Let Me Go Semi-Outside: A Human-Centric Comparison of Outdoor Comfort Models in a Hot-Humid Semi-Outdoor Environment During Summer and Mid-Season

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Modern conventions of indoor thermal comfort rely on thermal neutrality, reducing physiological adaptability to different thermal stresses and arguably associated with substantial energy consumption. Critiques often remark that it conflicts with modern sustainability standards. As a response, over the past 20 years, a marked increase in outdoor comfort model development has been observed in European and Asian countries (Zhao et al. 2021). During the Covid-19 quarantines, the results of long-term indoor stasis in 'thermally comfortable' environments have been shown to be detrimental, both through anecdotal social discourse and in the results of peer-reviewed studies (Stock et al. 2022). Evidence also shows the need for properly ventilated sheltered spaces, characteristics of the semi-outdoors, for mental and physiological health (White et al. 2019). Somewhere between the sealed box and an open field lies the semi-outdoor environment, such as balconies, courtyards, and transitional spaces. While several studies have been conducted in hot, humid outdoor environments, there is a lack of research on semi-outdoor spaces, especially in North America.

This study takes an empirical, human-centered approach to the understanding of several outdoor comfort models; PET, OUT_SET*, and UTCI. As part of a larger study to understand the relation between cognition, mood, and comfort in a semi-outdoor space, environmental data have been collected (airspeed, dry bulb temperature, relative humidity, black globe temperature) along with synchronous self-reported comfort surveys while participants are undertaking cognitive tests for approximately 60 minutes. These trials were performed in a semi-outdoor courtyard on a higher education campus between August and November 2024, representing typical summer and mid-season conditions of the local climate (hot and humid, latitude 29o45'). The courtyard has 40-foot-high walls on all sides, a large tree in the center, a mix of hardscape and softscape ground surfaces, and several ground-level openings that force higher air velocity through the space. During the study 55 participants sat for an hour on average, performing a series of computerized tasks, answering a series of surveys, and completing a cognition test. During the surveys, clothing levels were self-reported to properly compute thermal comfort models. Demographic information was collected from participants to determine correlations between age, sex, ethnicity, BMI, place of origin, length of time residing in local climate, and concurrent self-reported comfort levels. Using the ASHRAE 55 7-point Likert scale, subjective thermal and mood questions were asked at the beginning and the end of the 60-minute-long session. Subjective thermal and mood responses provided key data to assess the effectiveness of thermal comfort models in real-world scenarios, and establish correlations between individual microclimatic parameters and thermal comfort specific to semi-outdoor spaces.

Preliminary data indicate that short-term experiences moderately affect thermal comfort reporting in this environment, while long-term climatic-cultural experiences exhibit a strong correlation to coping with computed discomfort as indicated by the responses at the end of the 60-minute study. Gender and BMI will also be compared to reported comfort and individual microclimatic conditions will be assessed as predictors. Air velocity was observed to be the most varying parameter exhibiting a medium correlation to thermal comfort reporting, and mean radiant temperature was the second most critical factor. The results analysis is still ongoing. This research aims to break ground toward further research and discourse that will ultimately result in making the adaptive benefits of semi-outdoor spaces the standard in building design and public space development.

Keywords: outdoor thermal comfort, semi-outdoor spaces, field data collection, subtropical climate

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We study **semi-outdoor** spaces to bridge the gap between energy-intensive indoor environments and the variability of outdoor conditions, leveraging their potential to enhance **thermal adaptability**, reduce **energy consumption**, and support physiological and psychological **well-being** in a changing climate.

