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Heat Stress on the Balcony: Investigating the Effects of Facade Heat and External AC Units

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ABSTRACT

Balconies serve as vital semi-outdoor spaces in tropical residential architecture, yet they are often exposed to extreme heat stress that limits their usability. This study investigates the combined impact of facade surface temperature and air conditioning external units on outdoor Thermal Comfort (OTC) on residential balconies in Cau Ong Lanh Ward and Ban Co Ward, Ho Chi Minh City, Vietnam. In-situ climatic measurements were conducted in August, focusing on air temperature, surface temperature of adjacent walls, and radiant heat emissions from active AC outdoor units of 296 houses. Observations were paired with behavioral data indicating residents' willingness to use the balcony under different thermal conditions. Results reveal that balcony environments frequently exceed strong heat stress thresholds during daytime hours, driven by direct solar gain on facades and waste heat from outdoor units. Facade orientation and proximity to mechanical units were found to significantly influence the microclimate at occu-pant level. Most residents avoided using balconies during peak hours, identifying heat from outdoor units as a major discomfort factor. The findings highlight the need to reconsider mechanical unit placement, facade material choices, and shading strategies in balcony design. This study contributes to a growing body of knowledge on climate-responsive residential architecture in tropical regions, emphasizing the integration of mechanical systems and passive design to restore balcony usability and improve occupant well-being.

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Introduction

Heat stress (or thermal stress) is now a routine constraint on everyday life in Ho Chi Minh City (HCMC). Long-term observations show the city's mean Heat Index commonly peaks in April–May and tends to exceed 32 °C—conditions categorized as "extreme caution" for outdoor activity—while yearly averages have risen into the 27–32 °C band over 1990–2023 [1]. According to the National Center for Hydro-Meteorological Forecasting, HCMC registered temperatures soaring above 36 °C recently, the region endured a severe heatwave on March 19 with relative humidity dropped to 55–60%, exacerbating heat stress across southern Vietnam. Furthermore, the area covered by hard construction surfaces in HCMC increased markedly since the late 1980s, along-side documented increases in urban surface temperatures. Within this dense fabric, tube housing is the predominant dwelling form—about 95% of built-up residential land—and is typically a long, narrow plot (≈3–5 m wide, 20–25 m deep) with the main facade aligned to narrow streets or alleys [2,3]. These street-facing frontages are thus the city's principal dwelling–microclimate interface and the place where small architectural choices disproportionately affect thermal exposure and energy demand [2].

In this context, the balcony functions as a critical semi-outdoor buffer, filtering sun, air, and radiant exchange before reaching interiors. Recent HCMC-specific research identifies it as an "intermediate space" central to tube-house performance, with design parameters (depth, orientation, enclosure, solidarity, transparency) shaping shading, airflow, and heat dissipation [4,5]. Broader studies confirm balconies modulate indoor environmental quality and enhance ventilation in low-rise Southeast Asian housing, reinforcing their role beyond mere amenity [6,7]. Yet outdoor thermal comfort on Vietnamese balconies remains fragile: direct solar gains, radiant loads, and weak wind corridors often dominate occupant experience. Field analyses in HCMC show that acceptable OTC requires targeted shading plus strategies that boost evaporative cooling and airflow [2].

A growing concern in HCMC's tube-house frontages is the co-location of outdoor Air-Conditioning (AC) units on balconies, where they release waste heat into spaces intended for respite. Although previous studies have examined the optimal positioning of outdoor units for heat rejection efficiency and airflow dispersion, little attention has been paid to occupants' thermal comfort and perception in these semi-outdoor zones. This study addresses that gap by focusing on two coupled drivers of OTC on balconies—facade surface heat and outdoor AC unit heat rejection. We frame the balcony as both heat-vulnerable and heat-mediating: while orientation, solar exposure, and mate-rial properties elevate surface and radiant temperatures, strategic frontage design (balcony depth, enclosure type, shading devices, and vegetation) can measurably reduce thermal loads [4]. This study therefore examines how façade heat and external AC units jointly shape balcony microclimates in HCMC's tube-house frontages, with the aim of informing the placement of mechanical equipment and the passive design of shading, materials, and greenery to restore balcony usability and well-being

Materials and method

This study adopts a **mixed-method approach** to evaluate **heat stress conditions on balconies**, focusing on the combined effects of facade heat and external Air-Condition-Ing (AC) units. The research integrates literature review, field climatic measurements, and occupant surveys to establish a comprehensive framework for analysis.

