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Comparative Analysis of Courtyard Dynamics: Evaluating its Impact on Resident's Thermal Comfort

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Abstract
Traditional courtyards are still a crucial part of Kathmandu Valley's urban structure because of their architectural and cultural significance. In the context of this rich architectural heritage, this research presents a comparative analysis of courtyard dynamics and their effect on resident's thermal comfort. For this study, three traditional courtyards from Lalitpur, Bhaktapur and Kirtipur are considered with variation in courtyard design and layout. It uses a mixed-methods strategy that combines questionnaire surveys and visual evaluations. The structured questionnaire investigates the perceptions of roughly 52 residents from all three courtyards in total about thermal comfort, preferences for design, and the impact of microclimate. Visual evaluations record the architecture and features of the courtyard. The results of quantitative analysis of survey responses show a strong relationship between a particular courtyard design features and resident's thermal comfort. These findings highlight the influence of courtyard size and architectural features on the comfort level perceived by the residents. The understanding of residents' preferences and concerns is further enhanced by qualitative analysis, which provides nuanced insights into the interaction between cultural heritage and current comfort requirements. The results of this study offer suggestions for preserving and modifying traditional courtyards while enhancing resident's well-being, which supports sustainable architectural practices. The research deepens our knowledge of the complex interplay between courtyard dynamics and thermal comfort, and it provides a useful tool for architects, urban planners, and cultural preservationists attempting to strike a balance between tradition and modernity in Kathmandu Valley's built environment.

Keywords
thermal comfort, courtyard dynamics, ventilation, proportion, survey

1. Introduction

The Kathmandu Valley's traditional courtyards are architectural marvels that have influenced the social and cultural fabric of this historic area for many years. These courtyards are a beautiful fusion of cultural heritage and practical design, frequently found tucked away within traditional Newari architecture. They act as focal points within residential structures, providing areas for social gatherings, religious ceremonies, and solace from the valley's hectic urban life. Beyond their cultural significance, courtyards have a significant impact on the microclimate in their immediate vicinity, which in turn affects the thermal comfort of the locals.

Traditional courtyards in the Kathmandu Valley face challenges to their preservation as well as opportunities for adaptation as urbanization and modernization take hold. The preservation of these architectural wonders goes beyond simply being a matter of historical and cultural significance; it also involves improving the daily lives of the locals, particularly in terms of their thermal comfort. With a focus on traditional courtyards in the Kathmandu Valley, this study sets out to explore the complex relationship between courtyard dynamics and residents' thermal comfort. This research aims to close the gap between the preservation of cultural heritage and the requirements of modern living. By doing this, this study hope to shed light on how residents' perceptions of thermal comfort are affected by courtyard design, which includes factors like size, layout and architectural features. Figure 1 shows the courtyard view of Na: Baha, Patan.

Figure 2 shows the typical elevation of Newari house. The core of this research is a comparison of traditional courtyards in Lalitpur, Bhaktapur, and Kirtipur, three different parts of the Kathmandu Valley. These courtyards each embody a special fusion of architectural types, cultural practices, and historical settings. To collect information on residents' perceptions of comfort and courtyard design elements, this study used a

Figure 1: Courtyard view of Na: Baha

Figure 2: Traditional Facade of Newari Architecture

mixed-methods methodology that combined structured questionnaire surveys and visual assessments.

This study compares these courtyards and analyzes the data to find correlations between particular courtyard dynamics and thermal comfort. Additionally, qualitative information from residents offers complex viewpoints on how modern comfort requirements and cultural heritage interact. The study ultimately offers advice on the sustainable adaptation of traditional courtyards within the rapidly changing urban landscapes of the Kathmandu Valley, providing insightful contributions to the fields of architecture, urban planning, and cultural heritage preservation.

2. Research objective

2.1 Primary Objective:

- To conduct a comparative analysis of courtyard dynamics in conventional courtyards within Kathmandu Valley and evaluate their distinct impacts on residents' thermal comfort.

