

Thermal–Spatial Strategies for Rural Dwellings: Environment–behaviour nexus in Northern China

Chen Yang¹, Alamah Misni^{2*}, Mohamad Zulfadli Mohamad Zabidi³

¹ Studies for Postgraduate, Faculty of Built Environment, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia;

² Studies for Landscape Architecture, Faculty of Built Environment, Universiti Teknologi MARA, 42300 Puncak Alam, Selangor, Malaysia;

³ King Salman Park, 11564 Riyadh, Kingdom of Saudi Arabia

Email of ALL Authors: 2022445238@student.uitm.edu.my; alama884@uitm.edu.my *

Lazulfadli88@gmail.com

Tel. of 1st author only: +601117799029

Abstract

Rapid rural transformation in northern China presents challenges for thermal adaptation and residential satisfaction in the face of changing climatic conditions. This study explores the relationship between spatial configuration, building materials, courtyard design, and occupants' behavioural adaptation in rural homes. Using questionnaire surveys from 393 respondents and Partial Least Squares Structural Equation Modelling (PLS-SEM), the study examines the connections between dwelling type, thermal comfort, and housing satisfaction. The results indicate that dwelling type significantly influences spatial configuration, courtyard performance, and thermal comfort. Additionally, spatial configuration mediates satisfaction outcomes. These findings support the development of climate-responsive rural housing strategies that integrate passive design features and behavioural adaptation.

Keywords: Thermal Comfort; Spatial Configuration; Rural Environment; Environment–Behaviour Studies

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1.0 Introduction

Rural revitalization has become a significant development strategy in rapidly urbanizing regions, particularly in northern China, where climatic variability strongly impacts residential environmental performance. Traditional rural settlements have evolved through long-term adaptations to local climate and socio-cultural conditions, resulting in vernacular courtyard dwellings that feature passive environmental regulation and spatial flexibility. These housing forms utilize thermal mass, shaded open spaces, and natural ventilation to moderate indoor thermal conditions while minimizing energy consumption (Chandel et al., 2016; Izadpanahi et al., 2021). Given the substantial contribution of buildings to global energy use and carbon emissions, climate-responsive residential design has become increasingly vital for sustainable development (Aste et al., 2022; Allouhi et al., 2015).

However, contemporary rural reconstruction often replaces vernacular housing with standardized modern dwellings influenced by urban construction models. Reinforced concrete structures and compact spatial layouts usually prioritize construction efficiency over environmental adaptability, leading to higher cooling demands and reduced thermal resilience in the face of changing climatic conditions (Ren et al., 2022; Vagtholm et al., 2023). Northern China's hot-summer and cold-winter transitional climate further accentuates the importance of adaptive strategies, as indoor comfort relies not only on building performance but also on occupants' behavioural responses. Residents often adjust their thermal environments through actions such as operating windows and utilizing courtyards, which significantly influence their perceived comfort (Delzendeh et al., 2017; Du & Chen, 2024; Yadeta et al., 2023).

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From an environment-behaviour perspective, housing satisfaction arises from the interactions between spatial environments and human perception. Spatial configurations mediate the behavioural opportunities and environmental experiences within residential settings (Kadir et al., 2024; Safarkhani, 2025). Despite the growing research on adaptive comfort and vernacular sustainability, empirical studies that integrate spatial configuration, behavioural adaptation, and housing satisfaction using structural modelling approaches remain limited in rural northern China (Chen et al., 2022; Saleem & Alchalabi, 2025).

This study aims to investigate the environment-behaviour nexus in rural dwellings by examining how architectural and spatial strategies influence thermal comfort and housing satisfaction. The objectives are to:

1. Compare the thermal performance between vernacular and modern rural dwellings.
2. Evaluate the influence of courtyard morphology and building materials on indoor thermal conditions.
3. Establish structural relationships linking spatial configuration, adaptive thermal comfort, and housing satisfaction.

