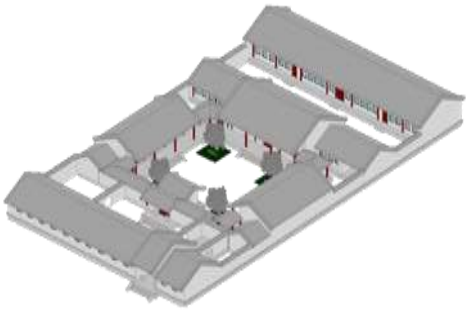


Figure 2: Fully enclosed courtyard
(Source: www.chinacenter.net)

Figure 3: Partially enclosed courtyard
(Source: www.chinacenter.net)

The most crucial ecological design factors for residential courtyards in dry regions are the efficiency of shade and ventilation. The direction, height, and sky opening of a structure all play a role in how a courtyard is shaded. The courtyard's ventilation impact is mainly based on the difference in internal temperatures caused by the outside air's wind condition and the chimney effect.

A paradigm shift is taking place in the way courtyards used to be shared spaces between houses and their design. Courtyards are seen as a way of life, acting as a focal point and barrier against bad weather. They improve our lives by influencing the ambience of homes and creating a peaceful retreat in busy lives. Open-air courtyards can brighten homes in densely populated areas, save energy, and promote a cozy atmosphere.

Courtyards are popular architectural elements in residential architecture due to their numerous benefits. They provide natural ventilation, fresh air, and cooling effects, enhancing the atmosphere of homes and providing a peaceful retreat. Courtyards also act as room dividers, providing shade, shelter, and a playground for children. They also offer privacy, psychological benefits, and cultural barriers, saving space and reducing maintenance costs. Courtyards are a natural choice for both traditional and contemporary home design, offering numerous benefits, including improved energy efficiency.

2.4. THERMAL PERFORMANCE OF THE BUILDINGS

Fundamentally defined, thermal performance is a component that has to do with how efficiently a building maintains heat. It relates to how well things holds heat or restricts its flow. This may make the difference between having a warm, comforting environment throughout the year or one that is bitterly uncomfortable (Sadineni et al,2011). Thermal performance can have advantages for the economy and the environment in addition to keeping everyone warm and pleasant during the harsh months.

The thermal behavior of a building varies with the seasons and temperature variations, time of day (difference between the maximum and minimum temperature of the day), solar and shade levels, incoming and outgoing thermal radiation, liquid and moisture uptake, airflow, seepage, differential pressure, and other factors.

2.5. THERMAL COMFORT

The satisfactory mind with the thermal environment is defined as the thermal comfort (Ferrari & Zanotto, 2012). Enhanced thermal comfort would be advantageous for the users of any environment and would increase their wellbeing. The primary elements affecting thermal comfort are both individual and environmental characteristics. An important key aspect impacting the thermal comfort of a place is air flow. Unusual low or high temperature can result in distress or discomfort to the occupant (Holopainen et al., 2014). Thermal comfort is influenced by six individual and contextual variables.: personal factors including metabolic heat (height and weight, age, fitness, etc.) and Clothing. Environmental factors including air velocity, air temperature, humidity, and radiant temperature.

2.6. FACTORS THAT AFFECT THE THERMAL PERFORMANCE OF THE COURTYARD

There were 3 factors identified namely the courtyard's geometry, means of evaporative cooling and the location of windows. Usage of vegetation or water sources can promote evaporative cooling which can increase the internal thermal comfort especially in the dry climate zones (Givoni, 1998). Evaporative cooling systems in courtyards promote comfort and reduce heat, especially in equatorial Middle Eastern countries. In addition to that, the natural ventilation process can be altered by the location of the windows, which is a subjective factor according to the social regulations. For maximum airflow, the windows are located around the ground level (to let air into the nearby rooms)

and upper floors (letting the hot air escape). However, this technique is all about creating internal air circulation rather than filling up the entire room with air.