2.2 Secondary Objective:

- To recognize essential courtyard design components and how they differ among various courtyards in the Kathmandu Valley.
- To evaluate residents' opinions on thermal comfort and preference for particular courtyard dynamics, taking into account elements like size, arrangement and architectural features.

3. Literature review

Traditional Newari communities in Nepal have a long history of implementing sustainable design features, including open areas, courtyards, and communal ponds. In Newari architecture, there are several different kinds of courtyards, including Bahal, Bahil, and Nani [1]. Courtyard has been essential in fostering global community connections. In all parts of the world, courtyards have been used as a design element to achieve sustainability. According to plans for Belapur Housing in India, there will be less need for mechanical ventilation, more natural light, and systems for collecting rainwater and treating sewage [2]. The project successfully combines traditional Indian architectural principles with cutting-edge technology to create livable spaces that are both cozy and energy-efficient. Other factors, such as the size of the courtyard, the building's orientation, and the materials used in construction, have a significant impact on the thermal comfort of courtyards[3]. The height-to-width ratio of courtyards in Bari was found to be 0.5:1, while courtyards in Florence and Milan were found to be more comfortable with a ratio of 1.5:1 [3].

The article [4] emphasizes the value of designing courtyards with the local climate in mind and goes over design elements like size, shape, orientation, and shading that have an impact on how well they perform. According to findings of the study[4], courtyards can significantly improve a building's thermal and microclimatic comfort by lowering the demand for mechanical cooling and heating. According to the study [5], the courtyard's orientation significantly affects the amount of shade it provides, with the east-facing courtyard offering the most shade in the morning and the west-facing courtyard offering the most shade in the afternoon. The height of the neighboring buildings also has a significant impact on the courtyard's level of shadowing, with taller buildings providing more cover[5]. Additionally, it was found in the study [5] that courtyards with a greater width-to-height ratio and deeper design offer more shade.

A higher aspect ratio enhanced thermal performance by increasing convective heat transfer and air velocity[6]. The authors from study [6] advised designers to consider the width, depth, and aspect ratio of the courtyard throughout the design process in order to enhance the building's thermal performance, particularly in warm, humid conditions. According to the study[7], a larger aspect ratio improved the courtyard's ventilation and temperature. Additionally, it was found that a north-south orientation was inferior to an east-west direction because it produced worse solar radiation incidence. The study [7] also highlighted the significance of the courtyard's architectural surroundings in determining its thermal conditions. Buildings with a high aspect ratio and an east-west orientation were found to provide the courtyard with more shading and ventilation[7]. The study [7] emphasized how important it is to build courtyards with natural ventilation in order to maximize thermal performance.

4. Limitations

- The survey was conducted in the Kathmandu Valley investigating only three traditional courtyards.
- The results of the survey cannot be generalized to other traditional buildings without further research.
- The research focused only on the impact of courtyard proportions on daylight, thermal comfort, and energy performance, and did not consider other factors such as building materials, orientation, and ventilation, which could also have an impact on the comfort and energy

performance of traditional buildings.

- The survey data were self-reported by the occupants of the buildings, which may introduce errors or biases in their responses that could affect the accuracy of the results.
- The cultural and social factors that influence the use and design of traditional buildings were not fully considered, which may have a significant impact on the design and use of courtyards, affecting their impact on daylighting, thermal comfort, and energy performance.