Nomenclature

DT	Dwelling Type
SC	Spatial Configuration
BM	Building Materials
CC	Courtyard Configuration
TC	Thermal Comfort
HS	Housing Satisfaction

2.0 Literature Review

2.1 Energy Transition and Thermal Performance in Residential Buildings

The building sector significantly contributes to global energy consumption and carbon emissions, making the enhancement of residential thermal performance essential for sustainable development (Aste et al., 2022; Allouhi et al., 2015). Rapid urbanization and climate change have increased thermal stress in residential environments, especially in Asian regions experiencing greater temperature variability (Ren et al., 2022). Thermal comfort and energy efficiency are closely linked in research on sustainable housing. Inadequate building envelopes and climate-insensitive construction practices often lead to higher cooling demands and operational energy consumption in modern residential developments (Niza et al., 2022). Although contemporary construction prioritizes efficiency and economic feasibility, neglecting local environmental conditions can reduce climatic responsiveness (Vagtholm et al., 2023). Recent studies highlight the effectiveness of integrated spatial and passive design strategies in improving thermal performance while supporting adaptive comfort mechanisms (Ascione et al., 2015).

2.2 Vernacular Architecture and Passive Climate Adaptation

Vernacular architecture embodies the accumulated environmental knowledge that has evolved over time through adaptation to climate and cultural practices. Traditional dwellings typically utilize passive strategies, such as courtyard ventilation, shading systems, and thermal mass, to regulate indoor microclimates (Chandel et al., 2016; Izadpanahi et al., 2021; Yang & Misni 2025). Courtyard housing designs are particularly effective in moderating thermal conditions by minimizing solar heat gain and improving airflow (Ghaffarianhoseini et al., 2015; Zhou et al., 2025). Research and simulation studies demonstrate that the shape of courtyards significantly influences ventilation performance and indoor thermal stability (Sun, 2024; Azimi & Shafaat, 2024). However, the rise of contemporary rural housing development is increasingly replacing these vernacular forms with standardized layouts that lack passive environmental strategies, resulting in diminished environmental satisfaction for residents (Chahbi, 2024; Zhang et al., 2022). These observations underscore the necessity of reinterpreting traditional spatial principles within modern sustainable housing design.

2.3 Occupant Behaviour and Adaptive Thermal Comfort

Thermal comfort is increasingly recognized as an adaptive process influenced by the behavioural responses of occupants rather than just fixed environmental conditions. Actions such as opening windows, adjusting clothing, and relocating activities play a significant role in shaping perceived comfort and the energy performance of buildings (Delzendeh et al., 2017). Field studies conducted in naturally ventilated homes indicate that behavioural adaptation allows occupants to maintain acceptable comfort levels even during varying climatic conditions (Du & Chen, 2024; Yadeta et al., 2023; Chen & Misni, 2025). Consequently, adaptive comfort theory emphasizes the interaction between humans and their environment over reliance on mechanical conditioning methods. Additionally, vernacular courtyard environments promote adaptive behaviour by offering flexible transitions between indoor and outdoor spaces, which enhance both environmental resilience and user control (Muqoffa et al., 2025).

2.4 Spatial Configuration, Environment–Behaviour Interaction and Housing Satisfaction

Research in Environment–Behaviour Studies indicates that housing satisfaction arises from the interactions between spatial environments and occupants' perceptions. The configuration of a space affects exposure to the environment, privacy levels, and

opportunities for adaptive behaviour, which in turn impact residential comfort and overall well-being (Kadir et al., 2024; Safarkhani, 2025).

Additionally, post-occupancy studies show that indoor environmental quality plays a significant role in housing satisfaction and psychological restoration (Chen et al., 2023; Kumar et al., 2021). Courtyard environments, in particular, foster social interaction and enhance perceived environmental quality (Sadat et al., 2025). Recent studies using Structural Equation modelling (SEM) have revealed that spatial and environmental factors influence housing satisfaction indirectly through mediating variables such as perceptions of thermal comfort and behavioural adaptation (Chen et al., 2022; Yang & Misni, 2026). However, there have been limited empirical applications of Partial Least Squares Structural Equation modelling (PLS-SEM) in studies of rural dwellings, especially in the context of northern China's transitional climate. This highlights the research gap that this study aims to address.

