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Enhancing Thermal Comfort and Movement in Public Markets Through Informed Space Syntax Approach: A Case Study of Lipa City Public Market

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Abstract

The traditional Filipino "palengke" is a vital part of daily life in Filipino communities, serving as a central hub that embodies the social, cultural, and economic essence of Philippine society. However, these historical spaces are under threat from the rise of supermarkets, outdated layouts, and thermal discomfort. These challenges are not just compromising the appeal and functionality of palengkes, but also threatening their very existence.

This study explores how users interact with the market's environment and how Space Syntax, combined with environmental data, can optimize spatial layout and thermal comfort. Data collection included user surveys on heat, humidity, and airflow alongside environmental measurements. Researchers used Computational Fluid Dynamics (CFD) simulations and Space Syntax analysis to examine the relationship between spatial configuration and thermal dynamics, identifying opportunities for improvement.

Findings reveal that market temperatures often exceed comfort standards set by ASHRAE 55 (23°C to 27°C), Code of Sanitation of the Philippines (26.7°C, and 60% relative humidity), and an empirically derived comfort range (26°C to 28.5°C). Congested areas, particularly in grocery and wet sections, experience the worst conditions. Space Syntax analysis showed that areas with better spatial integration, such as main hallways, benefit from improved airflow. CFD simulations underscored the role of layout in airflow patterns.

Recommendations include redesigning market layouts to reduce congestion, improving ventilation with natural cooling elements, and utilizing technology for real-time monitoring. By addressing these issues, the study aims to enhance the user experience and ensure the competitiveness of palengkes amid rapid modernization.

Keywords: Visual Comfort, Daylighting Design, Luminance Metrics, Sustainability.

Introduction

Despite the rapid growth of supermarkets, the palengke remains central to Filipino socio-cultural life, serving as both a marketplace and a community hub. However, many public markets still operate under outdated modular guidelines of 1989 by the Department of the Interior and Local Government (DILG), resulting in overcrowding, inefficient circulation, and substandard thermal environments marked by high humidity and poor air quality [1, 2]. These conditions diminish user comfort and market appeal, contributing to a steady shift toward air-conditioned supermarkets, with up to 70% of Filipinos favoring modern retail spaces due to environmental discomfort [3-5].

To remain competitive, public markets must address two interlinked issues: thermal comfort and movement efficiency. Studies consistently link spatial configuration to airflow, congestion, and perceived comfort, positioning Space Syntax as a promising analytical tool [1, 2]. Evidence from recent work highlights that improved connectivity and optimized layouts enhance natural ventilation, reduce energy consumption, and improve user experience [3-5].

Nonetheless, significant gaps persist. Most studies lack integrated analyses combining spatial metrics with empirical environmental data—temperature, humidity, radiant heat, and wind velocity—and rarely connect user perceptions with Computational Fluid Dynamics (CFD) simulations. Furthermore, few address the dynamic, seasonal variability of thermal comfort in tropical markets.

This study addresses these gaps by integrating Space Syntax, real-time environmental monitoring, and CFD simulations to investigate the interplay of spatial layout, movement dynamics, and thermal comfort in the Lipa City Public Market. By coupling environmental data with user perception surveys, the research develops evidence-based design strategies to improve circulation, enhance natural ventilation, and foster thermally comfortable, resilient market environments.

Guided by the theoretical framework (Figure 1), which conceptualizes comfort and movement efficiency as outcomes of the interaction between spatial configuration, environmental conditions, and user characteristics, this study applies a conceptual model (Figure 2) that operationalizes the integration of spatial analysis, environmental simulation, and user feedback.

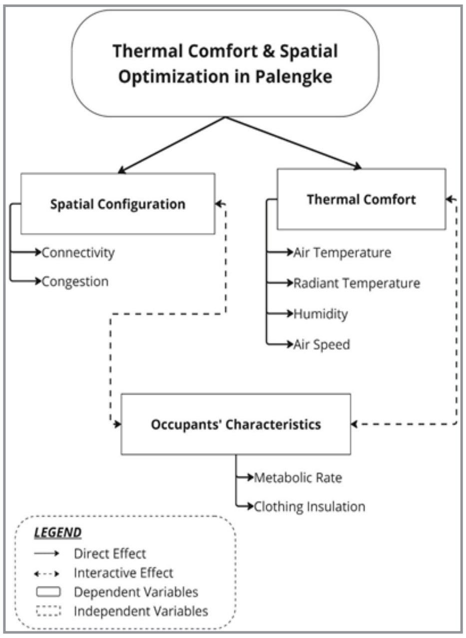


Figure 1: Theoretical Framework

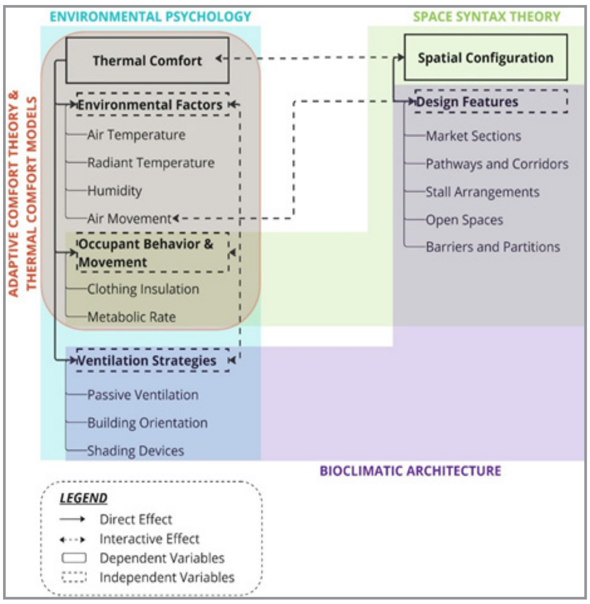


Figure 2: Conceptual Framework

Ultimately, the research seeks to provide practical guidance for revitalizing Philippine public markets, offering insights for architects, planners, and policymakers on human-centered, environmentally responsive design. It is driven by two key questions:

1. How do users perceive and navigate the spatial and thermal environments of the Lipa City Public Market?
2. How can Space Syntax, informed by environmental data and comfort thresholds, guide spatial reconfiguration to optimize movement and thermal conditions?

Methodology

This study employed a mixed-methods approach to investigate spatial optimization, thermal comfort, and user experience in Lipa City Public Market, Batangas, Philippines. Quantitative analyses were combined with qualitative inquiries to produce evidence-based design recommendations. Space Syntax analysis, environmental monitoring, Computational Fluid Dynamics (CFD) simulations, and statistical modeling were used to generate robust findings that inform design interventions.

Study Area

Lipa City Public Market, the city's primary marketplace and a vital socio-economic hub, was chosen for its central role in the community and ongoing rehabilitation plans. Located 78 km south of Manila in the CALABARZON region, Lipa experiences a tropical climate with distinct wet and dry seasons, with annual temperatures ranging between 20 °C and 31 °C. Access to site data was facilitated through the City Planning and Development Office, which provided the Comprehensive Development Plan (March 25, 2024) and granted approval for environmental data collection. Site visits began on April 7, 2024, and included remeasurement of market areas and validation of architectural drawings with the Engineering Office.

Research Design

A sequential exploratory mixed-methods design was adopted, combining qualitative insights with quantitative environmental and spatial data. The qualitative phase involved interviews, surveys, and field observations to capture user perceptions of thermal comfort and spatial efficiency. The quantitative phase followed with structured data collection on environmental variables—air temperature, humidity, wind velocity, and radiant temperature—alongside spatial configuration analysis. Statistical tests were then applied to evaluate relationships between measured variables and user comfort.

Participants and Sampling

Market vendors and shoppers served as the primary respondents. Purposive sampling was employed to capture a representative range of market sections and user demographics. Based on a visitor population of 1,328, a sample size of 298 was calculated using Cochran's formula at a 95% confidence level and a 5% margin of error. To account for potential non-responses, 321 completed surveys were collected, ensuring robust data representation.

Cochran's Formula $$n = \frac{Z^2 p(1-p)}{e^2} \quad (1)$$

Where:

* N is the population size = 1328
* Z is the Z-score for a 95% confidence level = 1.96
* e is the margin of error = 0.05
* p is the estimated proportion = 0.5

Research Instruments

Data collection utilized three key tools

1. Survey questionnaires based on ANSI/ASHRAE Standard 55, adapted to assess thermal sensation, comfort acceptability, and user satisfaction. Pilot testing and reliability checks were conducted through test-retest analysis (ANSI/ASHRAE Standard 55, 2023).

2. Environmental monitoring equipment—anemometers, hygrometers, and infrared pyrometers—were deployed to measure airspeed, humidity, temperature, and radiant heat (Figure 3).

3. Sensors were positioned across four quadrants of the market—Fruits and Vegetables, Rice, Meat and Poultry, and Seafood—to capture spatial variability. Measurements followed ANSI/ASHRAE 55 guidelines at heights of 0.1, 1.1, and 1.7 m, focusing on standing occupants (ANSI/ASHRAE Standard 55, 2023).

(a) (b) (c)

Figure 3: (a) Anemometer, (b) Hygrometer and (c) Infrared Pyrometer

3. Pedestrian counting tools, including manual tally counters, recorded entries at the three main gates to support agent-based modeling of pedestrian flow (Figure 4).

Data were collected across three representative days—summer, rainy season, and a typical day—during market hours (4:00 a.m.–5:00 p.m.). Measurement intervals adhered to ANSI/ASHRAE 55 standards, with adjustments for manual recording.

Figure 4: Digital hand tally counter

Data Gathering Procedures

The methodological workflow integrated qualitative and quantitative phases into a coherent framework (Figure 7). Initial literature review informed the design of survey instruments and the selection of environmental parameters. Fieldwork included on-site spatial documentation, environmental monitoring, pedestrian counts, and administration of surveys. Agent-based simulations were performed in DepthMapX to analyze pedestrian circulation and identify congestion points, with pedestrian count data informing the model.

Data Analysis

Data analysis comprised descriptive and inferential statistics to quantify user comfort, environmental conditions, and spatial efficiency. Space Syntax analysis using DepthMapX evaluated connectivity, integration, and movement dynamics, with agent-based simulations visualizing pedestrian flow and identifying bottleneck areas (Figure 5). CFD simulations using SimScale modeled airflow, thermal distribution, and ventilation performance across seasonal conditions (Figure 6). Integration of spatial and environmental results identified design interventions to enhance movement and thermal comfort.

