DESIGNING FOR COMFORT

A COMPUTATIONAL DESIGN FRAMEWORK

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ABSTRACT

This research explores how computational design can improve thermal comfort in buildings in the tropics. A framework of design principles was developed by analyzing existing literature, climate data, and simulation tools. Results show that simulations can guide early design decisions that reduce energy use and enhance thermal comfort without relying solely on air conditioning. The framework demonstrates how computational tools can turn climate data into practical, measurable design solutions. While tailored to Malaysia, the method offers transferable strategies for similar climates and supports more climate-responsive, energy-efficient architecture.

***KEYWORDS*:** *Computational Design, Climate-Responsive Architecture, Tropics, Malaysia*

I. INTRODUCTION

Modern residential buildings often prioritize aesthetics and function over responding to local climate conditions or energy conservation. As a result, many new buildings struggle with providing thermal comfort and rely heavily on mechanical ventilation and air conditioning, which significantly increases energy use. This growing dependency on cooling systems is expected to continue, with air conditioning alone projected to contribute to a 30% rise in global electricity demand by 2050 (Izzati et al., 2022).

Computational design offers a practical way to tackle these challenges by designing buildings that are adapted to their environment. It serves as a powerful tool for architects to test and refine their ideas using real data. Rather than solving the challenges directly, it helps evaluate and optimize both passive and active strategies, like natural ventilation, shading, and material choices, that can improve comfort and energy efficiency. This process allows for smarter design decisions that respond to the environment, reducing the need for mechanical cooling while creating homes that feel good to live in.

Knowledge Gap & Research Justification

While passive strategies and computational tools exist, their integration into architecture in tropical regions remains limited. There is a lack of accessible frameworks for how computational design can be applied early in the design process to produce measurable improvements in thermal comfort and energy use.

Thematic Research Objective

This thematic research focuses on how computational design methods can be applied to evaluate and enhance thermal comfort passively in buildings within Malaysia's tropical climate. Thermal comfort in this research is defined by a person's satisfaction with the indoor temperature, humidity, and airflow. All of which are critical factors in a hot and humid environment. However, current building practices in Malaysia often overlook climate-responsive strategies, leading to homes that are highly dependent on air conditioning, which increases energy use and does not always result in comfort.

To address this, the research investigates how computational tools can support early-stage design decisions that improve thermal comfort performance. The study explores how passive variables (such as orientation, facade design, or materiality) have an impact on thermal performance and how these can be optimized using simulation tools.

Thematic Research Question

How can computational design methods be systematically applied to evaluate and optimize passive strategies for thermal comfort of buildings in the tropics?

II. METHOD

This research begins with a review of existing literature on thermal comfort and computational design methods. Many past studies tend to zoom in on just one aspect, like ventilation, building orientation, or shading, without exploring how these elements interact with one another. This project aims to take a more holistic approach, looking at how multiple factors work together and how they can be optimized as a system rather than in isolation.

From there, the research identifies key design features based on insights from the literature and computational tools (see paragraph III). These features are categorized across three scales: macro (urban context), meso (building form), and micro (material and detail). For each, performance targets are set, drawing from Malaysian building standards, regulations, and academic studies, distinguishing between residential and commercial needs. These features are then translated into clear design principles, forming a structured framework that ties computational analysis to real-world design decisions. The goal is to create a practical framework that supports thermal comfort and in turn energy-efficiency.

It is important to note that in this research the decision is made to work with a static thermal comfort model. While many studies explore adaptive models, which take into account how people adjust their behavior, clothing, or environment to stay comfortable, this project focuses on fixed indoor temperature standards In other words, it assumes that comfort is achieved through mechanical systems like air conditioning, rather than personal adaptations (Saifudeen & Mani, 2024).

This framework will be tested in the design phase of the graduation project, a high-rise residential building in Kuala Lumpur. Simulations and performance analysis will be used to evaluate how well the approach works in practice. Beyond guiding this specific design, the aim is to develop a workflow that other architects and designers can adapt for similar climates and contexts.

In the end, this research hopes to bridge the gap between theory and practice, translating climate data and technical insights into design strategies that truly enhance how people live in Malaysia's urban housing environments.