3.0 Methodology

3.1 Research Design Framework

This study utilizes a quantitative Environment-Behaviour research approach to investigate the interactions between spatial configuration, thermal environment, and occupants' behavioural adaptation in rural residential settings. The methodology combines physical environmental evaluation with human perception analysis to assess the residential experience within climate-responsive built environments. A conceptual analytical framework was developed to explore the causal relationships among architectural characteristics and behavioural outcomes. This framework includes six latent constructs and eight hypotheses:

- H1. Dwelling Type (DT) significantly influences Spatial Configuration (SC).
- H2. Dwelling Type (DT) significantly influences Building Materials (BM).
- H3. Dwelling Type (DT) significantly influences Courtyard Configuration (CC).
- H4. Courtyard Configuration (CC) significantly influences Building Materials (BM).
- H5. Spatial Configuration (SC) significantly influences Building Materials (BM).
- H6. Spatial Configuration (SC) significantly influences Housing Satisfaction (HS).
- H7. Thermal Comfort (TC) significantly influences Courtyard Configuration (CC).
- H8. Thermal Comfort (TC) significantly influences Housing Satisfaction (HS).

The proposed model suggests that dwelling typology affects environmental performance through spatial and material characteristics, with thermal comfort perception mediating occupants' satisfaction outcomes.

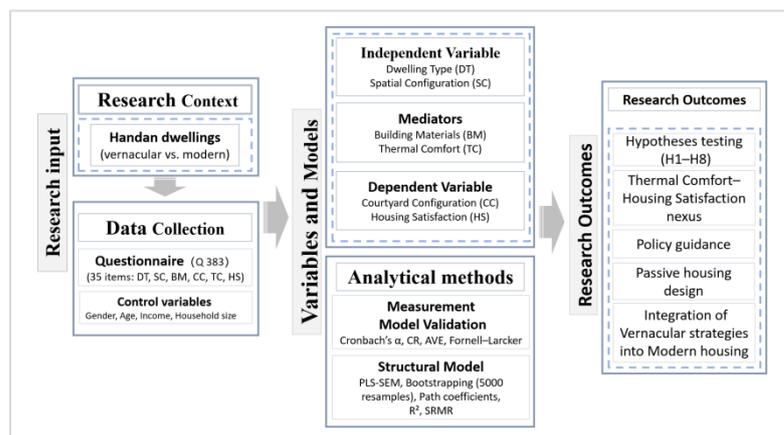


Figure 1. Framework for Understanding Environment-Behavior Relationships

3.2 Study Area

The empirical investigation took place in Shatun Village, Handan City, located in the northern region of China, which experiences a hot-summer and cold-winter transitional climate. This area is characterized by high solar radiation intensity, significant diurnal temperature variations, and seasonal thermal stress, making it an ideal setting for evaluating climate adaptability in rural housing. The study examined two primary types of residential buildings:

- i. Vernacular Courtyard Dwellings: These were built mainly before 2000, using brick masonry and designed with passive spatial layouts.
- ii. Modern Rural Dwellings: Constructed after 2010, these houses utilize reinforced concrete systems and are influenced by urban housing models.

The coexistence of these two housing types allows for a comparative assessment of their thermal and spatial performance under similar climatic conditions.



Fig. 2: Study Area Location and the Condition of Houses in the Surveyed Village

3.3 Data Collection and Survey Procedure

A structured questionnaire survey was conducted between July and August 2025 during peak summer conditions to capture occupants' thermal perception and behavioural responses. A total of 383 valid responses were obtained through stratified household sampling. The questionnaire consisted of four sections include: i. Demographic characteristics, ii. Spatial perception and dwelling characteristics, iii. Thermal sensation and adaptive behaviour, and iv. Housing satisfaction evaluation. Thermal perception indicators were measured using five-point Likert scales adapted from adaptive thermal comfort studies. Behavioural adaptation variables included window operation frequency, courtyard usage, ventilation practices, and activity relocation patterns. Participation was voluntary, and ethical approval was obtained from Universiti Teknologi MARA Research Ethics Committee.