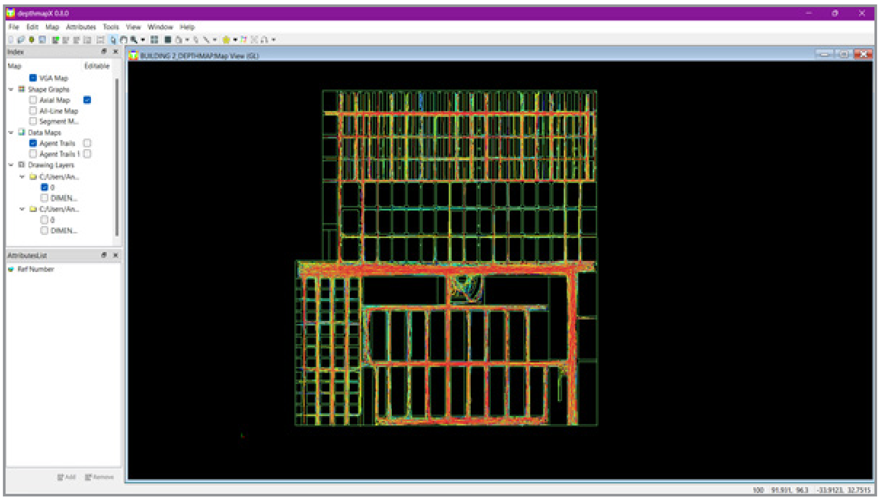


Figure 5: User interface of DepthMapX

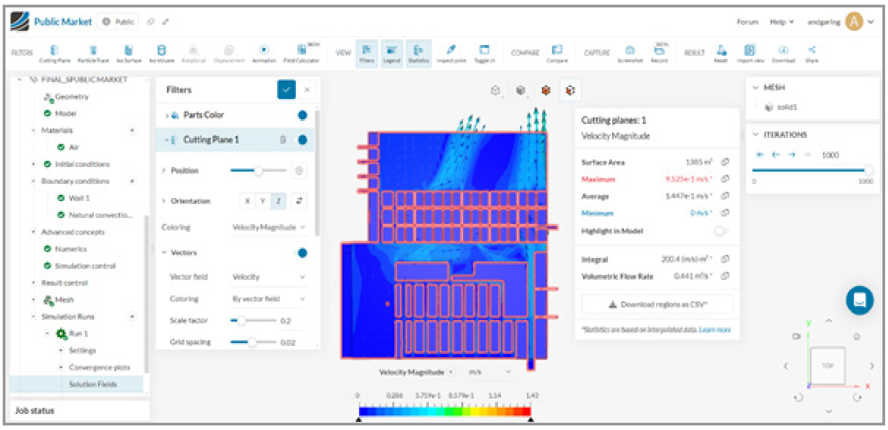


Figure 6: User interface of Sim Scale

Methodological and Analytical Frameworks

The methodological framework (Figure 7) illustrates the sequential integration of survey data, environmental monitoring, and computational modeling. The analytical framework (Figure 8) synthesizes spatial configuration, environmental variables, and user perceptions to evaluate design strategies that optimize thermal comfort and pedestrian flow.

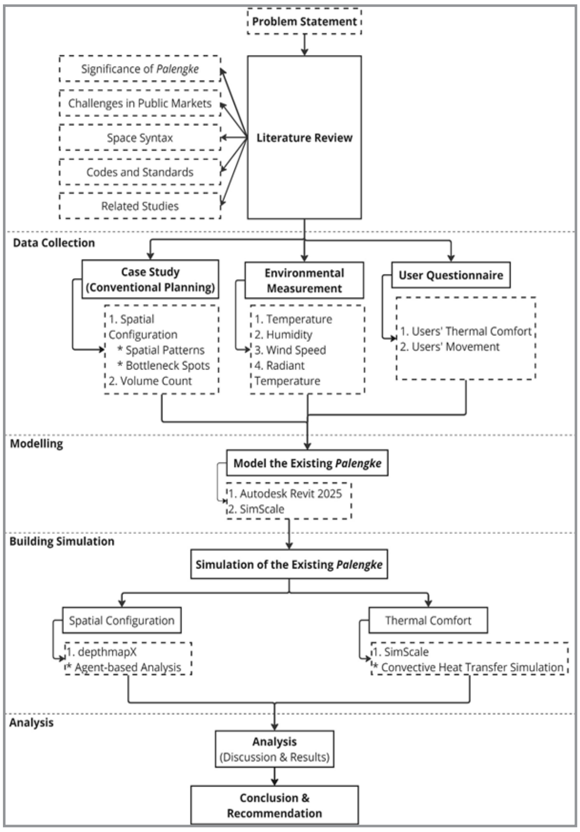


Figure 7: Methodological Framework

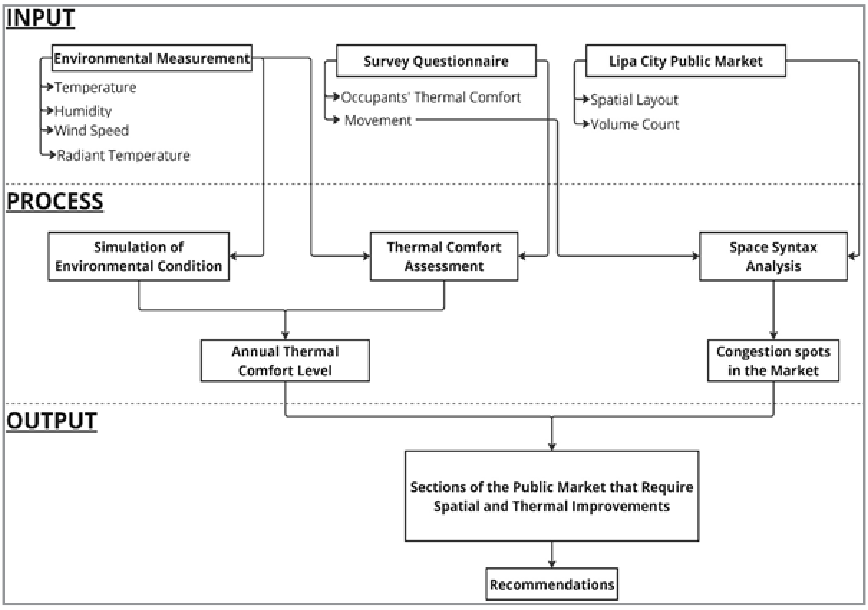


Figure 8: Analytical Framework

Results and Discussion

This section synthesizes findings from descriptive statistics, spatial configuration analyses (DepthMapX), and CFD simulations (SimScale) to elucidate thermal comfort drivers in the Lipa City Public Market.

Descriptive Statistics

Visit Frequency and Duration

The market functions as a daily node of activity: 50% of respondents visit daily and 65% at least weekly, confirming its socio-economic centrality (Table 1). Most trips are short (47% ≤30 min), with heat and humidity prompting early exits. Congestion prolongs visits for 10% who stay >2 h. Peak visits occur 6–7 a.m. (19%) and 5 p.m. (19%) for cooler conditions and after-work shopping (Table 2).

Table 1: Visit Frequency and Duration

Category	Subcategory	Count	Percent (%)
Public Market Visit Frequency	Everyday	161	50.2
	One times a week	47	14.6
	Two times a week	35	10.9
	Three times a week	5	1.6
	Four times a week	56	17.4
	One times a month	8	2.5
	Two times a month	9	2.8
Time Spent at the Public Market	2 hours	29	9.0
	30 minutes	116	36.1
	1 hour	95	29.6
	Less than 30 minutes	36	11.2
	More than 2 hours	31	9.7
	1 hour and 30 minutes	14	4.4

Table 2: Typical public market visit time

Category	Time	Count	Percent (%)	Time	Count	Percent (%)
Typical Public Market Visit Time	12:00 am	1	0.3	11:00 am	4	1.2
	2:00 am	2	0.6	11:30 pm	2	0.6
	3:00 am	5	1.6	12:00 pm	3	0.9
	4:00 am	5	1.6	1:00 pm	4	1.2
	4:30 am	1	0.3	2:00 pm	3	0.9
	5:00 am	22	6.9	2:30 pm	1	0.3
	6:00 am	25	7.8	3:30 pm	1	0.3
	6:30 am	1	0.3	4:00 pm	25	7.8
	7:00 am	36	11.2	4:30 pm	8	2.5
	8:00 am	40	12.5	5:00 pm	60	18.7
	8:30 am	3	0.9	5:20 pm	1	0.3
	9:00 am	20	6.2	5:30 pm	5	1.6
	9:30 am	2	0.6	6:00 pm	9	2.8
	10:00 am	14	4.4	6:30 pm	3	0.9

Clothing and Activity Patterns

Light, mobile attire dominates, with mean insulation 0.3 Clo (ANSI/ASHRAE Standard 55, 2023). Activities are physically demanding: shopping (51%, 2.1 met) and selling (46%, 1.4 met) predominate, underscoring the metabolic load in thermally challenging, congested settings (Table 3).

Table 3: Users' clothing and activity

Category	Shirts and Blouses	Trousers and Coveralls	Footwear	Clo	Count	Percent
Clothing Combinations	Short-sleeve shirt	Walking shorts	Sandals/Thongs	0.31	139	43.3
	Short-sleeve shirt	Straight trousers	Sandals/Thongs	0.38	91	28.4
	Sando	Walking shorts	Sandals/Thongs	0.26	39	12.2
	Short-sleeve shirt	Walking shorts	Slippers	0.32	9	2.8
	Short-sleeve shirt	Straight trousers	Ankle-length athletic socks, Shoes	0.33	15	4.7

	Sando	Walking shorts	Ankle-length athletic socks, Shoes	0.28	6	1.9
	Short-sleeve shirt	Straight trousers	Slippers	0.39	11	3.4
	Short-sleeve shirt	Walking shorts	Ankle-length athletic socks, Shoes	0.33	7	2.2
	Dress / Duster	-	Sandals/Thongs	0.35	13	4.1
Activity	-	-	Activity	(met)		
	-	-	Selling	1.4	148	46.1
	-	-	Shopping	2.1	164	51.1
	-	-	Walking	2	9	2.8

Met values (Source: ASHRAE 2020)
- Selling = Filing, standing (1.4) = 1.4 met
- Shopping = Lifting/ packing (2.1) = 2.1 met
- Walking = Walking, 0.9 m/s (2.0) = 2.0 met

Thermal Comfort Perceptions

Discomfort peaks at 11 a.m.–2 p.m. (49%), coinciding with peak solar gain. Heat (39%), humidity (24%), stagnant air (24%), and crowding (25%) dominate complaints. 62% perceive conditions as "very humid," exceeding the 60% Code of Sanitation limit; 57% report inadequate airflow, and 56% feel "hot." Coping behaviors include electric fans (32%), cold drinks (23%), relocating, or leaving early (16%) (Table 4).