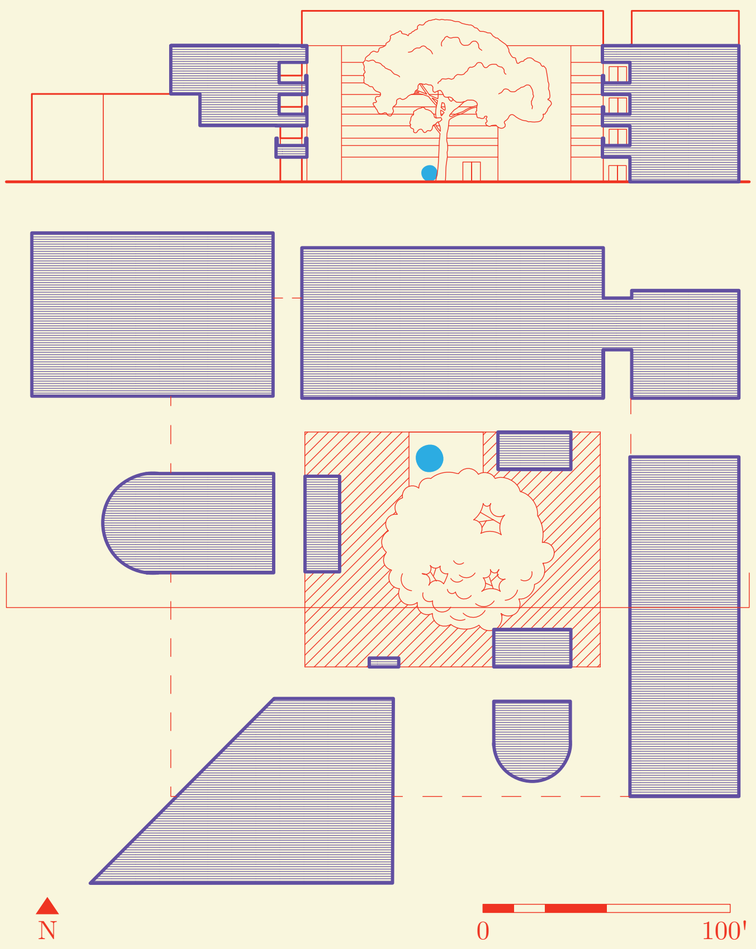

figure 1: case study building floor plan and section

Background

This study builds on increasing evidence that traditional thermal comfort models overlook the adaptive, psychological, and **health-related benefits of semi-outdoor environments**. It aims to fill critical gaps in research on climate- and activity-specific comfort by studying occupants in hot, humid **American contexts** using contextually appropriate thermal indices in comparison with occupants' percieved sensation.

Methodology

This study, conducted in a semi-enclosed courtyard in **Houston, TX** (figure 1), investigated thermal comfort responses of 67 seated participants engaged in computer-based tasks, combining detailed **environmental monitoring** with self-reported comfort data to evaluate the suitability of **thermal indices** (PETCat and PETCatH) for semi-outdoor spaces in a humid subtropical climate over a time span of 45 minutes on average.