Table 1. The operation definition.

Latent variable	Dimension	Content summary
DT	Dwelling Type	Architectural typologies and construction feature separate vernacular dwellings from modern ones.
SC	Spatial Configuration	The perception of architectural spatial layout includes aspects such as openings, circulation routes, and spatial functions.
BM	Building Materials	Key building materials, characteristics of the building envelope, and their perceived effectiveness in terms of thermal and sound insulation, as well as maintenance, play crucial roles in construction.
CC	Courtyard Configuration	The physical and functional attributes of a courtyard include elements like vegetation, shade, paving materials, and accessibility.
TC	Thermal Comfort	Thermal comfort was evaluated as a performance-based latent construct, which integrates indoor thermal conditions with residents' subjective perceptions, in accordance with ASHRAE Standard 55 (2017).
HS	Housing Satisfaction	Additionally, residents' overall satisfaction was assessed in relation to comfort, privacy, lighting, ventilation, and energy consumption within buildings.

3.4 Measurement Model Development

Each latent construct was operationalized using multiple reflective indicators derived from post-occupancy evaluations and environment-behaviour research frameworks. Reliability and validity assessments were conducted following recommended Structural Equation modelling procedures, including:

- Cronbach's Alpha (> 0.70)
- Composite Reliability (CR > 0.70)
- Average Variance Extracted (AVE > 0.50)
- Discriminant Validity using the Fornell-Larcker criterion

These procedures ensure internal consistency and construct validity before conducting structural analysis.

3.5 Structural Equation Modelling (PLS-SEM)

Partial Least Squares Structural Equation Modelling (PLS-SEM) was utilized using SmartPLS 4.0 software due to its effectiveness in predictive modelling involving complex latent relationships and moderate sample sizes. PLS-SEM is frequently used in studies related to environment-behaviour interactions and the built environment because it allows for the simultaneous assessment of measurement reliability and causal relationships between architectural and behavioural variables. To determine the statistical significance of the path coefficients, bootstrapping with 5,000 resamples was performed. The criteria for model evaluation included:

- Significance of path coefficients (β)
- Coefficient of determination (R^2)
- Predictive relevance (Q^2)
- Standardized Root Mean Square Residual (SRMR < 0.08)

3.5 Research Validity and Analytical Procedure

To ensure methodological rigor in line with E-BPJ publication standards, we conducted multicollinearity diagnostics using Variance Inflation Factor (VIF) values, ensuring they were below 5.0. We also assessed predictive capability through blindfolding procedures. The analytical process consisted of five sequential stages: developing the questionnaire, implementing the field survey, validating the measurement model, testing the structural model, and interpreting the relationships between the environment and behaviour.

4.0 Findings

4.1 Respondent Profile and Dwelling Characteristics

A total of 383 valid questionnaires were analysed to investigate thermal perception and residential satisfaction among rural occupants. The respondents were divided between two main types of dwellings: vernacular courtyard houses (51.7%) and modern rural homes (48.3%). Most participants had lived in their current homes for over ten years, providing a reliable basis for evaluating environmental performance after occupancy. Vernacular dwellings were primarily single-storey courtyard houses built with brick masonry walls that have high thermal mass and semi-open transitional spaces. In contrast, modern houses mainly consist of reinforced concrete structures characterized by larger window openings and compact internal layouts. Preliminary observations suggested that residents in vernacular dwellings reported better natural ventilation and lower perceived overheating during the summer months, while occupants of modern houses expressed a greater reliance on mechanical cooling systems.