Table 4: Thermal Comfort and Environment

Category	Subcategory	Count	Percent (%)
Hottest Time in the Public Market	Noon (11am - 2pm)	157	48.9
	Noon (11am - 2pm), Afternoon (2pm - 5pm)	23	7.2
	Morning (before 11am)	50	15.6
	Morning (before 11am) & Noon (11am - 2pm)	32	10
	Afternoon (2pm - 5pm)	8	2.5
	Entire day	51	15.9
Reason for Discomfort in the Public Market	Humid	77	24
	No air movement	77	24
	Sunny	32	10
	Hot	125	38.9
	Crowded	81	25.2
	Smelly	22	22
	Noisy	6	1.9
	Slippery	22	6.9
	None	17	5.3
How humid do you feel inside the market?	Very Humid	199	62
	Humid	14	4.4
	Slightly Humid	27	8.4
	Neutral	61	19
	Slightly Dry	7	2.2
	Dry	10	3.1
	Very Dry	3	0.9

Is there adequate airflow inside the public market?	Yes	138	43
	No	183	57
How would you describe your experience with the heat inside the market?	Cold	4	1.3
	Cool	14	4.4
	Slightly Cool	14	4.36
	Neutral	60	18.7
	Slightly Warm	25	7.8
	Warm	26	8.1
	Hot	178	55.5
Ways to ease discomfort in the market	Change location	46	14.3
	Use of electric fans	102	31.8
	Use of hand fans	47	14.6
	Drink water	6	1.9
	Cold drinks	75	23.4
	Go home	52	16.2
	Bath	6	1.9
	None	29	9

Demographic Profile

Middle-aged females dominate (45–54 years: 29%; women: 74%), reflecting household provisioning roles. Typical budgets are ₱500–₱1,000 (47%); occupations highlight the market's dual function as livelihood center and supplier of daily goods (Tables 5–6).

Table 5: User demographics

Category	Subcategory	Count	Percent (%)
Age of Users	65 and above	30	9.3
	45-54	93	29.0
	35-44	58	18.1
	55-64	63	19.6
	25-34	54	16.8
	18-24	23	7.2
Gender of Users	Female	237	73.8
	Male	84	26.2
Budget for Shopping	₱500 - ₱1,000	152	47.4
	More than ₱4,000	18	5.6
	₱1,001 - ₱2,000	57	17.8
	Less than ₱500	69	21.5
	₱2,001 - ₱3,000	18	5.6
	₱3,001 - ₱4,000	7	2.2

Table 6: Work of users

Category	Work of Users	Count	Percent (%)	Work of Users	Count	Percent (%)
Work of Users	Vendor	51	15.9	Student	1	0.3
	Fruit Vendor	24	7.5	Chef	5	0.3
	Vegetable Vendor	12	3.7	Teacher	3	1.6
	Food Vendor	2	0.6	Online Business	3	0.9
	Loader	7	2.2	Enforcer	1	0.9
	Sales Lady	57	17.8	Mechanic	1	0.3
	Housewife	38	11.8	Factory Worker	1	0.3
	Business owner	49	15.3	Housekeeper	1	0.3
	Retired	11	3.4	Tracker	1	0.3
	Cashier	3	0.9	Nurse	1	0.3
	Tailor	23	7.2	Office staff	1	0.3
	Tricycle Driver	2	7.2	Clerk	2	0.3
	Labor	1	0.6	Tanod	1	0.6
	Technician	3	0.3	Secretary	1	0.3
	Massage Ther-apist	9	0.9	Barangay Kaga-wad	1	0.3
	Service Crew	1	2.8	Warehouse Man	1	0.3
	Loan Processor	1	0.3	Fish Vendor	1	0.3

Case Study
This case study analyzes spatial dynamics shaping movement in the Lipa City Public Market, emphasizing entry/exit configurations, pedestrian volumes, and physical layout constraints.

Entry and exit Points
The market operates through three main entryways: A (primary, serving Grocery and Fruits & Vegetables), B (Fruits & Vegetables), and C (Fruits). These access points channel pedestrian flows along distinct axes, concentrating circulation through Entry A, the principal node of shopper movement (Figure 9).

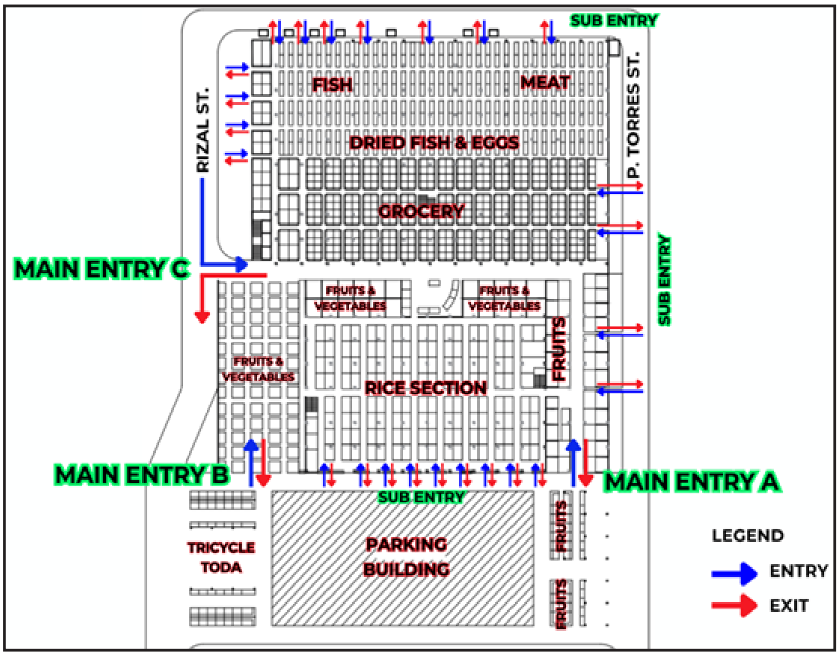


Figure 9: Entry and exit points in Lipa City Public Market

Foot Traffic Patterns
Peak-hour counts (Table 7; Figure 10) confirm Entry A as the busiest, recording 648 morning and 835 afternoon visitors. Entry B and C experience marked afternoon declines (356 → 261 and 324 → 221), suggesting temporal shifts in shopper preference and underlining the need for time-sensitive crowd management and signage optimization.

Table 7: Volume count in main entry points during peak hours

Main Entry Points	Morning	Afternoon
A	648	835
B	356	261
C	324	221

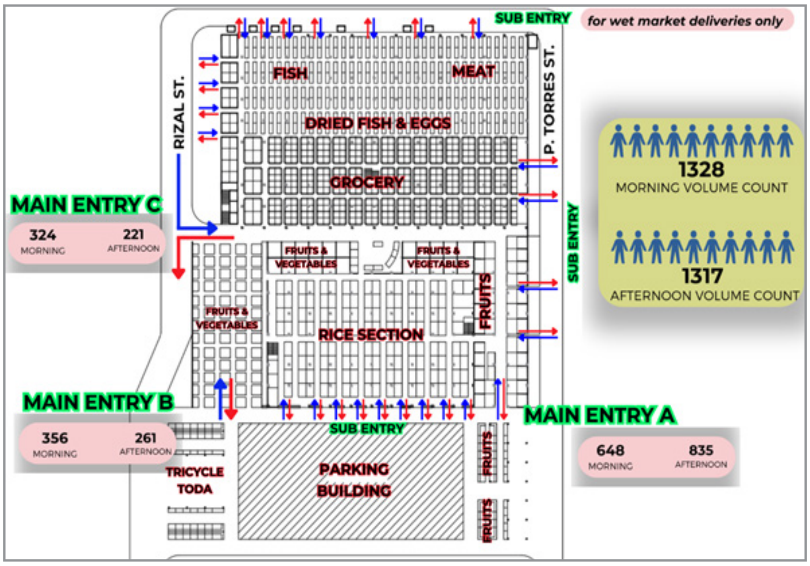


Figure 10: Volume count at entry and exit points

Spatial Bottlenecks

On-site mapping identified circulation bottlenecks caused by narrow aisles, irregular stall dimensions, and obstructive structural columns (Table 8). Corridor widths in the Wet Market (1.2 m) and Dried Fish & Egg section (0.9 m) fall well below the 3.5 m international standard, impeding flow and intensifying congestion at peak hours. Fruits & Vegetables corridors narrow further to 0.6 m, creating abrupt flow constrictions. Rice Section aisles, at 1.7 m, perform marginally better but remain insufficient. Compact Grocery stalls (1.6 × 1.6 m) and oversized Fruits & Vegetables stalls (2.8 × 2.6 m) further compress circulation space, amplifying shopper frustration.

Table 8: Corridor width and stall size of each section

Sections	Corridor Width as per NPMC (m)	Corridor Width Int.'l Std. (m)	Existing Corridor Width (m)	Stalls Size as per DILG (m)	Existing Stalls Size (m)
Wet Market	1.20	3.50	1.20	1.20 x 2.40	1.00 x 2.25
Dried Fish & Egg			0.90	2.40 x 2.40, or 2.40 x 4.80	1.00 x 2.50
Grocery			0.90	2.40 x 2.40, or 2.40 x 4.80	1.60 x 1.60
Fruits & Vegetables			1.20 m & 0.60	2.40 x 2.40	2.80 x 2.60
Rice			1.70	2.40 x 2.40, or 2.40 x 4.80	2.15 3.55

Space Syntax Analysis

Agent-based simulations using DepthmapX quantify the spatial configuration's impact on movement and congestion. Mean gate count reached 2,645 with a maximum of 2,645 and a standard deviation of 594.5 across 4,464 analyzed gates, revealing extensive flow heterogeneity (Table 9). Spatial visualization (Figure 11) shows near-continuous congestion (red-coded), with mid-level flows (green) confined to peripheral paths. High variability signals concentrated congestion at primary nodes and underutilized secondary spaces, resulting in slower movement, overcrowding, and impaired safety and comfort. Redistribution of flows through design interventions—optimizing circulation networks, signage, and access hierarchies—would mitigate these issues, enhancing user experience and operational efficiency.