Courtyard's geometry is the shape of the yard which is a key to providing optimum thermal comfort in the summer. It blocks solar radiation, which is highly impacted either by courtyard's form, including the proportion of height, length, and breadth. In this respect, (Dunham, 1960) was correct in saying that "only a small coat can block the sun", providing more shade and reducing the effects of temperature. This can be achieved by adding more levels to the courtyard and increasing the sunlight cut-off limit set. This results in less sunlight penetrating the surface (Al-Azzawi, 1984). This may make the one-story home not perform as well for shaded spaces as his two-story home. This can negatively affect the thermal efficiency of our garden, especially at night. Below is a comparison of single-story and two-story courtyard dwellings and S.V.F. In terms of availability to direct sunlight.

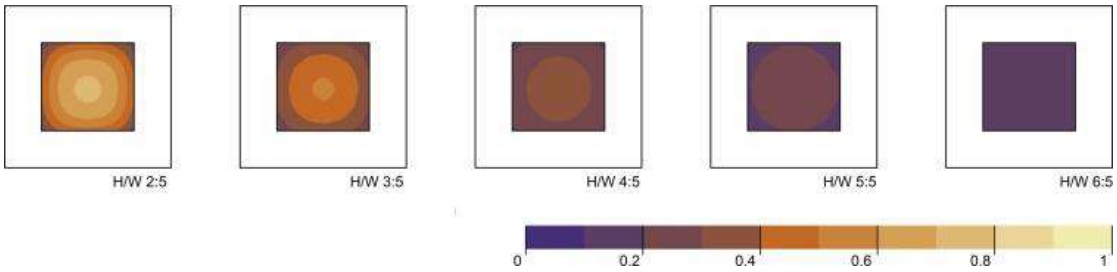


Figure 4: Courtyard thermal comfort With Influence of H/W proportions house
(*Source: Martinelli & Matzarakis, 2017)*

In this research, with concern on time of the study the key factor is limited to one aspect, the courtyard's geometry. The methodology focuses in that means and case studies are also analysed with that.

3. Methodology

Sampling from existing twenty-two vernacular houses in the Jaffna District was selected for typology analysis. The typologies were analyzed based on the factors such as plan form, sectional form, floor material, orientation, type of the courtyard and courtyard area etc. The selected 22 houses were classified under plan form, section form, and orientation. From the analyzed 22 courtyard houses two of them from two different courtyard types were selected for further studies based on the effectiveness of the courtyard performance and accessibility of the building.