Table 2. Demographic Characteristics of Respondents

Sample data items	Distribution
Gender	Male: 56.9% / Female: 43.1%
Age group	18 – 35 years old (28.2%), 36 – 50 years old (38.6%), 51 – 60 years old (12.3%), ≥61 years old (20.9%)
Height (CM)	≤140(0.5%), 140 – 150(0.5%), 151 – 160(17%), 161 – 170(39.9%), 171 – 180(41.3%), ≥181(0.8%)
Weight (KG)	≤40(0.5%), 41 – 50(6.8%), 51 – 60(33.9%), 61 – 70(33.9%), 71 – 80(12.0%), ≥81(6.0%)
Occupation	Employed for wages (48.3%), Self-employed (7.6%), A homemaker (11.0%), Farmer (11.2%), Student (8.6%), Military (0.3%), Retired (13.1%)
Monthly Salary	1000(15.1%), 2000(14.9%), 3000(16.2%), 4000(14.9%), 5000(11.2%), ≥5000(27.7%)

4.2 Measurement Model Assessment

The measurement model was evaluated before conducting hypothesis testing to ensure its reliability and validity. Internal consistency reliability was confirmed, as all constructs achieved Cronbach's Alpha and Composite Reliability (CR) values above the recommended threshold of 0.70.

Table 3. Measurement Model Reliability and Validity Results

Construct	Cronbach's α	Composite Reliability (CR)	AVE
BM	0.900	0.929	0.649
CC	0.714	0.901	0.623
DT	0.886	0.901	0.695
HS	0.777	0.873	0.402
SC	0.793	0.838	0.477
TC	0.806	0.891	0.527

Convergent validity was assessed using Average Variance Extracted (AVE), with most constructs meeting the recommended value of 0.50. Although Spatial Configuration and Housing Satisfaction had slightly lower AVE values, they were still considered acceptable due to their adequate composite reliability. This finding aligns with the guidelines for PLS-SEM in exploratory studies on environment and behaviour. Additionally, discriminant validity was confirmed using the Fornell-Larcker criterion, which showed that each construct shared a greater variance with its indicators than with other constructs. Overall, these results indicate that the measurement model demonstrates satisfactory reliability and validity for structural analysis.

4.3 Structural Model Evaluation

After validating the measurements, the structural model was analysed using bootstrapping procedures with 5,000 resamples. The results indicate significant causal relationships among architectural characteristics, perceptions of thermal comfort, and housing satisfaction. Among the factors studied, Dwelling Type had the strongest influence in the model, significantly affecting Thermal Comfort ($\beta = 0.959$, $p < 0.001$), Courtyard Configuration ($\beta = 0.891$, $p < 0.001$), and Spatial Configuration ($\beta = 0.890$, $p < 0.001$). These findings suggest that housing typology plays a fundamental role in determining environmental adaptability and spatial performance in rural residential settings.

Additionally, Building Materials had a significant positive effect on Spatial Configuration ($\beta = 0.355$), indicating that the characteristics of the building envelope influence spatial environmental behaviour through their capacity for thermal regulation. Courtyard Configuration also positively contributed to Spatial Configuration ($\beta = 0.322$), emphasizing the climatic importance of semi-open spatial systems. Furthermore, Spatial Configuration positively influenced Housing Satisfaction ($\beta = 0.167$, $p < 0.05$), confirming its role as a mediator between physical architectural conditions and the experiential outcomes of occupants.