Literature Review

Previous research on semi-outdoor spaces and urban heat stress provides essential background for this study. Work on balconies in tropical and subtropical climates [8,9] highlights their role in ventilation and shading but also their vulnerability to solar gain and insufficient protection. Microclimate studies show that facade surfaces can reach 40–50 °C, intensifying discomfort even under moderate ambient conditions [10,11]. In Southeast Asian cities, including Ho Chi Minh City, persistent heat stress is driven by urban heat islands, high humidity, and dense tube-house morphologies [2,5,12,13]. Beyond solar exposure, AC outdoor units (AC-OU) are recognized as significant anthropogenic heat sources, with emissions raising local air temperatures by 2–3 °C in compact or semi-outdoor settings [14-16]. Comparative work in Mediterranean climates further shows how street orientation and canyon geometry influence balcony comfort, with east–west streets producing the highest stress and lower balconies more favorable [17]. Yet, despite their prevalence, the combined effects of façade heat and AC-OU on balcony usability remain underexplored, particularly in tropical dense housing.

In Ho Chi Minh City, where high humidity, direct solar gains, and AC waste heat contribute greatly to balcony conditions, air temperature alone underestimates occupant stress. To align environmental measurements with behavioral responses on balcony us-ability, this study adopts the **Heat Index (HI) with Steadman calculation**. The HI combines air temperature and relative humidity, making it well-suited to humid tropical climates and straightforward for field surveys [1,18,19].

Table 1: Heat Stress Classification [19]

Classification	Heat Index	Effect on the body
Caution	27°C - 32°C	Fatigue possibly due to prolonged exposure and/or physical activity
Extreme Caution	32°C - 41°C	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	41°C - 54°C	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	54°C or higher	Heat stroke highly likely

Data Collection and Analysis

The empirical investigation was conducted in Districts 1 and 3 (now is Cau Ong Lanh Ward and Ban Co Ward) of Ho Chi Minh City. A total of 859 tube houses were screened, and 296 valid household surveys were collected. Data collection took place in August 2024, a period with intense solar gain and widespread AC operation. Two datasets were developed:

Climatic Measurements: air temperature, relative humidity, facade surface temperature, and heat radiation from operating AC-OU, using thermo-hy-grometer (GM-1361), covering from –10°C to 50°C (±1.0°C) for ambient tem-perature, and 0–99.9% (±5%) RH for humidity; and infrared thermography (FLIR One Pro).

Occupant Surveys: capturing balcony use frequency, perceptions of AC-OU heat, satisfaction and usability.

This combined dataset enables both physical measurement of heat stress and subjec-tive assessment of thermal acceptability, ensuring robustness through methodological triangulation. The analytical framework addresses 2 central research questions:

- How much additional heat do AC-OU generate at balcony facades, and does this reduce balcony usability?
- What percentage of shading coverage on the facade results in the highest satisfaction response?

To ensure comparable solar exposure, balconies were grouped by street orientation so that each group shared similar survey times, temperature conditions, and urban context. For the first research question, façade surface temperatures of balconies with and without AC-OU were compared using an independent t-test. Balcony usability, recorded from survey responses, was analyzed with a Chi-square test of independence to determine whether AC-OU presence significantly affected usage. This approach directly links measured thermal differences with behavioral outcomes.

The second question is addressed by developing a shading coverage index (%), defined as the proportion of the balcony's front elevation shaded by physical elements, as shown in Figure 1. This includes the railing, fixed devices (overhangs, louvers), movable devices (awnings), vegetation, and other architectural components that cast shadows on the façade. By quantifying their combined coverage as a percentage of the façade plane, the index allows systematic comparison of different shading configurations and their associated satisfaction levels.