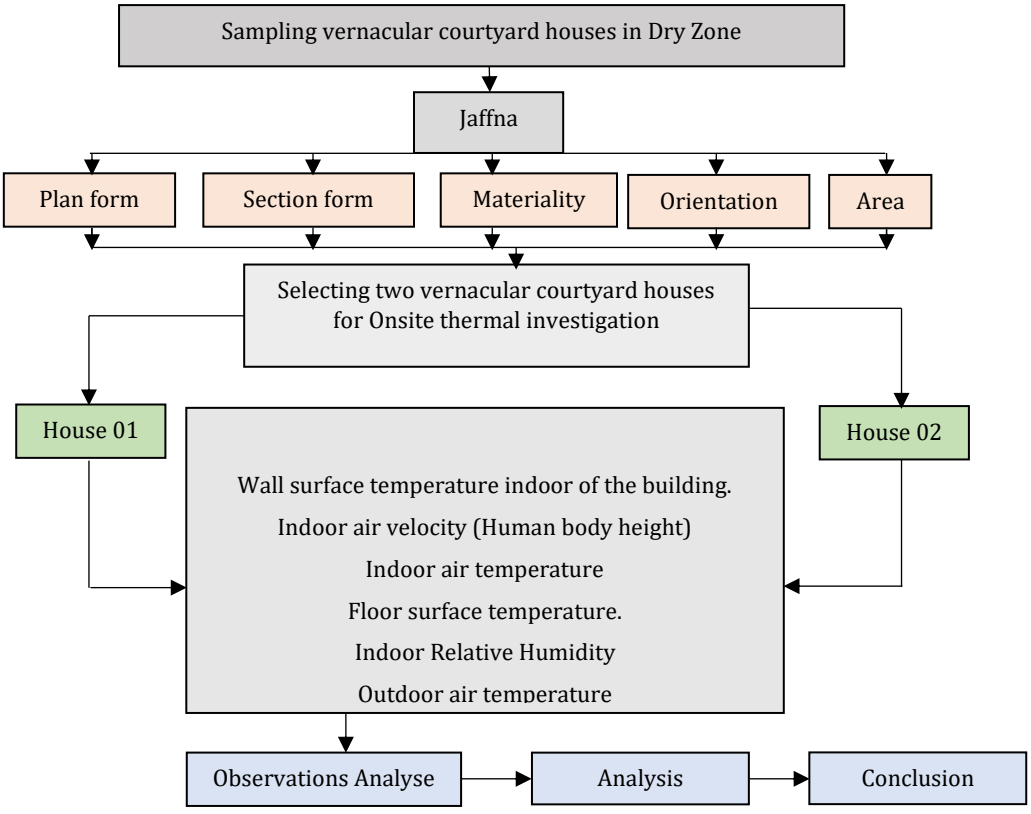


Figure 5: Methodology of the study (*Source: Author)*

On site thermal performance investigation for 24 hours measured indoor and outdoor air temperature, indoor air velocity, surface temperatures and relative humidity. Ambient temperature is got from the Department of Meteorology, Colombo. The thermal performance of each courtyard house for the duration of 24 hours on a typical hot day and the observations of the effectiveness of selected courtyards in the hot, dry climate of Jaffna are analysed.