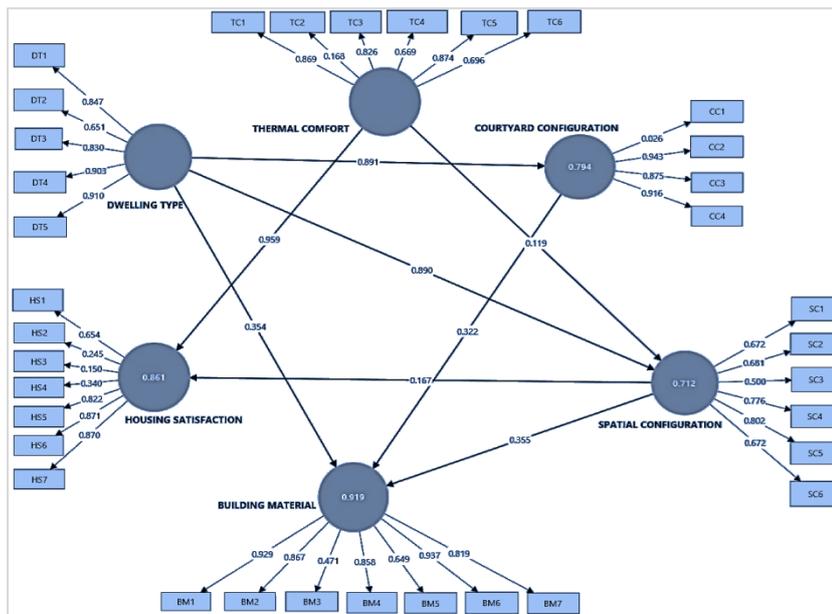


Fig. 2: Structural Equation Model with Path Coefficients

4.4 Predictive Power of the Model

The explanatory power of the structural model was evaluated using coefficients of determination (R^2). Both Thermal Comfort and Spatial Configuration demonstrated significant explanatory levels, indicating strong predictive relationships between dwelling characteristics and environmental perception. The predictive relevance, assessed through Q^2 values, confirmed that the proposed model has satisfactory forecasting capability for behavioural and satisfaction outcomes. Additionally, the Standardized Root Mean Square Residual (SRMR) value was below the recommended threshold of 0.08, indicating an acceptable model fit consistent with PLS-SEM analytical standards. These results show that the integrated thermal-spatial framework effectively explains occupants' environmental experience within rural dwellings.

Table 4. Model Fit Summary for PLS-SEM Analysis.

Dimensions	Saturated model	Estimated model
SRMR	0.165	0.168
d_ULS	17.202	17.691
d_G	n/a	n/a
Chi-square	infinite	infinite
NFI	n/a	n/a

Table 5. Coefficient of determination (R^2) for endogenous constructs.

Endogenous Variable	R ²	R ² Adjusted
Building Materials (BM)	0.919	0.919
Courtyard Configuration (CC)	0.794	0.794
Housing Satisfaction (HS)	0.861	0.860
Spatial Configuration (SC)	0.712	0.711

4.5 Environment–Behaviour Mediation Effects

Further analysis reveals that Spatial Configuration serves as a vital link between dwelling characteristics and housing satisfaction. Instead of directly impacting satisfaction, architectural features influence behavioural opportunities that allow occupants to adapt to thermal conditions. Courtyard spaces, for instance, encourage adaptive behaviours such as spending time outdoors, adjusting ventilation, and shifting activities over time. These adaptations enhance perceived comfort without leading to increased energy consumption. This finding supports the Environment-Behaviour hypothesis, which posits that environmental quality arises from the interaction between spatial affordances and human adaptation processes. The results confirm that passive spatial design strategies improve both environmental performance and subjective well-being in rural residential settings.

5.0 Discussion

5.1 Thermal–Spatial Interaction in Rural Residential Environments

The findings suggest that the thermal performance of rural dwellings is mainly influenced by the interaction between spatial configuration and the behavioural adaptations of occupants, rather than by building materials alone. The notable impact of dwelling type on thermal comfort indicates that vernacular courtyard houses incorporate climate-responsive spatial strategies developed through long-term environmental adaptation. In contrast to modern rural housing, vernacular dwellings manage indoor conditions through spatial buffering, shaded transitional areas, and natural ventilation mechanisms. The design of courtyard spaces serves as a microclimatic regulator by reducing solar heat gain while facilitating airflow and outdoor activities. These results indicate that sustainable rural housing should revisit and adapt vernacular spatial principles instead of relying on standardized construction models that undermine passive environmental regulation. From an Environment–Behaviour perspective, architectural space functions as an adaptive system that allows occupants to respond dynamically to thermal conditions through their daily use of space.