Table 9: Agent-based Analysis

Agent Analysis	Average	Minimum	Maximum	Std. Dev	Gate Count
Gate Count	2645	1	2645	594.458	4464

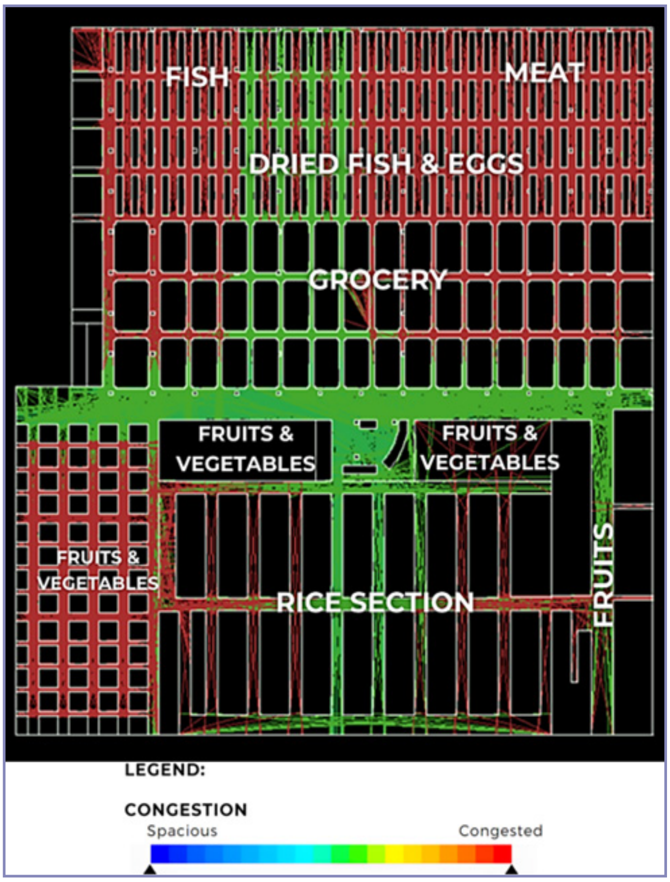


Figure 11: Agent trails and gate counts

Thermal Comfort Data Analysis

This section examines thermal comfort in the Lipa City Public Market by correlating occupants' perceptions with environmental parameters—air temperature (TA), relative humidity (RH), radiant temperature (TR), and wind velocity (VEL)—and comparing these with Predicted Mean Vote (PMV) scores to determine comfort zones and spatial variability.

Occupants' Perception and Environmental Data

a. Air temperature. Thermal sensation closely matches recorded temperatures (Figure 12), with a comfort band of 27–29.5 °C (PMV –0.5 to +0.5), exceeding ASHRAE Standard 55 (23–27 °C) and the Code of Sanitation of the Philippines (26.7 °C). Frequent exceedances indicate thermal discomfort, while inter-individual differences suggest the influence of acclimatization and transient microclimates.

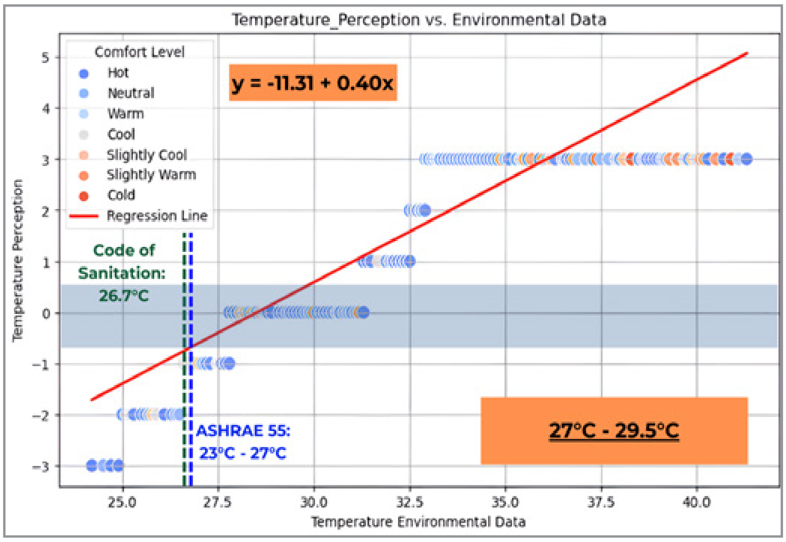


Figure 12: Temperature – occupants' perception vs. environmental data

b. Relative humidity. Perceived and actual RH are positively correlated (Figure 13), with comfort spanning 52.2–62.2%. Although within ASHRAE's upper limit (65%), RH surpasses the Philippine 60% standard, contributing to discomfort. Wide perceptual variability highlights RH's critical yet underappreciated role in thermal satisfaction, warranting integrated control alongside TA.

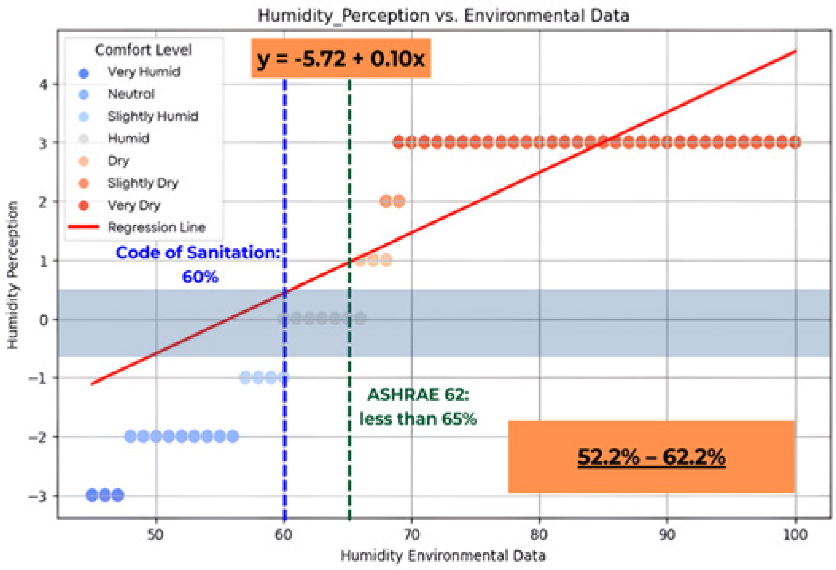


Figure 13: Humidity – occupants' perception vs. environmental data

Inter-correlation of Environmental Variables and PMV

Correlation analysis (Table 10) confirms TA as the dominant determinant of PMV ($r > 0.90$; $p < 0.01$) across all sections and seasons. TR also exerts a strong positive effect, underscoring the additive impact of air and radiant heat. RH's influence strengthens in the rainy season, reflecting greater sensitivity under cooler, more humid conditions, while VEL shows weaker and inconsistent associations, potentially confounded by instrumentation error. Controlling TA and TR emerges as the most effective approach for comfort optimization [6, 7].

Table 10: Inter-correlation between independent variables and PMV in different sections

Sections	Season	Category	TA	RH	VEL	TR
GROCERY	Summer	Correlation	0.965	-0.342	-0.396	0.943
		T-Statistic	49.323**	-4.868**	-5.765**	38.081**
	Rainy	Correlation	0.989	0.441	0.306	0.982
		T-Statistic	89.60329**	6.565498**	4.29673**	69.96408**
FISH	Summer	Correlation	0.907	-0.033	0.332	0.792
		T-Statistic	28.817**	-0.448	4.710**	17.336**
	Rainy	Correlation	1.000	-0.005	-0.020	0.240
		T-Statistic	449.455**	-0.061	-0.265	3.312**
MEAT	Summer	Correlation	0.935	0.0616	-0.490	0.856
		T-Statistic	35.238**	0.825	-7.526**	22.193**
	Rainy	Correlation	0.993	-0.374	0.068	0.719
		T-Statistic	116.5566**	-5.39795**	0.907105	13.85525**
FRUITS	Summer	Correlation	0.939	0.0377	-0.271	0.874
		T-Statistic	36.60122**	0.504888	-3.76276**	24.03566**
	Rainy	Correlation	0.992	0.823	0.552	-0.894
		T-Statistic	103.802**	19.392**	8.847**	-26.761**
FRUITS & VEGETABLES	Summer	Correlation	0.970	0.499	0.092	0.687
		T-Statistic	53.098**	7.701**	1.234	12.641**
	Rainy	Correlation	0.990	0.662	0.297	0.975
		T-Statistic	94.920**	11.822**	4.165**	58.408**

Thermal Comfort Zones by Season

a. Air temperature. Summer comfort narrows to 22.05–26.51 °C (Figure 14), whereas rainy-season comfort broadens to 25.4–28.91 °C (Figure 15), reflecting greater tolerance for warmth under humid conditions. Both ranges frequently exceed ASHRAE and national standards, necessitating targeted passive and mechanical cooling interventions.

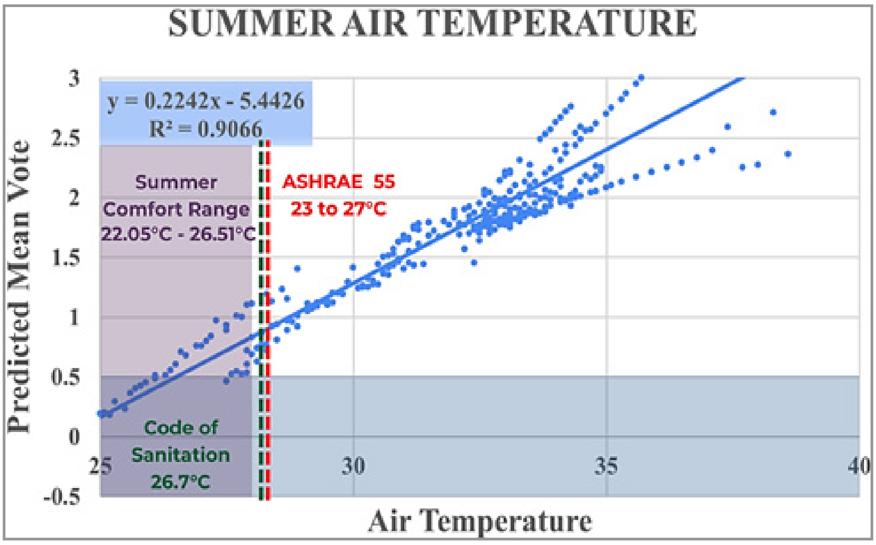


Figure 14: PMV vs. summer air temperature

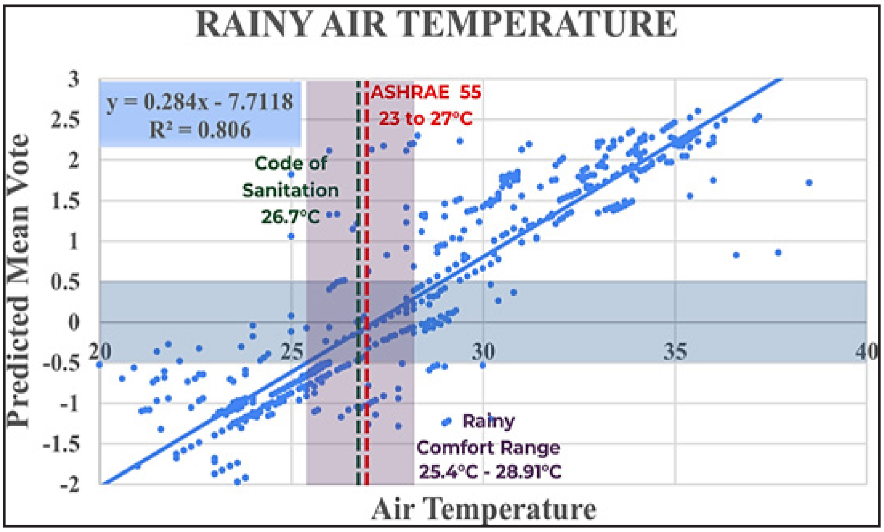


Figure 15: PMV vs. rainy air temperature

b. Radiant temperature. Comfort spans 20.41–24.85 °C in summer and shifts upward to 24.41–28.97 °C in the rainy season (Figures 16–17). Elevated summer TR notably raises PMV, reinforcing the need to minimize heat gain from structural and operational sources.