III. COMPUTATIONAL DESIGN IN THE TROPICS

Kuala Lumpur's hot and humid climate is a constant in everyday life. With high temperatures, heavy rainfall, and minimal wind throughout the year, the city presents unique challenges when it comes to creating comfortable indoor environments (Hassan, 2001). Thermal comfort is central to this research and often defined as the feeling of being satisfied with the temperature around you and is influenced not just by weather conditions, but also by how buildings are designed and how people interact with their spaces (Frontczak & Wargocki, 2011). In climates like Kuala Lumpur's, energy use in buildings is often driven by how well we design for comfort. Factors such as the shape of a building, how air moves through it, the use of air conditioning, and even how people behave inside play a big role (Elshafei et al., 2021). This is where computational design becomes especially powerful. Rather than relying on trial and error, computational tools let us simulate how different design choices will perform in real weather conditions. They help us test ideas, make adjustments, and find solutions that are not just efficient, but tailored to the specific climate and needs of the people who live there (Maksoud et al., 2024). There are different types of computational design, but this research uses a *performative design approach*, which focuses on how buildings actually perform in real environmental conditions. With the help of computational tools, we can simulate and test design decisions early in the process, making the building more responsive to factors like heat, sunlight, and airflow (Novatr, 2023). While adaptive comfort models take into account how people adjust their behavior (Saifudeen & Mani, 2024), this research deliberately leaves those human adaptations out.

To guide climate-responsive design decisions, a set of target performance metrics has been developed with a specific focus on the tropical context (see Table 1). In tropical cities, the built environment tends to trap and radiate heat, making urban areas significantly warmer than their rural surroundings. This phenomenon, known as the Urban Heat Island (UHI) effect, makes it harder to keep buildings cool and reduces comfort for people both indoors and outside. Reducing UHI is especially important in the tropics, where high temperatures and humidity are already a challenge. Research by Elsayed (2012) and Harun et al. (2020) shows that building materials, surface colors, lack of vegetation, and dense layouts all contribute to this added heat.

However, to understand the effect it has on the person, we have to look beyond just the temperature. In many cases the Universal Thermal Climate Index (UTCI) is a measure used to estimate the outdoor thermal comfort. It combines air temperature, mean radiant temperature, relative humidity and wind speed into a single value that reflects how hot or cold a person actually feels (Gong, Huang, Huang, & Wang, 2023). This is especially relevant in tropical cities like Kuala Lumpur, where high humidity and solar exposure make outdoor conditions feel much warmer than the temperature alone suggests.

The reason windspeed is also used as a variable is because the combination of high humidity and intense solar radiation means that even moderate airflow can make a noticeable difference in how comfortable a space feels. When air remains stagnant, heat and moisture accumulate, leading to discomfort, especially at the pedestrian level. Research by Zhou et al. (2023) indicates that increasing air speed can alleviate thermal discomfort in hot-humid climates. Their study found that mean skin temperatures decreased by 0.2°C to 0.6°C for every 1 m/s increase in air speed. A widely used simulate and enhance airflow is by using Computational Fluid Dynamics (CFD) analysis which helps to visualize airflow patterns to assess natural ventilation strategies and identify areas with low air movement and overheating (Rodrigues Marques Sakiyama, Frick, Bejat, & Garrecht, 2021).

When it comes to indoor thermal comfort the Predicted Mean Vote (PMV) index offers a scientifically validated way to predict how comfortable people feel in a space. It takes into account not just temperature but also humidity, airflow, clothing, activity levels, and radiant heat (Kim, Lim, Cho, & Yun, 2015) . In a tropical climate, PMV is essential because conventional temperature readings alone don't reflect actual comfort.

Designing for better thermal performance through passive strategies helps reduce the total energy needed for cooling in buildings. An overview of the metrics and targets are found in Table 1. These metrics guide the architect in making climate-responsive architecture in tropical climates such as Kuala Lumpur. Rather than relying on mechanical systems alone, they support an approach that prioritizes passive strategies and environmental integration, essential for sustainable buildings in the tropics.

This research then translates the performance metrics into a framework of design principles, guiding decisions from large-scale urban planning to the smallest architectural details. At each stage, macro, meso, and micro, specific tools and simulations support the evaluation of climate performance. Paragraph IV outlines the framework across these three design scales.