3.1. CATEGORIZING HOUSES INTO TYPOLOGIES

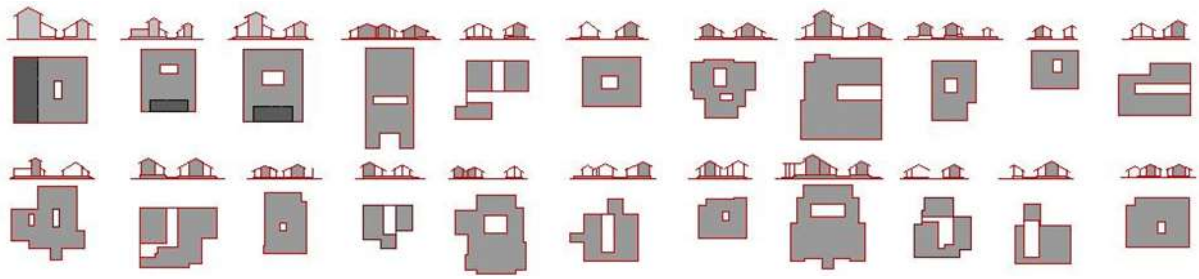


Figure 6: Illustration of sampled twenty-two houses (*Source: Author)*

3.1.1. Typologies based on plan form

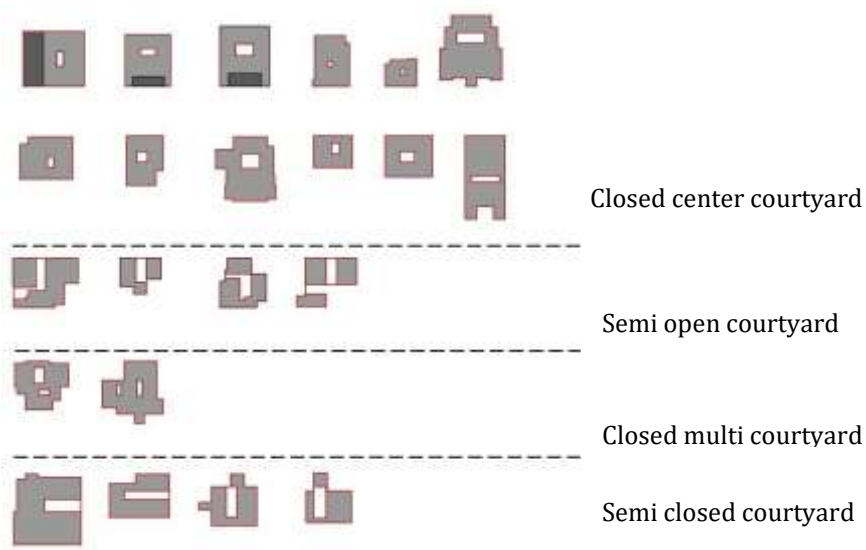


Figure 7: Typologies based on plan form (*Source: Author)*

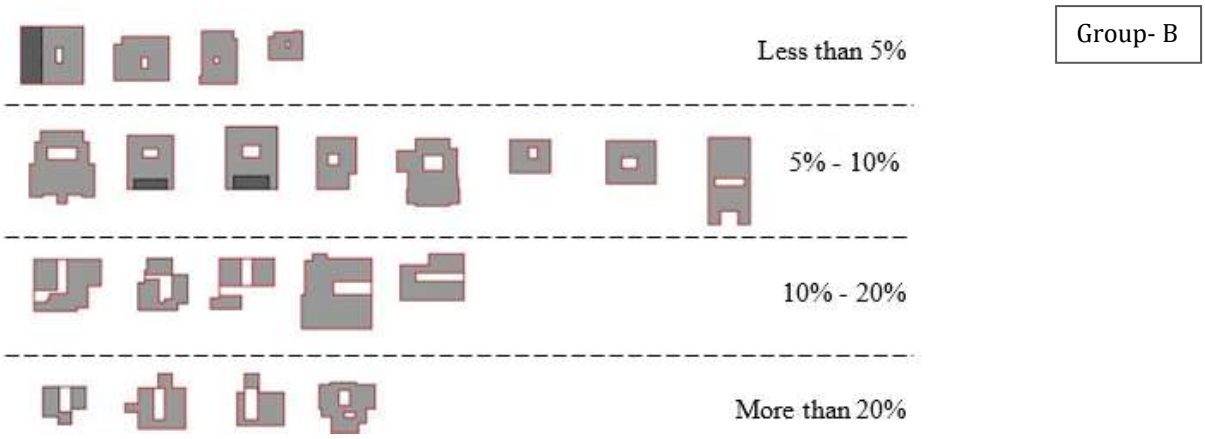


Figure 8: Typologies based on courtyard percentage (*Source: Author)*

- Under Group A, all the 22 sample houses are categorized based on the courtyard plan forms as: semi closed, closed, semi open, and center courtyards. Center courtyard is further categorized as closed multi courtyard.
- Semi open courtyards have free form and semi closed courtyards are mostly in “U” shape.
- The courtyards less than 5% of whole building footprint are providing more shade and reducing the adverse effects of temperature.
- The houses mentioned under closed center courtyards are less than 10% of the building’s footprint,

3.1.2. Typologies based on sectional form

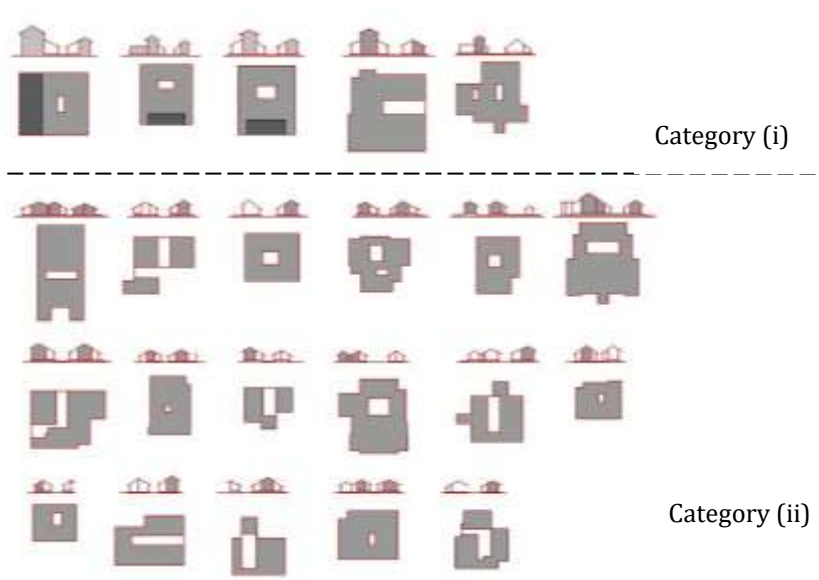


Figure 9: Typologies based on houses' sectional form (Source: Author)

Shallow courtyard form

- The analysed 22 Vernacular Houses are found be of shallow form, since they were vernacular houses, they are limited to single storey height.
- The houses mentioned under Category (i) have a part of the house with double storey building but it is not centered on the courtyard.
- All the houses under Category (ii) are single storied.