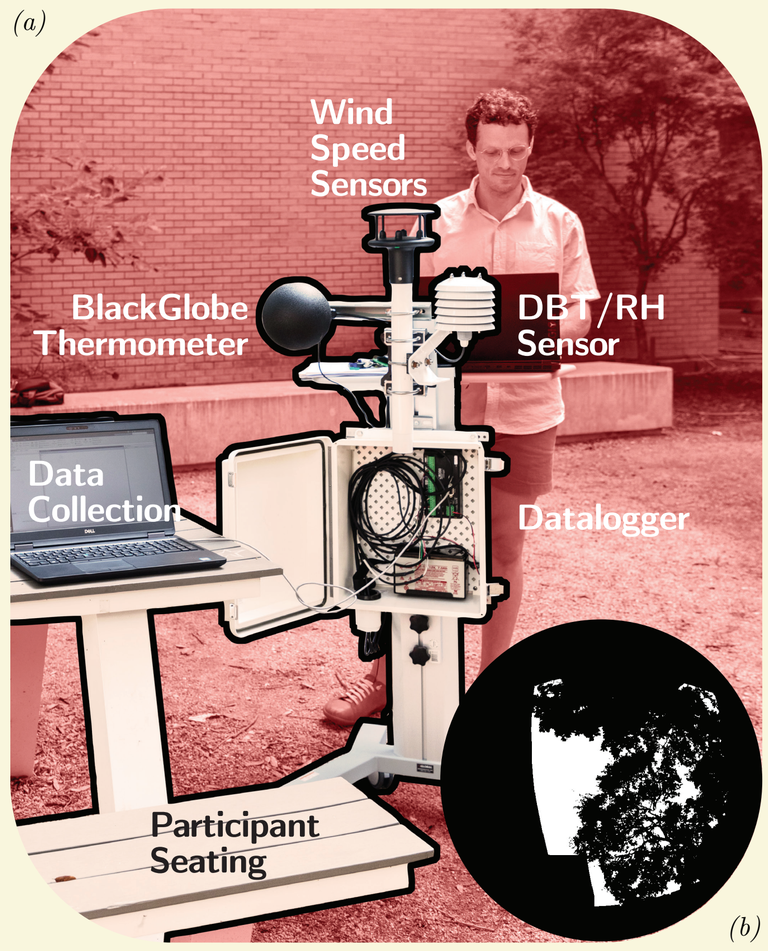

figure 2: (a) testing setup and equipment used and (b) SVF (0.25) of courtyard taken with an 8mm lens camera

Results

- Despite low WS, air movement strongly correlates with thermal sensation, mitigating discomfort from high temperatures—highlighting its importance in semi-outdoor spaces.
- Over time, more participants expressed a preference for "no change" in their thermal environment, particularly those feeling "slightly warm." (figure 3)
- The mean participants TSV shifted warmer after the 45 minute session. (figure 4a)
- PET (C°) was similar pre- and post- session with a mean 1.8 C° warmer attributed to higher MRT temperatures. (figure 4b)
- PETCat (PET categorization based off of PET(C°)for typical environment[1]) was a better predictor of comfort than PETCatH (PET categorization based off of PET(C°)for humid environments[2]). (figure 5)
- Many participants preferred warmer or cooler conditions although reporting feeling neutral.