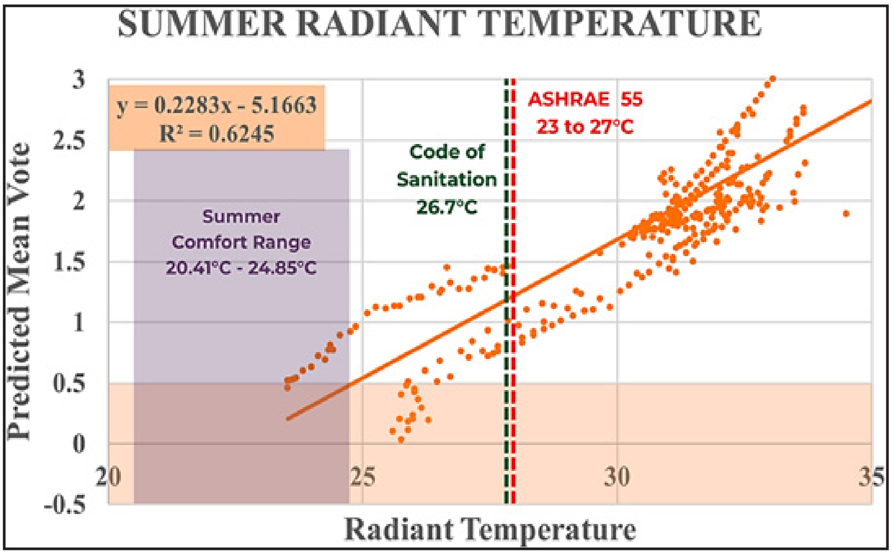


Figure 16: PMV vs. summer radiant temperature

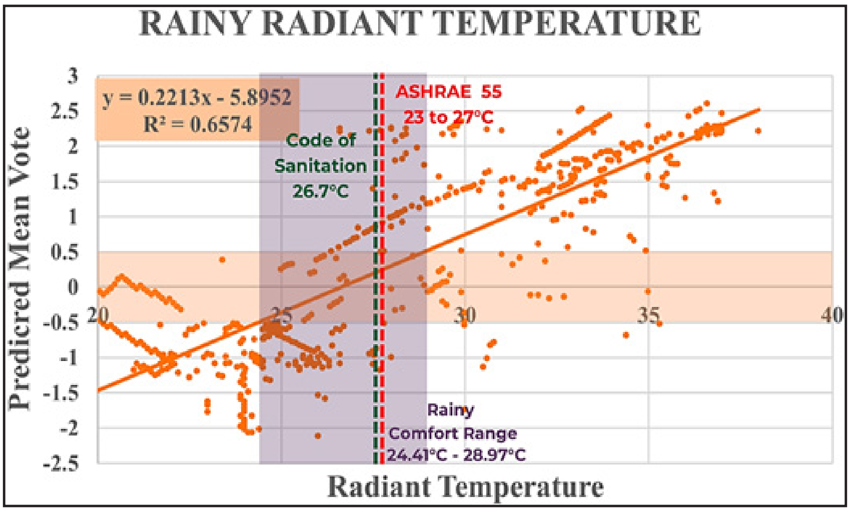


Figure 17: PMV vs. rainy radiant temperature

c. Relative humidity. Observed RH consistently exceeds the 60% Code of Sanitation limit and approaches ASHRAE's 65% threshold (Figures 18–19), creating persistent discomfort and microbiological risk. Season-specific ventilation and dehumidification strategies are required.

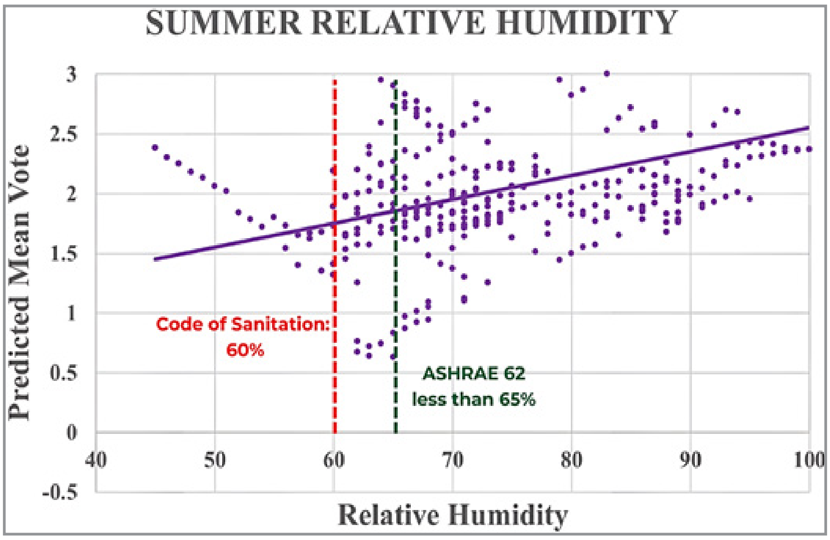


Figure 18: PMV vs. summer relative humidity

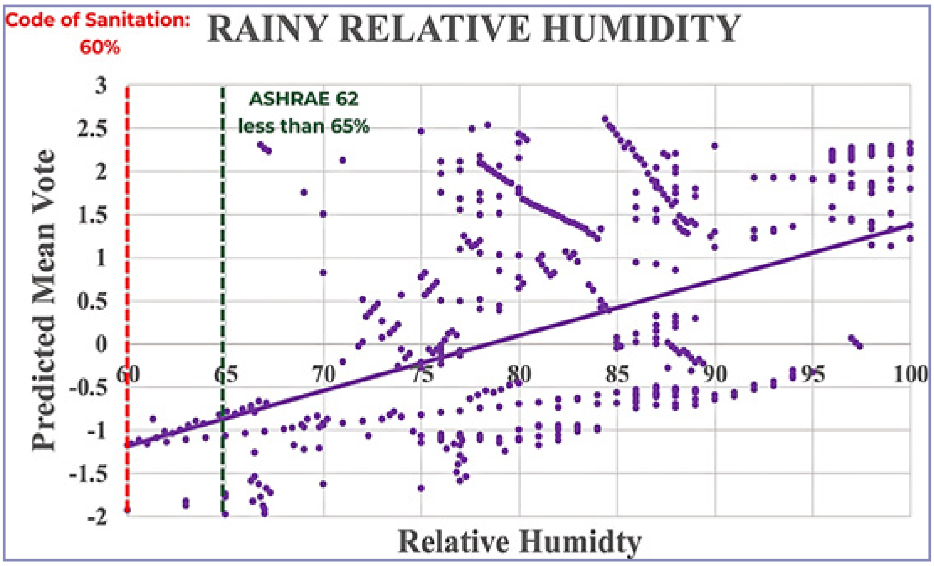


Figure 19: PMV vs. rainy relative humidity

Standard Effective Temperature (SET) Distribution

SET analysis (Figures 20–21; Table 11) confirms frequent deviations from ASHRAE and Philippine comfort standards. Comfort is transient, confined mainly to early mornings, particularly in the rainy season. The Fish Section records no summer comfort, while the Fruits Section achieves the most extended rainy-season comfort. No section maintains all-day comfort, illustrating persistent operational challenges.

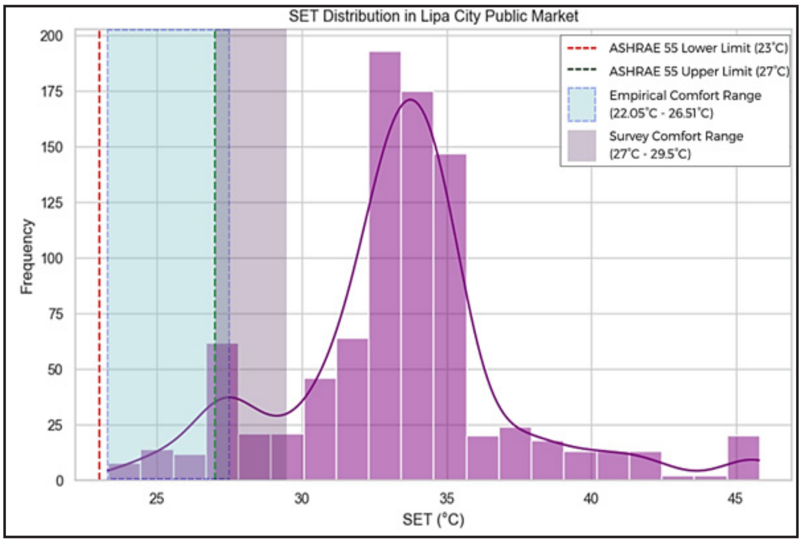


Figure 20: Summer Season's SET distribution

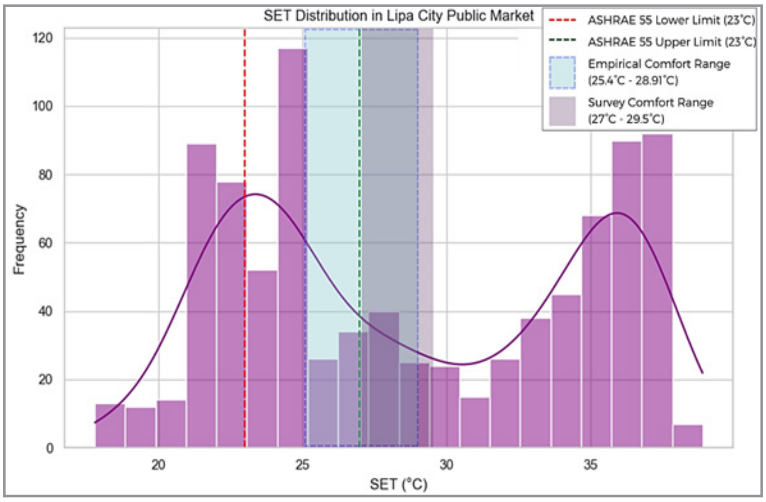


Figure 21: Rainy Season's SET distribution

Table 11: Time within the thermal comfort range of each section

Section	Season	Frequency in every 5 mins. interval	Time within the Thermal Comfort Range
GROCERY	Summer	12	4:00 am - 5:45 am
	Rainy	45	4:00 am - 7:40 am
FISH	Summer	0	-
	Rainy	96	4:00 am - 8:50 am & 1:40 pm - 3:25 pm & 5:50 pm - 7:00pm
MEAT	Summer	8	4:00 am - 5:50 am
	Rainy	41	4:00 am - 6:30 am & 6:15 pm - 7:00 pm
FRUITS	Summer	6	4:00 am - 4:55 am
	Rainy	177	4:00 am - 7:00 pm
FRUITS & VEGETABLES	Summer	21	5:35 pm - 7:00 pm
	Rainy	35	5:10 am - 8:00 am