3.1.3. Typologies based on orientation

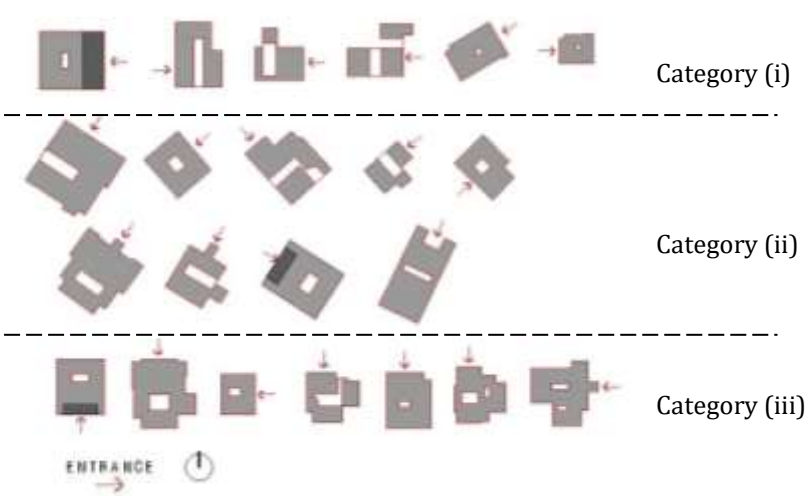


Figure 10: Typologies based on courtyard orientation (*Source: Author)*

- Group D classifies the sample houses based on their orientation. The whole sets are divide into 3 categories namely"
    1. Long façade of the courtyard facing East-West.
    2. Long façade of courtyard facing Northeast-Southwest and Northwest-Southeast.
    3. Long façade of the courtyard facing North-South.
- Most of these houses have North, East or North-East entrance since the wind flows from South-west direction during April-November. This can bring cross ventilation inside the building.
- Another reason for this type of orientation is that, most of the people in Jaffna are Hindus and they have followed 'Vastu' techniques, which has also facilitated cross ventilation.

3.1.4. Typologies based on material of courtyard

- Most of courtyard houses have replaced the courtyard floor material as concrete after the civil war. Other than that some houses still use the native materials such as gravel and earth soil. None of the courtyard have vegetation or water bodies.

- Most of the courtyard houses are covered with steel mesh to avoid entering of crows and other birds. The courtyards in rural areas, with smaller plot areas are covered with steel rods for security purpose.
- The houses with earth soil and gravel are built with lime stone and palmyrah timber rafters and the destructed parts of s that are affected by the Civil war are made with cement and brick.