5. Methodology

In order to comprehend the topic and identify research gaps, this study conducted an extensive review of the literature. It specifically examined how courtyard proportions affect thermal comfort in Kathmandu Valley traditional buildings. Based on factors like building materials, courtyard dimensions, and building heights, three locations were selected. Each site's climate was analyzed as part of the research methodology, taking into account variables like temperature, humidity, and solar radiation. Through household surveys and questionnaire distribution, information on thermal comfort was gathered. Data analysis was done using statistical analysis software, which included regression, correlation, and descriptive statistics. The goal of this methodology is to assist policymakers and building experts in enhancing energy efficiency and indoor comfort by providing insights for upcoming construction projects in the Kathmandu Valley. In terms of philosophy, it used a positivist strategy to achieve the goals regarding courtyard dynamics. The KoBo Toolbox, a free toolset for effective data collection and analysis on mobile devices, was used to carry out the questionnaire survey. This study aims to improve our comprehension of the complex interactions between courtyard dynamics and thermal comfort in Kathmandu Valley's traditional buildings. It is based on empirical data and quantitative analysis.

6. Introduction to Site

Three different courtyards from three different districts of Kathmandu Valley were taken for the sample survey. The questionnaire survey was taken to do the study through Kobo Toolbox. Each courtyard was taken from each district of Kathmandu valley i.e., Khama Nani from Etachhen, Bhaktapur, Joshi Nani from Kirtipur, Kathmandu and Na: Baha: from Patan, Lalitpur.

Khama Nani is located in Bhaktapur, one of the three ancient cities in the Kathmandu Valley. Bhaktapur is a popular tourist destination and is known for its extensive cultural heritage. Khama Nani is in Bhaktapur, which is also a sub-tropical climate zone. The average temperature in this region is like that of Na: Baha: with temperatures ranging from 10°C to 22.77°C. The hottest months are May to June, with temperatures sometimes exceeding 35°C, and the coldest months are December to January, with temperatures dropping to 2.7°C. All the weather data was collected from (DHM,2022). The region also receives a significant amount of rainfall, with an average annual precipitation of 1350mm, mainly from June to August. Figure 3 shows the courtyard view of Khama Nani where people are using the courtyard for their daily household activities. Khama nani is situated on Etachhen tole which is the 100m western side of the Bhaktapur Durbar Square.

Figure 3: Courtyard View of Khama Nani

Joshi Nani is located in Kirtipur, another old city in the Kathmandu Valley. Both its ancient temples and places of worship, as well as its traditional handicrafts, make Kirtipur famous. The courtyard dwellings of Joshi Nani also feature traditional Newari architecture. It is located on eastern side of Chilancho Mahavihar. Figure 4 shows the courtyard view of Joshi nani. The temperature in this region is typically warm throughout the year, with an average temperature of 17.3°C. The hottest months are April to June, with temperatures often exceeding 30°C, and the coldest months are December to January, with temperatures dropping to 4.4°C. This region also receives a significant amount of rainfall, with an average annual precipitation of 1,300 mm, mainly from June to August. All the weather data was collected from (DHM,2022). This weather data is also similar to Na: Bahal Patan.

Figure 4: Courtyard View of Joshi Nani

Na: Baha resides in Lalitpur, the third-oldest city in the Kathmandu Valley. Famous historical sites including the wellknown Patan Durbar Plaza can be found in Lalitpur. The courtyard cottages in Na: Baha are typical of the Newari architecture found in Lalitpur. It is located on western side of Patan Durbar Square. Figure 5 shows the courtyard view of Na: Baha.

Figure 5: Courtyard view of Na: Baha

7. Analysis and Discussion

The survey data from three traditional courtyards in the Kathmandu Valley yields insights into how courtyard proportions impact thermal comfort and energy performance. Figure 6 shows the graph representing the summary of the questionnaire survey from Khama Nani where it is shown that 72% people feel somewhat comfortable during summer, 57% people living in the Khama nani feel not very comfortable during winter and 100% people voted that they don't feel comfortable during monsoon season. Notably, Na: Baha: boasts the most favorable courtyard proportion (1:4), offering ample daylight and thermal comfort with a spacious courtyard (112 feet by 112.5 feet) and suitable building heights (28 feet for old buildings, 50 feet for new ones).