Section specific Differences in Thermal Comfort

ANOVA (Table 12) indicates highly significant PMV variability among sections ($F = 42.316$, $p < 0.001$). Tukey's HSD (Table 13) identifies the Fruits & Vegetables Section as the least comfortable, with PMV significantly exceeding that of Fish, Fruits, and Grocery. No significant differences exist between Grocery and Meat. Wind-velocity mapping (Figures 22–23) attributes these disparities to airflow heterogeneity, narrow aisles, and structural barriers, which intensify discomfort in thermally stressed areas [8-10].

Table 12: Comparison of PMV scores across sections using ANOVA

Source	sum_sq	df	F	PR(>F)
C(Section)	89.388	4	42.316	1.67E-32

Table 13: Comparison of PMV scores across sections using Turkey's HSD test

Group 1	Group 2	Mean Difference	p-adj	Lower	Upper	Reject Null Hypothesis
Fish	Fruits	0.0528	0.9598	-0.1581	0.2637	FALSE
Fish	Fruits & Vegetables	-0.8182	0	-1.0291	-0.6073	TRUE
Fish	Grocery	-0.3577	0	-0.5686	-0.1468	TRUE
Fish	Meat	-0.1584	0.2507	-0.3714	0.0545	FALSE
Fruits	Fruits & Vegetables	-0.871	0	-1.0798	-0.6622	TRUE
Fruits	Grocery	-0.4106	0	-0.6194	-0.2018	TRUE
Fruits	Meat	-0.2113	0.0493	-0.4222	-0.0004	TRUE
Fruits & Vegetables	Grocery	0.4604	0	0.2516	0.6692	TRUE
Fruits & Vegetables	Meat	0.6597	0	0.4488	0.8706	TRUE
Grocery	Meat	0.1993	0.0744	-0.0116	0.4102	FALSE

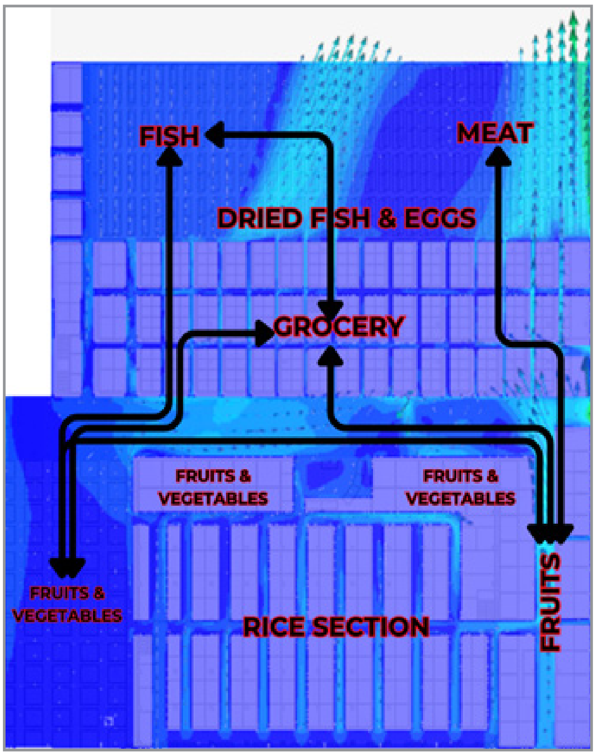


Figure 22: Wind velocity map showing user movement (true - reject null hypothesis)

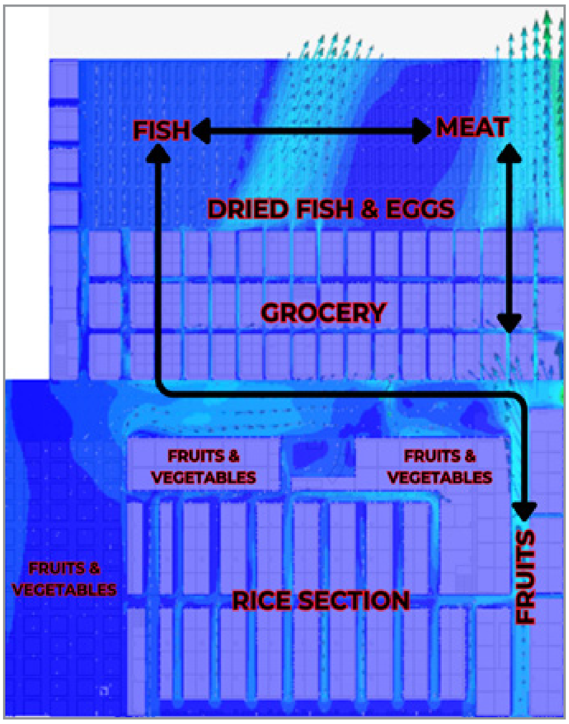


Figure 23: Wind velocity map showing user movement (false - accept null hypothesis)

Thermal Comfort Simulation Through SimScale

Computational Fluid Dynamics (CFD) simulations using SimScale quantified airflow and heat transfer dynamics in the Lipa City Public Market, evaluating thermal comfort during summer and rainy seasons. Parameters included air temperature (TA), wind velocity (VEL), turbulent kinetic energy (TKE), and turbulent thermal diffusivity (TTD), critical for understanding comfort under crowded, semi-enclosed conditions (ANSI/ASHRAE Standard 55, 2023).

Table 14: Summary statistics from SimScale simulation

Statistics	Season	Temperature	Velocity	Turbulent Kinetic Energy	Turbulent Thermal Diffusivity
Maximum	Summer	3.39E+01	1.58E-02	1.43E-02	4.21E-05
	Rainy	2.79E+01	1.04E+00	1.67E-02	1.84E-02
Average	Summer	3.31E+01	3.64E-07	3.92E-04	8.96E-07
	Rainy	3.00E+01	1.50E-01	4.68E-04	1.65E-03
Minimum	Summer	3.24E+01	0.00E+00	3.67E-14	0.00E+00
	Rainy	3.22E+01	0.00E+00	2.64E-14	0.00E+00
Integral	Summer	5.43E+05	8.08E-04	8.72E-01	1.99E-03
	Rainy	6.64E+05	2.07E+02	1.04E+00	5.44E+00
Volumetric Flow Rate	Summer	-	-5.2E-09	-	-
	Rainy	-	3.31E-01	-	-

Temperature

Simulated TA exceeded the ASHRAE 55 (23–27 °C) and Philippine Code of Sanitation (The Code on Sanitation of the Philippines (Presidential Decree No. 856), 1976) (26.7 °C) limits across both seasons, with summer averages at 33.1 °C (min 32.4 °C; max 33.9 °C) and rainy-season averages at 30 °C. Even minimum values surpass comfort thresholds, indicating systemic overheating (Table 15; Figure 24). This aligns with occupant-perceived comfort bands (27–29.5 °C), confirming the need for passive and mechanical cooling strategies.

Table 15: Thermal comfort range based on standards and result

Standards and Results	Temperature Range
ASHRAE 55	23°C - 27°C
Code of Sanitation of the Philippines	26.7°C
Users' Perception	27°C - 29.5°C
Empirical	Summer (22.05-26.51°C), Rainy (25.4-28.91°C)

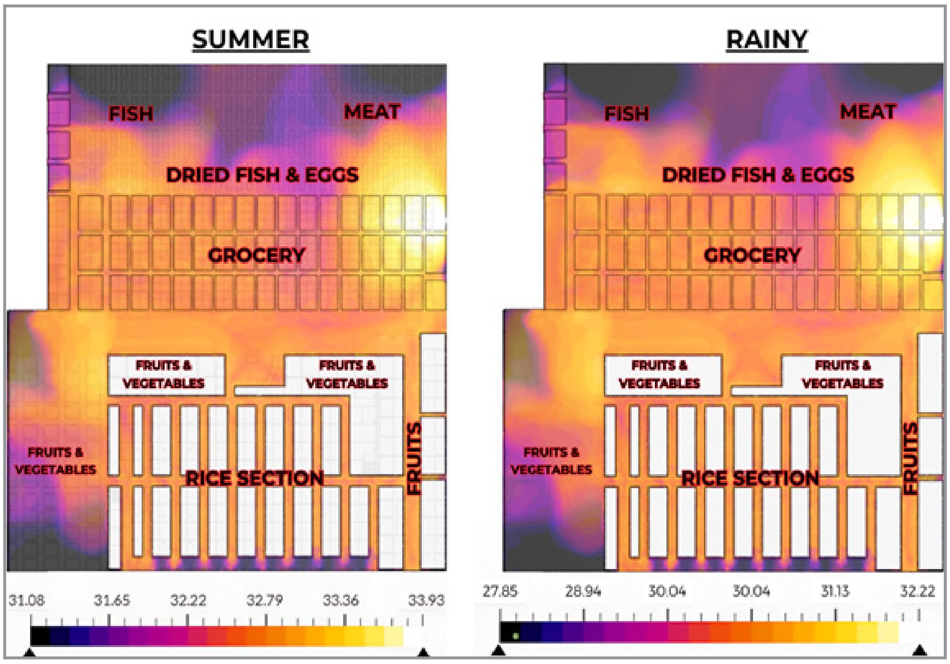


Figure 24: Temperature

Wind Velocity

Recorded VELs were generally below the 0.2–0.5 m/s comfort range for moderately active indoor markets (ASHRAE 55, 2021), with stagnant air zones (0.00 m/s) contributing to localized stratification and heat retention (Figure 25). Such conditions amplify discomfort by limiting convective cooling and exacerbating uneven temperature distribution.