IV. RESULTS

Table 1. Target metrics for Kuala Lumpur, Malaysia

Nr	Metric	Target for Residential, KL Malaysia	Target for Commercial, KL Malaysia	Reference
1	**Urban Heat Island (UHI) Reduction**	1 - 2°C reduction compared to surrounding urban areas	1 - 2°C reduction compared to surrounding urban areas	Elsayed, I. S. (2012). A study on the urban heat island of the city of Kuala Lumpur, Malaysia. Journal of King Abdulaziz University, 23(2), 121. and Harun, Z., Reda, E., Abdulrazzaq, A., Abbas, A. A., Yusup, Y., & Zaki, S. A. (2020). Urban heat island in the modern tropical Kuala Lumpur: Comparative weight of the different parameters. Alexandria Engineering Journal, 59(6), 4475-4489.
2	**Universal Thermal Climate Index (UTCI)**	26 - 32°C (outdoor spaces) (Comfortable to Moderate Heat Stress)	26 - 32°C (outdoor spaces) (Comfortable to Moderate Heat Stress)	Błażejczyk, K., Kuchcik, M., Błażejczyk, A., Milewski, P., & Szmyd, J. (2014). Assessment of urban thermal stress by UTCI–experimental and modelling studies: an example from Poland. DIE ERDE–Journal of the Geographical Society of Berlin, 145(1-2), 16-33.
3	**Wind Speed Pedestrian Level**	≥1.5 m/s at pedestrian level, 50% of time	≥1.5 m/s at pedestrian level, 50% of time	Du, Y., & Mak, C. M. (2018). Improving pedestrian level low wind velocity environment in high-density cities: A general framework and case study. Sustainable cities and society, 42, 314-324.
4	**Relative Humidity Reduction**	50-70% indoor RH	55 - 70% indoor RH	MS 1525:2007 (Commercial), MS 2680:2017 (Residential)
5	**Solar Radiation Exposure Reduction**	~1,500–1,600 kWh/m^2/year	~1,500–1,600 kWh/m^2/year	Qahtan, A. M. (2019). Thermal performance of a double-skin façade exposed to direct solar radiation in the tropical climate of Malaysia: A case study. Case Studies in Thermal Engineering, 14, 100419.
6	**Air Changes per Hour (ACH)**	≥ 6 ACH in naturally ventilated areas	≥ 6 ACH in naturally ventilated areas	MS 1525, ASHRAE Standard 62.1 (2019)
7	**Surface Temperature Reduction**	≥ 3°C reduction compared to standard façades	≥ 3°C reduction compared to standard façades	Santamouris, M. (2012). Advances in Building Energy Research: Volume 1 (Vol. 3). Earthscan.
8	**CFD Airflow Performance (Velocity)**	0.5 - 2.0 m/s (optimal natural ventilation range)	0.5 - 2.0 m/s (optimal natural ventilation range)	Aynsley, R., & Shiel, J. J. (2017). Ventilation strategies for a warming world. Architectural Science Review, 60(3), 249-254.
9	**Energy Use Intensity (EUI)**	≤120 kWh/m^2/year	≤100 kWh/m^2/year	MS 1525 (Commercial), MS 2680 (Residential)

10	**PMV (Predicted Mean Vote)**	-0.5 to +0.5 (Neutral thermal sensation)	-0.5 to +0.5 (Neutral thermal sensation)	Fanger, P. O. (1970). Thermal comfort: Analysis and applications in environmental engineering. Copenhagen: Danish Technical Press.
11	**Airflow Distribution Uniformity**	Uniformity ≥ 75% across ventilation paths	Uniformity ≥ 75% across ventilation paths	Awbi, H. B. (2003). Ventilation of buildings (2nd ed.). London: Spon Press.
12	**Facade U-value**	≤ 1.8 W/m^{2}K for opaque, ≤ 3.0 W/m^{2}K for glazing	≤ 1.8 W/m^{2}K for opaque, ≤ 3.0 W/m^{2}K for glazing	MS 1525 (Commercial), MS 2680 (Residential)
13	**Reduction in Direct Solar Radiation**	≥ 25% compared to baseline conditions	≥ 25% compared to baseline conditions	Littlefair, P. (1998). Solar shading of buildings. Garston: Building Research Establishment (BRE).
14	**Daylight Factor Indoor**	2% - 5%	2% - 5%	MS 1525 (Commercial), MS 2680 (Residential)
15	**Recommended dry bulb temperature indoor**	24°C	23°C – 26°C	Malaysian Standard MS 1525:2007 (commercial), MS 2680:2017 (Residential)
16	**Recommended relative humidity (RH) indoor**	50-70% indoor RH (55% recommended)	55% – 70%	Malaysian Standard MS 1525:2007 (commercial), MS 2680:2017 (residential)
17	**Recommended air movement indoor**	not specified; can use 0.15 m/s to 0.5 m/s	0.15 m/s to 0.5 m/s	Malaysian Standard MS 1525:2007
18	**Minimum dry bulb temperature indoor**	24°C	22°C	Malaysian Standard MS 1525:2007 (commercial), MS 2680:2017 (residential)
19	**Minimum air movement indoor**	not specified; use 0.7 m/s	0.7 m/s	Malaysian Standard MS 1525:2007

MACRO-SCALE

PHASE 1: URBAN THERMAL COMFORT

1. **Site Planning**

   Position buildings to facilitate airflow through the site, reduce heat islands, and provide shaded, comfortable communal outdoor spaces.

   Verification Metric: [8] Wind comfort (CFD analysis), [2] outdoor thermal comfort indices (UTCI).