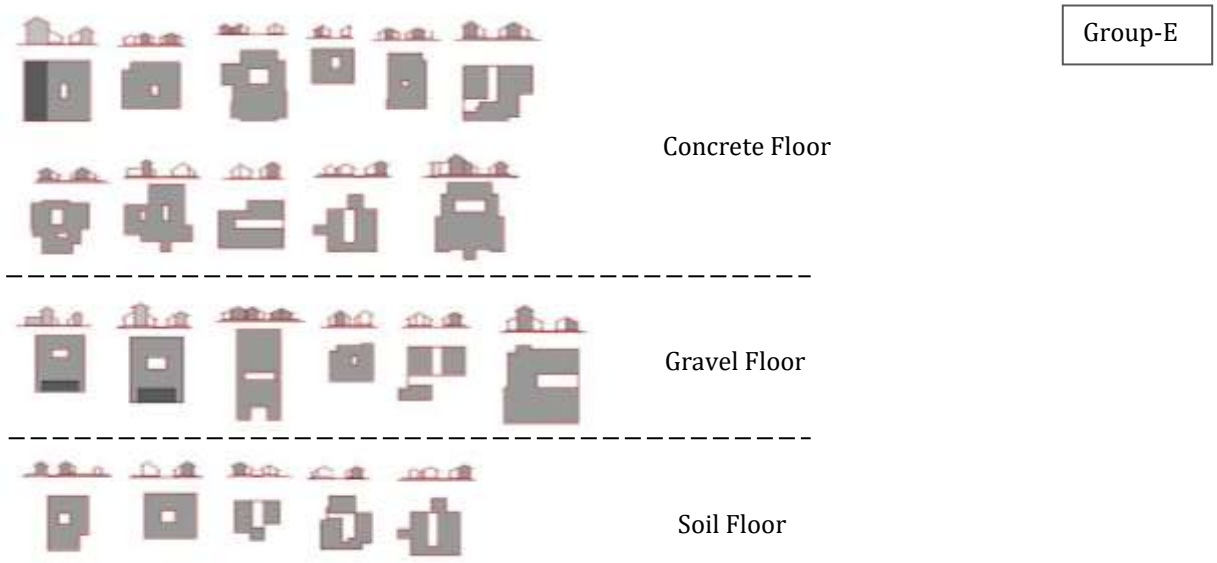


Figure 11: Typologies based on courtyard material (*Source: Author)*

3.1.5. Typologies based on courtyard thermal performance
Apart from the general physical classification of these houses, it is identified that, there can be another typology based on climate responsiveness and the effectiveness of the courtyard. This type of study is innovative and can help in detail understanding of their thermal performance. Further, a clear and detail understanding can assist in integrating courtyards as a sustainable strategy, in contemporary buildings. More details on this area is discussed under conclusion.

3.2. EQUIPMENT USED FOR INVESTIGATION
The measurements were taken for 24hours at five minutes interval and the average is calculated for each hour. The spot measurements were taken by placing the HOBO loggers along two sections through internal and external walls. HOBO loggers were launched to measure the humidity and indoor and outdoor air temperatures.
Monitored locations of the building,

- Wall surface temperate indoor of the building.
- Indoor air temperature (Human body height)
- Indoor & Outdoor humidity
- Floor surface temperature.
- Outdoor air temperature
- Ambient temperature – Ambient temperatures of related area have taken from Department of Meteorology, Colombo

Equipment used for investigation

A- Temperature & RH loggers (HOBO UX 100) – Relative Humidity & Air Temperature
B- Thermocouple 4 channel Logger (HOBO UX 100) – Surface Temperature
C- Multifunctional Air Velocity Meter – Air Velocity

4. Case study findings

The conclusion of the comparative analysis between the two case study houses shows how thermal performance can varies with courtyard design. Based on the observations of onsite thermal performance investigations, the Author is able to identify two different types of courtyards. It is visible that, the thermal performance of case study 01, is acting effectively with the existing climate. The results obtained for case study 02 is contrary to that of case study 01, where indoor overheating can be observed. Possible reasons for this are mentioned in Table 02 above.

As the long façade of the courtyards of case study 02 is facing East and West, it has higher possibilities for internal heat gain. Compared to case study 01, case study 02 has larger surface area that get contact with the direct sky. Smaller sky view factor as compared to the overall floor area can reduce the internal heat gain due to solar radiation.

Therefore, it can be concluded that other than classifying the courtyards with general physical factors such as plans, sections, dimensions, area, orientation, shape, floor material, and sky view factor; there can be a new **"Typology analysis based on the Thermal Performance of Vernacular Courtyards".** The thermal performance of the analysed typologies can vary. To summarise further, the analysed all 22 courtyard houses can be aligned between these two case studies, that works to the extremes of good and bad for the dry climate conditions. Thus, a detailed analysis of all these vernacular courtyard houses, can reveal their thermal performance and can lead to a new research topic.