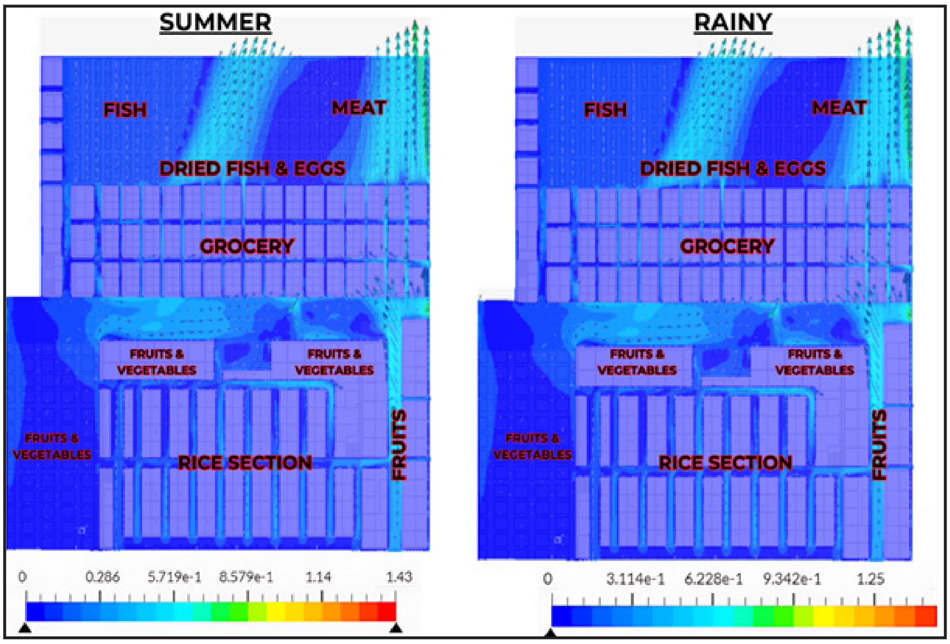


Figure 25: Wind velocity

Turbulent Kinetic Energy

TKE, an indicator of airflow mixing, was highly variable (max 1.43×10^{-2} m²/s² in summer; 1.67×10^{-2} m²/s² in rainy season; Fig. 26). Excessively high TKE indicates chaotic drafts perceived as cold spots, while near-zero TKE signifies stagnant air with inadequate mixing, both detrimental to comfort and air quality.

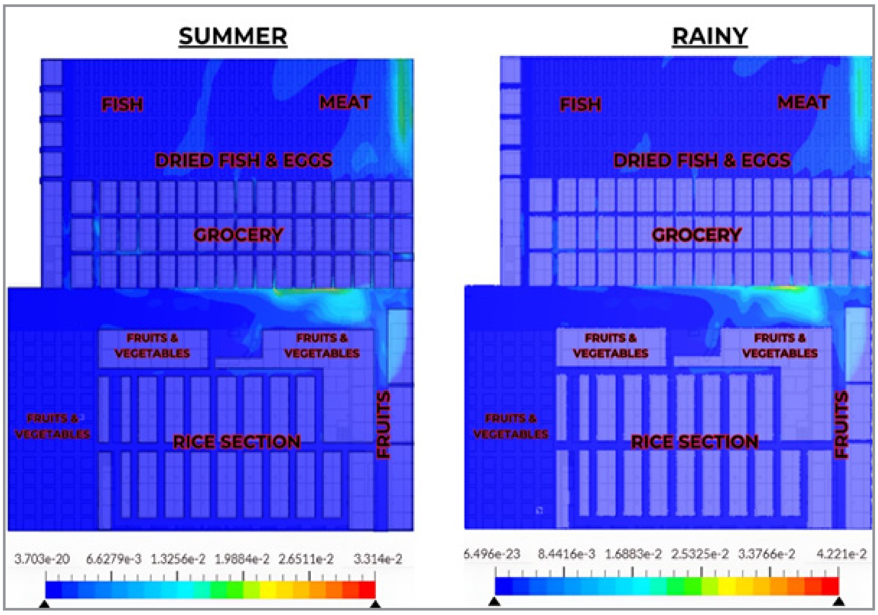


Figure 26: Turbulent kinetic energy

Turbulent Thermal Diffusivity

TTD values were seasonally dependent, reaching 1.84 × 10^{-2} m^2/s in the rainy season versus 4.21 × 10^{-5} m^2/s in summer (Figure 27). Elevated TTD accelerates thermal energy dispersion, causing rapid temperature fluctuations and localized hot/cold zones, while very low values create persistent thermal gradients.

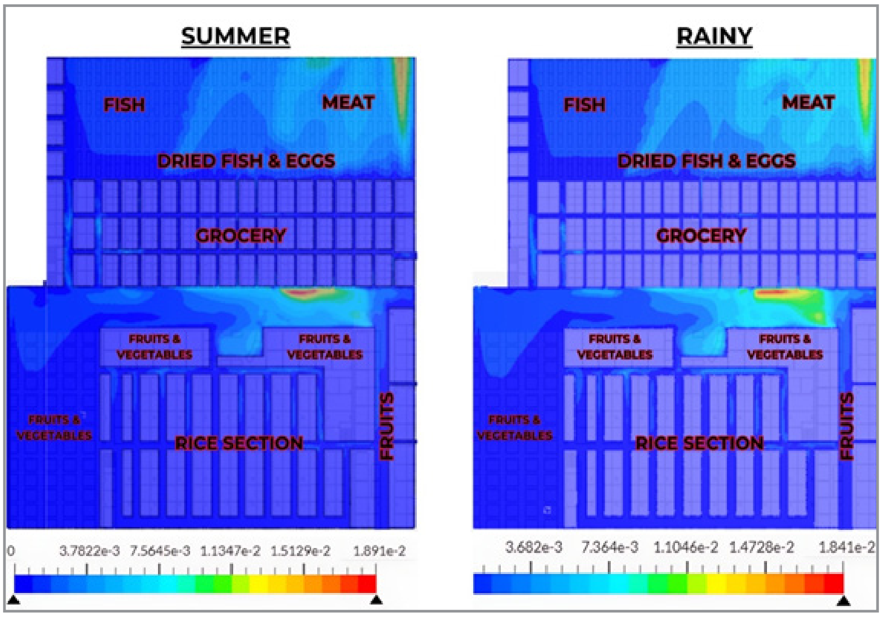


Figure 27: Turbulent thermal diffusivity

Overall, CFD findings reveal persistent overheating, uneven airflow distribution, and inadequate convective cooling. High occupant density, structural heat retention, and poorly ventilated zones intensify discomfort, necessitating interventions such as improved natural ventilation, targeted dehumidification, and adaptive HVAC strategies to achieve compliance with ASHRAE 55 and Philippine standards.

Informed Space Syntax Approach

Space syntax analysis, integrated with CFD-based thermal discomfort mapping, was applied to assess the influence of market layout, airflow patterns, and spatial configuration on comfort within the Lipa City Public Market across summer and rainy seasons [11, 12].

Temperature Distribution and Entry Points

Heat maps reveal that entry points consistently exhibit lower temperatures (31.1 °C in summer, 27.9 °C in the rainy season) due to unobstructed ventilation, providing initial comfort for incoming patrons (Figure 28). In contrast, central zones remain significantly overheated (33.9 °C summer; 32.2 °C rainy) because of restricted airflow, structural obstructions, and intensified body heat loads from congestion. This aligns with ASHRAE 55 (23–27 °C) and Philippine Code of Sanitation (26.7 °C) exceedances noted in CFD simulations, underscoring persistent overheating linked to spatial layout.

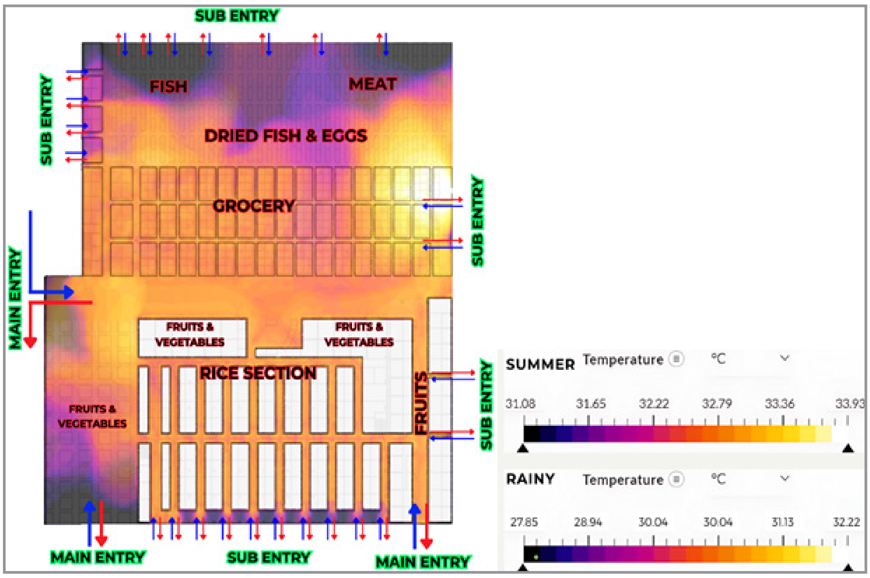


Figure 28: Temperature and entry points

Congestion and Thermal Discomfort Patterns

Thermal discomfort maps (Figure 29) demonstrate consistent heat distribution across seasons, indicating that internal market factors—stall configuration, airflow blockages, and internal heat loads—dominate over external climatic variations. Main hallways and wider corridors, benefiting from greater openness, experience less congestion and improved airflow, whereas confined sections combine high occupant density, limited ventilation, and heat accumulation. Internal heat sources (e.g., cooking stalls and artificial lighting) further intensify localized hotspots. All areas remain outside the recommended thermal comfort zone, reinforcing the need for ventilation-focused interventions

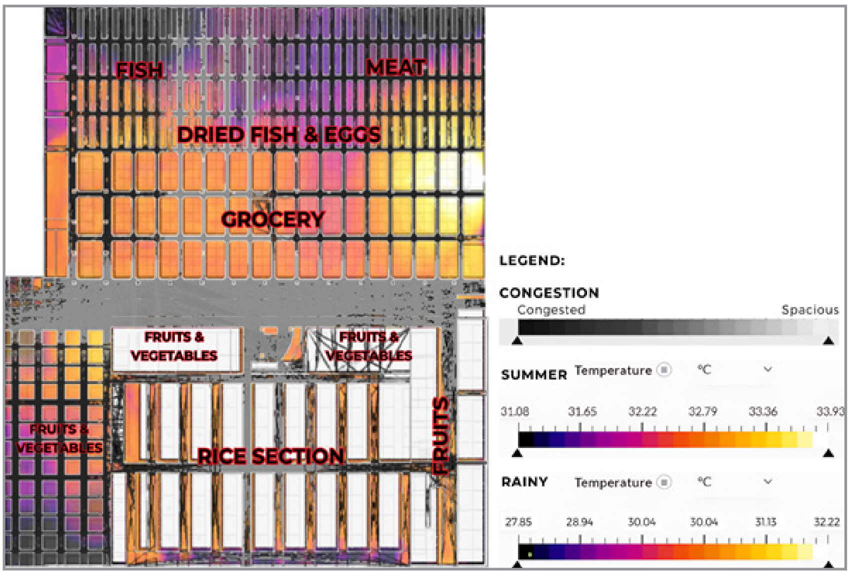


Figure 29: Mapping of congestion and thermal discomfort for both seasons

Wind Velocity–Congestion Correlation

CFD results and agent-based accessibility modeling highlight a positive relationship between wind velocity and spatial accessibility (Figure 30). Areas with unobstructed pathways—such as the Fruits & Vegetables hallways, inter-section corridors, and parts of the Meat Section—exhibit superior airflow, reduced congestion, and greater user preference [12]. Patrons gravitate toward well-ventilated areas, confirming that airflow and spatial connectivity directly shape movement patterns and comfort.