5.2 Behavioural Adaptation as a Mediating Mechanism

A key contribution of this study is the identification of spatial configuration as a crucial link between environmental performance and housing satisfaction. The findings indicate that occupants actively adapt to thermal conditions by engaging in behaviours such as opening windows, using courtyards, and relocating activities. In line with adaptive thermal comfort theory, comfort arises from the interaction between humans and their environment rather than from fixed indoor temperature settings. Courtyard spaces enhance behavioural flexibility by providing semi-outdoor environments that support both seasonal and temporal adaptations. This mediation effect suggests that improving spatial adaptability can lead to greater residential satisfaction while reducing reliance on mechanical cooling. Consequently, it presents a viable pathway toward achieving low-carbon rural living environments.

5.3 Implications for Climate-Responsive Rural Housing Design

The shift towards modern rural housing has changed traditional environmental behaviour patterns by limiting spatial adaptability and the connection between indoor and outdoor spaces. The structural model shows that restricted adaptive spaces hinder occupants' ability to naturally manage their thermal conditions. The findings suggest several key design implications:

- i. Reintegration of courtyard systems as passive regulators of microclimates.
- ii. Creation of shaded semi-open transitional areas that support behavioural adaptation.
- iii. Climate-responsive envelope designs that combine thermal mass with controlled ventilation.
- iv. Design approaches focused on human behaviour that prioritise spatial interaction rather than relying on technology.

These strategies emphasise a human-centered approach to environmental design, moving beyond conventional energy-efficiency optimization.

5.4 Contribution to Environment–Behaviour Studies and Sustainable Development

This study enhances Environment–Behaviour research by empirically validating the relationships among spatial configuration, thermal perception, behavioural adaptation, and housing satisfaction using a PLS-SEM framework. Integrating spatial and behavioral variables aligns with the interdisciplinary goals of the Environment–Behaviour Studies. The findings support broader sustainability objectives, particularly:

SDG 11 – improving rural residential liveability toward thermal comfort.

To enhance the liability of rural residential areas, it is crucial to address thermal comfort, particularly during hot seasons. Many rural homes suffer from overheating due to poor design, inadequate ventilation, and a lack of climate-responsive features. Improving thermal comfort can be achieved through passive design strategies, such as optimizing orientation, ensuring cross-ventilation, providing shading, using suitable building materials, and incorporating surrounding vegetation. These solutions should be affordable and adaptable to the

local socio-economic context. Ultimately, improving thermal comfort is vital for promoting health, well-being, and sustainable development in rural communities.

SDG 13 – promoting passive strategies that reduce operational energy demand.

The text supports the use of passive design strategies to reduce the operational energy demand in buildings. By incorporating natural ventilation, proper orientation, shading, and climate-responsive materials, buildings can minimize their reliance on mechanical cooling systems. This approach not only reduces energy consumption and greenhouse gas emissions but also enhances thermal comfort and promotes environmental sustainability.

By highlighting the mediating role of spatial configuration, the study emphasizes the necessity of integrating cultural continuity with climate-responsive design in rural revitalisation efforts.

6.0 Conclusion and Recommendations

This study examined the thermal and spatial relationships in rural dwellings through an Environment-Behavior framework using empirical modelling techniques. Key conclusions include the following:

- i. The type of dwelling is the primary factor influencing environmental performance.
- ii. Spatial configuration plays a key role in mediating the relationships between architectural design and resident satisfaction.
- iii. The shape and design of courtyards significantly enhance adaptive thermal comfort.
- iv. Behavioural adaptation improves the effectiveness of passive design strategies.

Future rural dwelling policies should focus on climate-responsive planning instead of standardized construction methods. Additionally, expanding research to include various climatic regions and seasonal conditions would enhance the generalizability of the findings. Integrating an understanding of human behaviour into architectural design provides a practical approach to creating resilient and sustainable rural environments throughout Asia.

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