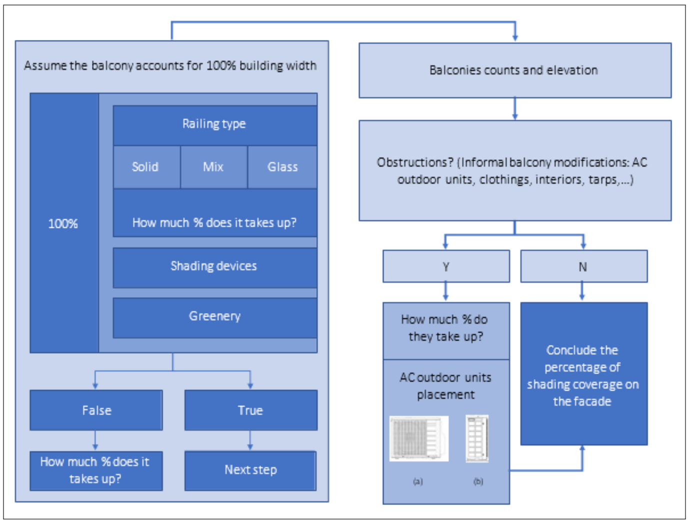
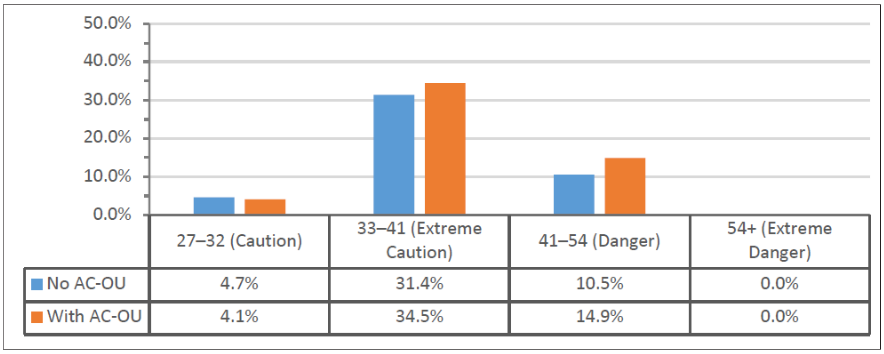


Figure 1: Procedure for Calculating Shading Coverage Index Results

Impact of AC Outdoor Units on Heat Stress and Balcony Usability

As shown in Figure 2, the majority of balconies in the dataset fall within the Extreme Caution range (33–41 °C HI), representing roughly two-thirds of all cases, indicating that substantial thermal stress is common under typical daytime conditions. Approximately one-quarter of balconies experience Danger-level heat (41–54 °C HI), while none exceeded the Extreme Danger threshold (>54 °C HI). This confirms that although heat stress is frequent, it rarely reaches the most severe levels during the study period.



	27–32 (Caution)	33–41 (Extreme Caution)	41–54 (Danger)	54+ (Extreme Danger)
No AC-OU	4.7%	31.4%	10.5%	0.0%
With AC-OU	4.1%	34.5%	14.9%	0.0%

Balconies with and without AC-OU are evenly distributed across heat index categories, showing no clustering in particular ranges. On average, balconies with AC-OU recorded +**0.35 °C** higher facade surface temperatures than those without; this difference is not statistically significant (*independent t-test*, $p = 0.345$). The even distribution is methodologically advantageous, as it allows controlled comparison between the two groups. Despite the small measured heat gap, balconies with AC-OU exhibit significantly lower usability: only ~25% were used compared to 50% of those without; a Chi-square test confirmed this difference ($p = 0.018$, $p < 0.05$). This aligns with occupant reports identifying AC waste heat as a discomfort factor with 23% of the votes.

Effect of Shading Coverage on Balcony Satisfaction and Heat Index

Overall, the data show that balcony satisfaction declines as heat stress intensifies and no balcony is in Extreme Danger level, with fewer residents reporting comfort at higher HI levels (see Figure 3). The relationship is consistent as HI rises from Caution to Danger levels, the proportion of satisfied users decreases while discomfort responses increase, in details:

- 27–32 °C (Caution): 53.8% comfortable, 46.2% not comfortable
- 33–41 °C (Extreme Caution): 44.1% comfortable, 55.9% not comfortable
- 41–54 °C (Danger): 37.3% comfortable, 61.3% not comfortable