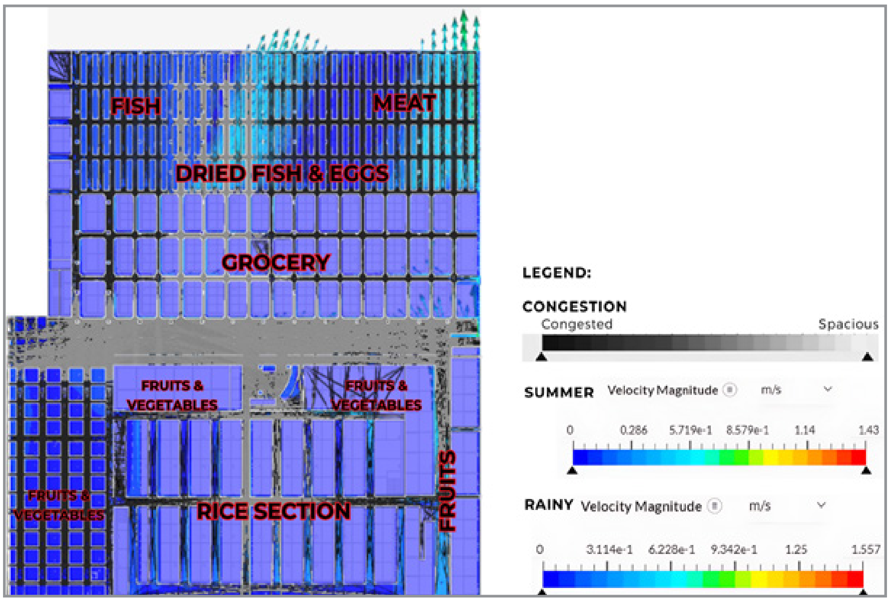


Figure 30: Wind velocity and congestion map

Implications for Design

Findings stress that spatial configuration governs both thermal environment and user flow. Interventions should prioritize open, connected pathways to enhance cross-ventilation, redistribute heat, and relieve congested zones. Strategic stall placement, improved airflow pathways, and management of internal heat sources can mitigate thermal stress, ensuring compliance with comfort standards (ASHRAE 55; Philippine Code of Sanitation). Integrating these spatial and environmental considerations in market redesign offers a pathway toward a thermally efficient and user-friendly environment.

Presentation of Simulations on the Proposed Lipa City Public Market

Computational simulations were conducted to evaluate congestion and thermal comfort performance of the proposed Lipa City Public Market, addressing critical design parameters for spatial efficiency and occupant comfort [13, 14].

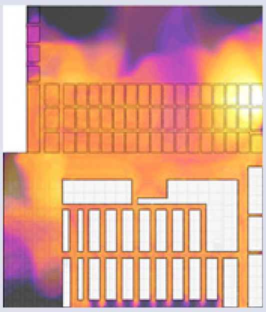
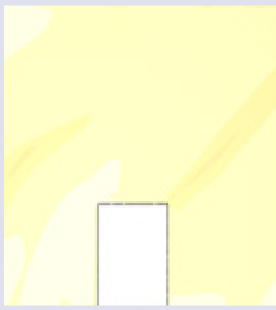
Congestion Simulation: Peak vs. Non-Peak Hours

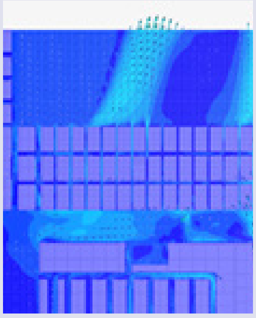
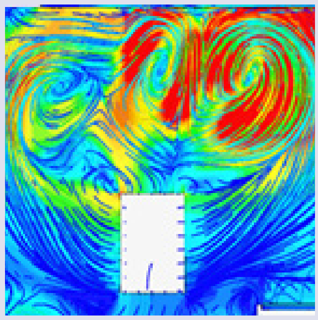
Agent-based simulations examined corridor widths ranging from the existing <1.2 m to 7.2, 10, 12, and 15 m. Results confirm that wider corridors reduce congestion but entail significant stall reduction: −15.4% at 10 m, −21.0% at 12 m, and −32.2% at 15 m. A 7.2 m width optimally balances stall retention (143 stalls) and circulation, eliminating non-peak congestion and limiting peak-hour bottlenecks (8:00 AM and 5:00 PM). Targeted flow management strategies—e.g., staggered vendor schedules and customer routing—are recommended for peak times. Moreover, a 7.2 m corridor offers cost efficiencies, minimizing construction and maintenance overheads while preserving retail density.

Thermal Comfort Simulation: Existing vs. Proposed

SimScale-based CFD simulations compared temperature and air velocity under existing and proposed designs (Table 17).

Table 17: Comparison of Thermal Comfort Parameters (Temperature and Air Velocity) Between Existing and Proposed Plans Using SimScale Simulation

Thermal Comfort Parameters	Existing Plan	Proposed Plan
1. Temperature • Code on Sanitation: 26.7°C • ASHRAE 55: 23°C to 27°C • Empirically for summer: 22.05°C to 26.51°C • Empirically for rainy: 25.4°C to 28.91°C • (SQ) comfort range: 27°C to 29.5°C	 31.08°C – 33.93 °C	 22.5 – 26.5°C

2. Air Velocity • ASHRAE 55 Moderate activity: 0.2 to 0.3 m/s • ASHRAE 55 High activity: 0.3 to 0.5 m/s • Summer Max: 0.0158 m/s • Rainy Max: 1 m/s • Min: 0 m/s (both seasons)	 0 m/s – 0.2 m/s	 0 m/s – 0.5 m/s

a. Temperature: Existing indoor temperatures (31.1–33.9 °C) exceed ASHRAE 55 (23–27 °C) and Philippine Code of Sanitation (26.7 °C) thresholds, with central areas most affected due to restricted ventilation, high occupant density, and obstructed airflow. The proposed design—incorporating an internal courtyard and external pocket plaza—reduces temperatures to 22.5–26.5 °C, fully aligning with comfort standards.
b. Air velocity: Current conditions reveal stagnant air pockets (0 m/s), causing thermal stratification and uneven cooling. Proposed modifications raise velocities up to 0.5 m/s, meeting ASHRAE criteria for moderate activity (0.2–0.3 m/s).

Key Design Interventions Include

a. Internal courtyard acting as a thermal chimney, expelling warm air and enhancing cross-ventilation;
b. Pocket plaza facilitating outdoor–indoor airflow exchange; and
c. Wider hallways reducing airflow resistance in high-traffic areas.

Collectively, these modifications mitigate stagnant air, enhance thermal stability, and ensure compliance with comfort standards, providing a sustainable and user-centered indoor environment. Improved airflow also supports reduced energy loads, aligning with passive cooling strategies advocated for dense public spaces (ANSI/ASHRAE Standard 55, 2023).

Conclusion

This study explored strategies to improve thermal comfort and pedestrian movement in the Lipa City Public Market through an informed space syntax approach, integrating spatial configuration with environmental parameters—air and radiant temperatures, humidity, and wind velocity—across summer and rainy seasons. Results highlight the interplay between internal design, airflow dynamics, and user comfort, with implications for sustainable public market planning.

User Behavior and Perceptions

Surveys reveal that users experience comfort at 27–29.5 °C, exceeding ASHRAE 55 (23–27 °C) and the Philippine Code of Sanitation (26.7 °C) standards. Reported discomfort ("hot" by 178 respondents; "humid" by 199) correlates with measured conditions: indoor humidity (70–90%) surpasses the recommended 60%, and airflow velocities (0.0158 m/s in summer; 1.0 m/s in rainy season) fall below ASHRAE 55 thresholds (0.2–0.5 m/s). Alignment between subjective perceptions and quantitative data underscores the need for targeted thermal interventions.

Space Syntax for Optimization

Space syntax analysis revealed a strong link between spatial configuration, airflow, and comfort. Main hallways and wide corridors maintained better ventilation, while congested sections—Meat and Fish areas—reached extreme temperatures (up to 41.5 °C), exceeding comfort standards. Seasonal variations were minimal, indicating that internal design factors outweigh external climate effects.

Key Findings

• Temperatures regularly exceeded empirical comfort ranges (22.1–26.5 °C summer; 25.4–28.9 °C rainy).
• Airflow velocities were consistently below ASHRAE standards, worsening congestion and discomfort.
• High humidity (>70%) exceeded recommended limits, intensifying thermal stress.
• Improved spatial integration enhances airflow and reduces heat buildup in high-traffic areas.

These results highlight the critical importance of spatial reconfiguration and ventilation strategies over reliance on seasonal adjustments.

Recommendations

Interventions Should Prioritize

1. Enhanced ventilation and spatial redesign to reduce congestion and improve airflow.
2. Management of internal environmental loads, as design factors exert greater influence than external weather.
3. User-informed assessments to address disparities between empirical and standardized comfort ranges.

Future work should incorporate longitudinal studies, IoT-based monitoring, advanced CFD simulations, and comparative analyses across similar markets to refine adaptive, sustainable design solutions. Collaborations with policymakers and community stakeholders are critical for implementation.

Practical adoption of these strategies can transform the market into a thermally comfortable and efficient environment, improving vendor operations and user experience while providing a replicable model for other public markets in comparable tropical settings.

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