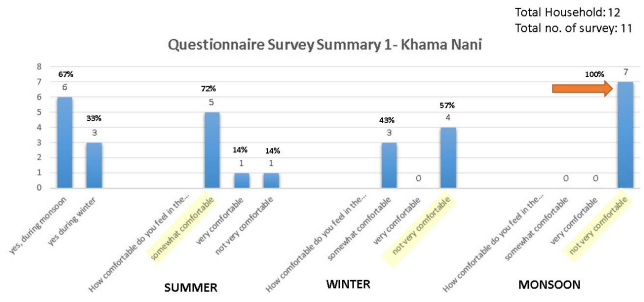


Figure 6: Graph showing the summary of Questionnaire survey from Khama Nani

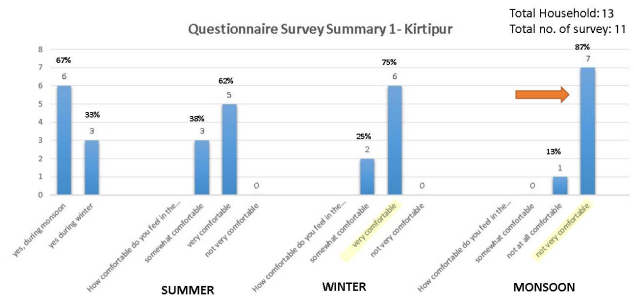


Figure 7: Graph showing the summary of Questionnaire survey from Joshi Nani(Part 1)

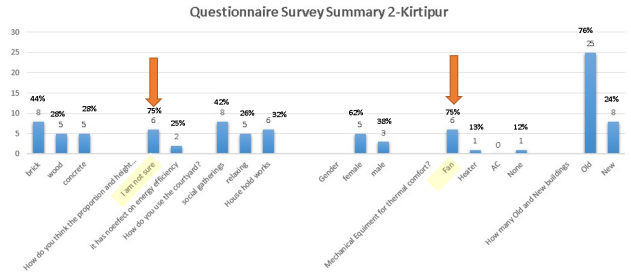


Figure 8: Graph showing the summary of the Questionnaire survey from Joshi Nani(Part 2)

The use of concrete and brick in new households further improves thermal comfort, although monsoon discomfort persists due to courtyard limitations. Conversely, Khama Nani's courtyard proportion (1:1.16) is less favorable, with a smaller courtyard (32 feet by 33 feet) and lower building heights (28 feet for old buildings, 40 feet for new ones). Residents face challenges during the monsoon season, including insufficient sunlight for daily activities and dampness in the walls. Despite these issues, overall thermal comfort remains acceptable. Joshi Nani presents the least favorable courtyard proportion (1:1.26) among the three buildings. Figure 7 shows the summary of the questionnaire survey from Joshi Nani. The graph, shows that 87% people voted that they feel very uncomfortable during monsoon, 75% voted very comfortable during winter and 62% voted very comfortable during summer season. In Figure 8 it is shown that 75% people have no idea about the effect of courtyard dynamics on their thermal comfort and in the case of mechanical equipment they use to gain thermal comfort, 75% people voted on Fan and 13% voted on heater.

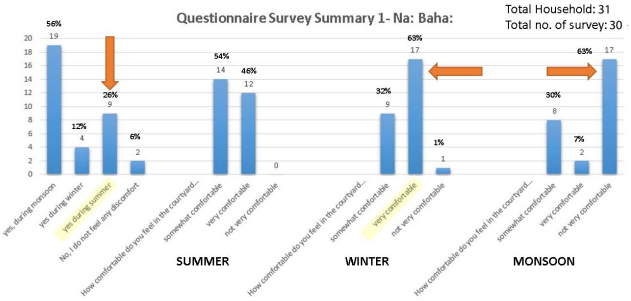


Figure 9: Graph showing the summary of the Questionnaire survey from Na: Baha (Part 1)