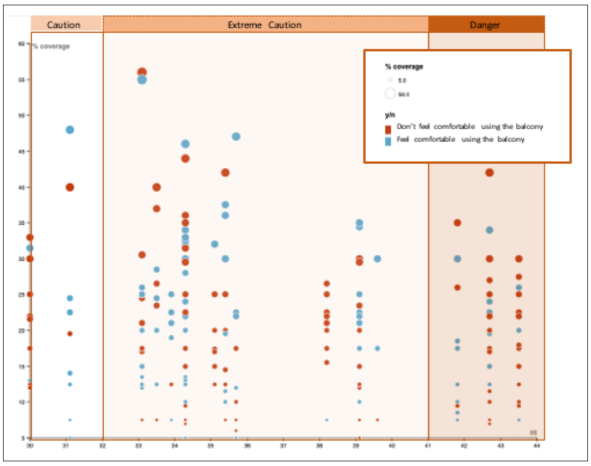


Figure 3: Combined Influence of Shading Coverage and HI on Balcony Comfort

User satisfaction varied noticeably across shading coverage categories. At low coverage (0–25%), only 40.8% of users felt comfortable, highlighting the vulnerability of exposed balconies to heat stress. Satisfaction peaked at 26–50% coverage, where 53.6% reported comfort, suggesting that moderate shading provides the most effective balance between protection and usability. Higher coverage levels (51–75%) produced a 50% comfort rate, but the very small sample size (n=2) prevents meaningful interpretation.

When shading coverage is considered alongside the HI results, the data suggest that balcony satisfaction declines consistently with rising heat stress but can be partially mitigated by moderate shading. At Caution level HI (27–32 °C), over half of users felt comfortable even with low shading, but comfort rates fell sharply as HI entered the Extreme Caution and Danger ranges. This demonstrates that while heat stress is primarily governed by HI, balcony usability can be improved through moderate shading coverage that helps offset heat exposure.

Discussion

The results confirm that design parameters are directly linked to shading coverage, as noted in previous studies on semi-outdoor thermal environments [4,5,7]. Larger balconies produce higher coverage percentages, as increased depth and length extend self-shading from the floor slab and railings. Railing type further modifies this baseline: solid railings (made of concrete or opaque panels) add significant facade coverage, while permeable railings (bars and glass) provide little protection against solar penetration [4]. These differences explain why balconies of similar size can fall into distinct shading categories depending on railing design.

Beyond fixed design parameters, user behavior introduces additional variability. Vegetation, shading fabrics, or stored furniture act as ad-hoc obstructions, raising shading coverage in some cases while simultaneously affecting other aspects of indoor environmental quality such as airflow, daylight access, and visual openness. This aligns with prior findings that balconies function as flexible buffer zones whose performance depends on both architectural design and user adaptation [20].

In this study, satisfaction peaked at 26–50% coverage (~54% comfort), a range often achieved through the combination of moderate balcony size and semi-solid railing designs. By contrast, minimal coverage (0–25%) corresponded to lower comfort rates (40.8%). These findings reinforce that coverage percentage is not an abstract measure but a direct outcome of design and occupant practices, linking architectural parameters and behavioral modifications to thermal usability in dense tropical housing. Within the dataset and scope of this study, the Heat Index reflects environmental conditions and their physical effects on people but does not adequately capture occupants' psychological responses. This limitation arises because HI is typically applied at the country level, for example in classifying regions into heat index "climate zones" [21]. Applying HI at finer spatiotemporal scales and integrating it with additional environmental and social data could provide deeper insights into how heat stress interacts with urban systems and the community within it. Future work should address the balance between environmental vulnerability and human sensation, potentially adopting alternative indices better suited to capturing extreme heat and its impacts within complex adaptive systems.

Conclusion

This study shows that balconies in Ho Chi Minh City frequently experience heat stress at Extreme Caution to Danger levels, limiting their usability. While the measured façade heat difference between balconies with and without AC outdoor units was small (+0.35 °C, $p > 0.3$), their presence significantly reduced balcony use ($p = 0.018$), confirming that perceived waste heat is a key discomfort factor. Shading coverage was also critical, with moderate coverage (26–50%) yielding the highest satisfaction (~54%) compared to only 40.8% at low coverage (0–25%). These results demonstrate that mechanical equipment placement, design parameters (such as railing type, balcony size), and user modifications can directly affect thermal comfort. Integrating passive shading with careful AC unit positioning is therefore essential to restore balcony usability and enhance well-being in dense tropical housing.

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