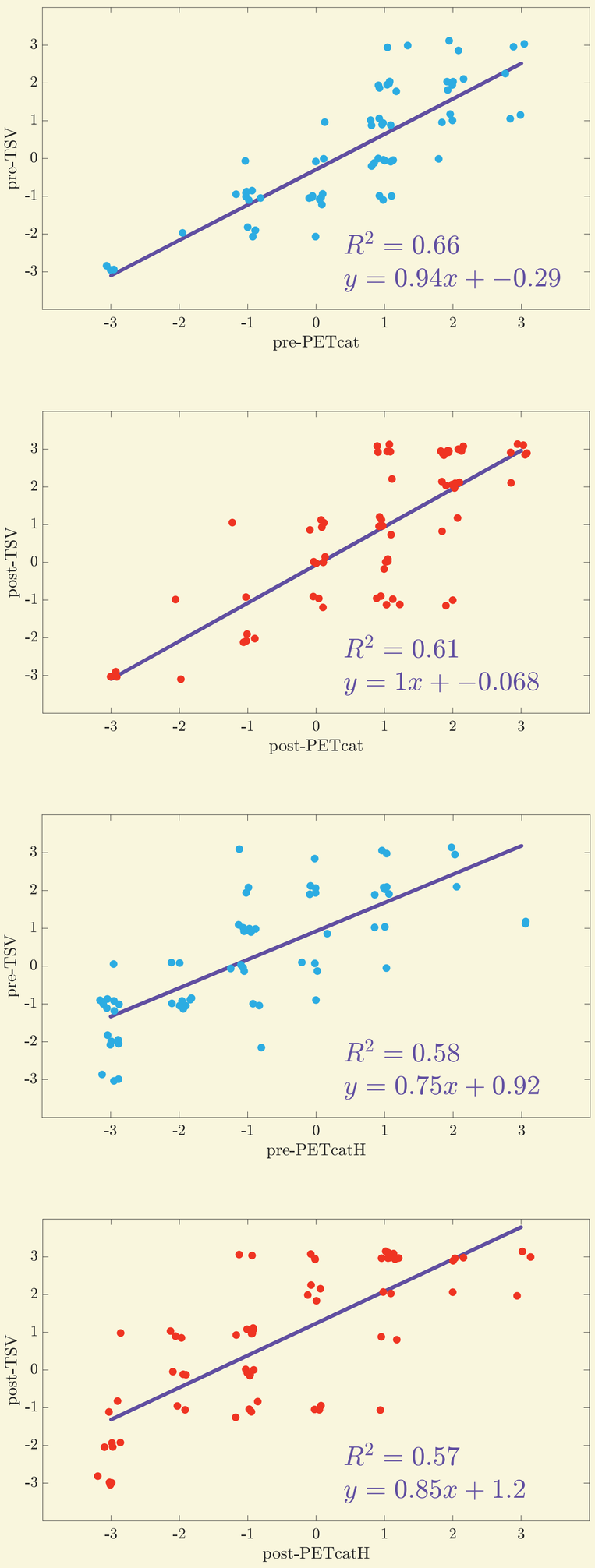

figure 5: Thermal Sensation Votes correlated with calculated PETCat and PETCatH for a typical and humid environment.

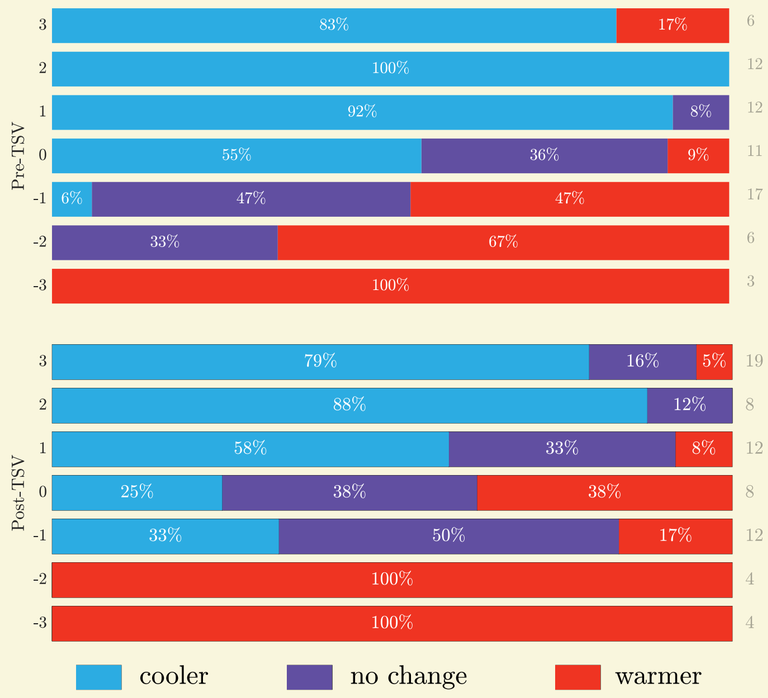

figure 3: Pre- and post-Thermal Sensation Votes (TSV) compared with pre- and post- Thermal Preference Votes (TPV).

figure 4: Paired samples T-test for (a) Pre- and post-Thermal Sensation Votes and (b) Pre- and post-PET (C°)

Conclusions

- Design strategies that enhance airflow—through open configurations, massing, or low-energy solutions like fans—are recommended.
- Despite Houston's hot-humid climate, widespread air conditioning affects outdoor comfort expectations.
- The TSV–TPV comparison reveals that the commonly used as comfortable feelings, "neutral," "slightly cool," and "slightly warm" categories may not accurately reflect comfort

This study demonstrates that semi-outdoor environments in hot-humid North American climates not only support **short-term thermal acclimatization** but also offer a compelling alternative to fully sealed buildings, **fostering thermal resilience** through controlled exposure to environmental variability.

References and Acknowledgements

The authors would like to thank undergraduate students Deyala Abousaad and Jennifer N Hernandez Quinones for assisting with data collection. They also thank the UH small grant and the UH small equipment grant for funding the project.

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