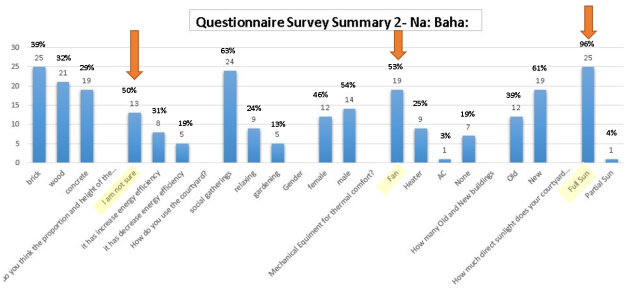


Figure 10: Graph showing the summary of the Questionnaire survey from Na: Baha (Part 2)

The courtyard (34.5 feet by 36 feet) and building heights (28 feet for old buildings, and 44 feet for new ones) provide limited space for sunlight penetration. Occupants report discomfort during the monsoon season, insufficient sunlight for daily activities, and somewhat acceptable thermal comfort. These findings emphasize the significance of courtyard proportions in traditional building design. Na: Baha: showcases a well-balanced design, while Khama Nani and Joshi Nani face challenges due to less favorable proportions. Tailoring building designs to consider these proportions is essential for optimizing daylight, thermal comfort, and energy performance in traditional Kathmandu Valley buildings. Figure 9 and Figure 10 show the summary of the questionnaire survey from Na: Baha. The graph of Figure 9 shows 26% people living in Na: Baha feel discomfort during the summer season whereas 63% feel very comfortable during winter and 63% people feel very uncomfortable during the monsoon season. In the case of using mechanical equipment, 53% people voted to use a Fan, 25% voted for a heater and 3% voted for an Air Conditioner. Figure 11 shows the sectional sketch of Na: Baha.

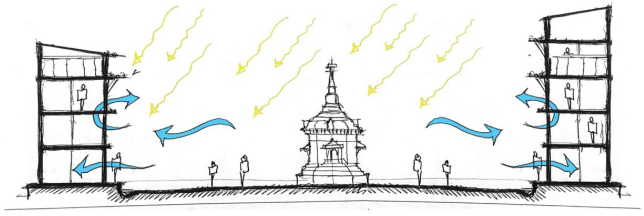
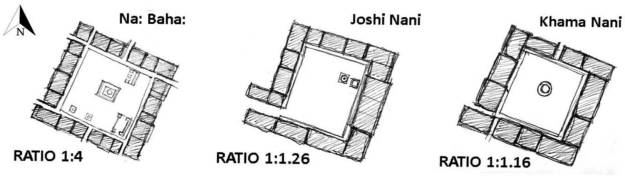


Figure 11: Sketch showing the section of Na: Baha

8. Comparison of all three courtyards

All three sites have a comparable ratio between the size of the courtyard and the building height, which ranges from 1:1.16 to 1:4. This suggests that The traditional architects in the region have followed a certain ratio to ensure the optimal utilization of daylight and thermal comfort in the buildings. Figure 12 shows the comparison of all three courtyards. All three of the courtyards are facing southwest in terms of orientation. This direction may have an impact on the amount of solar radiation that enters the building, which may affect how comfortable the occupants are on a thermal level. The best lighting atmosphere is found in Na: Baha. Overall daylighting conditions, with 3 hours on average of direct sunlight daily. The average daily direct solar exposure for Joshi Nani and Khama Nani is 1.5 hours and 1 hour, respectively. Na:Baha: may have had better lighting conditions due to its wider courtyard and south-facing placement. This study includes a thorough examination of the microclimatic impacts on three different types of traditional courtyards in the Kathmandu Valley. Apart from the main focus of this research, which is thermal comfort factors and user preferences, a microclimate analysis of these courtyards has been included, taking into account variations in design and orientation. Let's examine the personalities of each courtyard, which have distinct design elements and face various directions, to better understand this strategy. The layout of Na Bahal is open and exposed to the sun, which causes significant temperature fluctuations throughout the day. These fluctuations can affect residents' needs for heating and thermal comfort. On the other hand, Khama Nani experiences comparatively lower temperatures because it is shaded by the nearby structures for a significant amount of the day. Joshi Nani has a semi-enclosed design that strikes a balance between shade and sunlight exposure.