Table 1: Analyse and observations of case studies

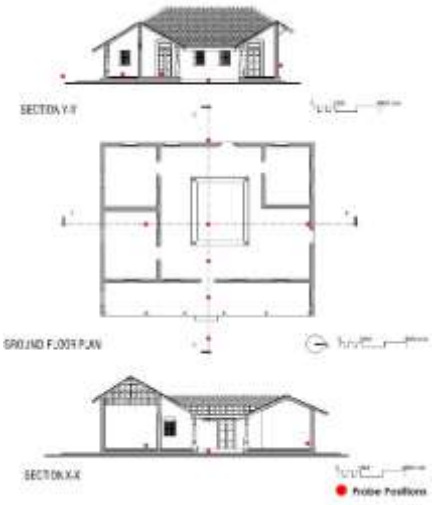
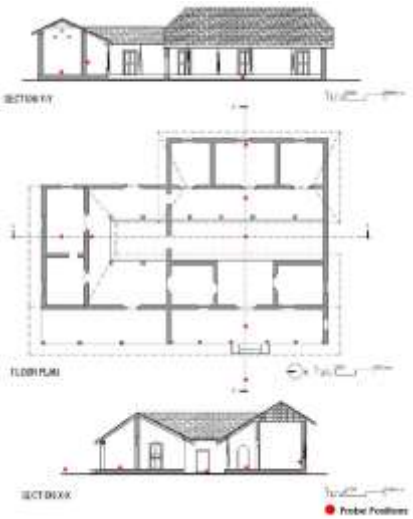
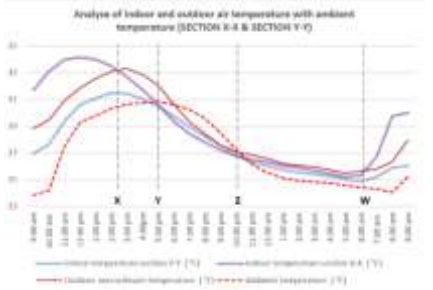
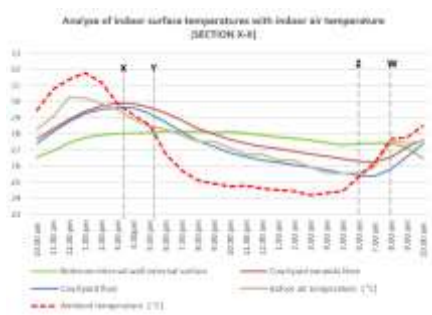
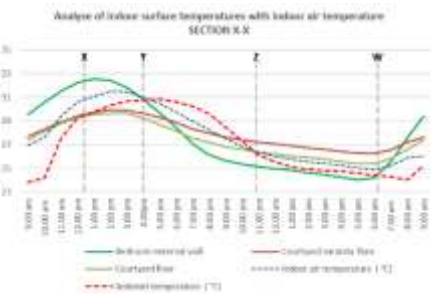
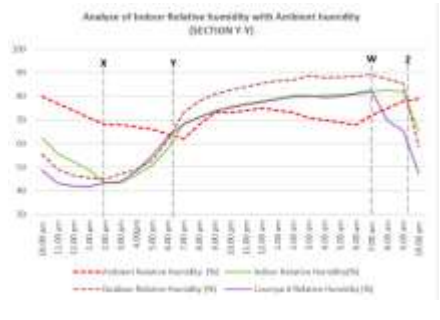
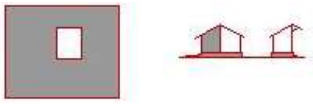
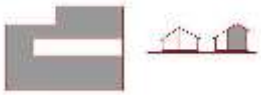
Analyzing Varying Factors	***Case Study House -01***	***Case Study House -02***
Plan & Sections		
Indoor, Outdoor air temperature with Ambient temperature		
Indoor surface temperature with Indoor air temperature		
Indoor relative humidity with ambient relative humidity		

Table 2: Comparative study of case studies

Analyzing Varying Factors	***Case Study House - 1***	***Case Study House - 2***
Diagram		
Plan form	Closed center	Semi closed
Sectional form	Shallow form	Shallow form
Courtyard orientation	Long façade facing North-South	Long façade facing East-West
Material	Concrete	Concrete
Courtyard percentage	7.2%	16.3%
Courtyard- Building ratio	5%-10%	10%-20%
Sky view character	Smaller area compare to the total floor area	Larger area compared to the total floor area
Size	3.94m x 3.14m	17.17m x 3.1 m
Area of courtyard	12.37m^2	54.6m^2

5. Conclusion

The main aim of this study is to understand the importance of courtyards in maintaining the thermal performance of residential building in dry climate. Courtyard houses are a popular type of houses in Jaffna. Generally based on the literature and past research, the vernacular courtyard houses are considered as effective bioclimatic solution to dry climates in maintaining the internal thermal comfort. The classification of courtyards is commonly based on the physical factors such as plans, sections, position, shape, orientation, floor material, sky view factor and the area of the courtyard. But this paper has identified that courtyards can be classified based on their thermal performance too especially based on the specific climatic context. The above mentioned factors can be integrated in this analysis.
Even though courtyards are considered as effective design strategies, there are occasions where thermal performance can act effective or not to the existing climate zone. A well detailed analysis on vernacular courtyard houses, can lead to an innovative study on **"Vernacular courtyard typologies based on thermal performance"**. This can act as a climate responsive typology analysis other than the physical parameters.

6. Acknowledgement

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