	Na: Baha	Joshi Nani	Khama Nani
No. of houses	New 61%, Old 39%	New 62%, Old 38%	New 8%, Old 92%
Courtyard size	112' x 112.5'	36' x 34.5'	32' x 33'
Survyed Sample of Total House hold	30 of 31	11 of 13	11 of 12
Issues	High temp. during Summer	Air circulation	Dampness
Overhanging size	4'	4'	4'
Discomfort season	Summer and Monsoon	Monsoon	Monsoon and Winter
Direct Sunlight	3.5 Hrs	1.5 Hrs	1 Hrs
Efficiency	Not sure	Not sure	Not sure
Daylight	Sufficient	Sufficient	Average
Mechanical Equipment	Fan	Fan	Fan/Heater

Figure 12: Comparison chart of three courtyards

In terms of thermal comfort, all three sites have reported some discomfort during the monsoon season. However, the discomfort is more significant in Khama Nani and Joshi Nani, where the courtyard gets wet, and the occupants cannot use it for their daily activities. Regarding the use of energy in the buildings, all three sites have reported low energy consumption, as they primarily rely on natural ventilation and daylighting. Each of the three traditional buildings in Kathmandu Valley has its unique features and characteristics. However, a detailed comparison of their survey data reveals some similarities and differences, which can provide valuable insights into their design and construction. The findings of this study can help architects and designers to improve the design of traditional buildings in the region, considering the thermal comfort and energy performance. The current analysis of this research aims to identify the unique microclimatic profiles of these courtyards. This involves measuring the humidity and temperature fluctuations in every courtyard. This research attempts to provide a detailed understanding of how courtyard design and orientation shape both microclimate and comfort levels by connecting these microclimatic variables to resident thermal comfort and preferences. The hygrometer has been used to account for variations in both temperature and humidity. Joshi Nani, Na Baha, and Khama Nani recorded temperatures of 21°C on May 12, 2023, 24°C on May 13, 2023, and 20°C on May 14, 2023, respectively. Joshi Nani, Na Baha, and Khama Nani had humidity levels of 55% on May 12, 2023, 42% on May 13, 2023, and 61% on May 14, 2023, respectively. In contrast to the other three orientations, residents facing southward in each of the three courtyards experienced significant daylight fall and rise in their homes. In addition to adding value to this study, the comparative approach is a useful tool for architects, urban planners, and cultural preservationists who are trying to balance modernity and tradition in the Kathmandu Valley's architectural landscape.

9. Conclusion

The project's goal was to investigate how courtyard sizes affected thermal comfort and energy efficiency in Kathmandu Valley's traditional structures. A survey study was conducted to gather the data from three different locations. Na: Baha: had the highest average daylight factor, according to the data, because of its wider courtyard and proportionately taller buildings. Khama Nani had the lowest average daylight factor since its courtyard was smaller and its buildings were more closely spaced out. Khama Nani had the lowest internal temperature, whereas Na: Baha had the highest. The analysis recommends that to enhance people's quality of life and energy efficiency, architects, planners, and policymakers should take these aspects into account while planning and renovating conventional structures. The project has demonstrated the distinctive characteristics of traditional Kathmandu Valley structures that can support sustainable architecture and energy efficiency. In the area, older structures showed superior energy consumption performance than more recent structures. The project's findings can be utilized to create plans for developing and remodeling old structures that consider courtyard dimensions, building heights, and local climate. The resident's quality of life will improve, and energy efficiency will rise. The initiative emphasizes the necessity of preserving and using traditional construction designs in Kathmandu Valley and demonstrates the possibility for these methods to be environmentally and economically sustainable

Acknowledgments

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