2. **Urban Heat Island Mitigation**

   Design masses with *reflective surfaces, integrated green roofs and extensive vegetation to reduce urban heat buildup.*

   Verification Metric: [1] Urban Heat Island intensity reduction (°C).

3. **Microclimate Analysis**

   Orient building strategically, integrating landscape elements to channel tropical breezes, shade public spaces, and manage humidity effectively.

Verification Metric: [2] Outdoor Thermal Comfort (UTCI) , [4] Relative humidity reduction (%).

MESO-SCALE

PHASE 2: FORM DEVELOPMENT

4. **Building Density and Form Variations**

   Develop stepped, tapering, or clustered massing forms to facilitate airflow, minimize shading impact on adjacent structures, and enhance daylight penetration.

   Verification Metric: [3] Wind speed pedestrian level (m/s), [14] Daylight Factor (%).

5. **Form Optimization**

   Optimize building forms using computational methods to improve aerodynamic performance, reduce solar heat loads, and enhance natural ventilation.

   Verification Metric: [8] CFD airflow performance (m/s), [13] solar radiation reduction (kWh/m²/year).

PHASE 3: ORIENTATION AND BUILDING DESIGN

6. **Sunlight / Radiation / Shadow Analysis**

   Refine design through sunlight, radiation, and shadow analyses to enhance indoor comfort and minimize solar heat gain.

   Verification Metric: [5] Reduction in direct solar radiation (kWh/m²/year).

7. **Environmental Feedback (Radiation, Comfort)**

   Shape and articulate facades based on radiation simulations to optimize shading, balcony placement, and glazing for maximum comfort in tropical sunlight.

   Verification Metric: [5] Facade solar radiation exposure reduction (kWh/m²/year).

8. **Passive Strategy Evaluation**

   Implement passive cooling strategies such as stack ventilation cores and cross-ventilated floors to naturally moderate indoor temperatures.

   Verification Metric: [15] Indoor operative temperature (°C), [6] air changes per hour (ACH).

MICRO-SCALE

PHASE 4: MATERIAL SELECTION

9. **Thermal Analysis of Façade Materials**

   Evaluate and specify facade materials with low heat absorption, high reflectance, and low conductivity to minimize thermal loads.

   Verification Metric: [7] Surface temperature (°C), [12] U-value (W/m²K).

10. **Optimization of Materials**

    Use optimization algorithms to select the most effective tropical building materials, balancing thermal performance, cost, and sustainability.

    Verification Metric: [12] Thermal resistance (U-value).

11. **Building Energy Modeling**

    Perform simulations to identify optimal insulation, glazing ratios, and cooling system efficiencies, specifically addressing high cooling demands in the tropics.

    Verification Metric: [9] Energy use intensity (kWh/m²/year),

12. **Passive Cooling Strategy Simulation**

    Assess the effectiveness of rooftop gardens, water features, shading devices, and evaporative cooling systems to reduce overall cooling demands.

    Verification Metric: [7] Indoor temperature reduction (°C)

PHASE 5: INDOOR THERMAL COMFORT

13. **Operative Temperature Calculations**

    Determine operative temperatures throughout the building, particularly in naturally ventilated or transitional spaces, to fine-tune passive and active cooling strategies.

    Verification Metric: [15] Indoor operative temperature compliance (°C).

14. **Thermal Comfort Simulation**

    Use PMV index compliance to inform interior layouts, air conditioning zoning, and air distribution strategies, ensuring vertical thermal comfort distribution in high-rise towers.

    Verification Metric: [10] PMV index compliance.

15. **CFD Airflow Simulation**

    Use CFD tools to analyze airflow through atriums, corridors, and residential units, optimizing natural ventilation pathways in tropical climates.

    Verification Metric: [8] Air velocity (m/s), [11] airflow distribution uniformity.

V. CONCLUSION

This research explored how computational design can improve thermal comfort in tropical buildings. By combining climate data, simulation tools, and clear performance metrics, a step-by-step framework was created that helps architects make better design decisions, from an urban scale to building scale, reflecting both indoor and outdoor thermal comfort.

The results show that decisions made early in the design process have a big impact on comfort and energy use. Using computational tools gives designers the ability to test ideas before anything is built, helping them move from guesswork to data-driven design. A key takeaway is that combining strategies, like shading, ventilation, and material choices, works better than applying them in isolation.

This limitation of the research is that it assumes a static comfort model, which doesn’t reflect how people naturally adapt to the building in real life. Also, because the results are based on simulations and not yet tested in built projects, real-world performance may vary.

Although the framework is tailored for Malaysia, it can be adapted to other tropical cities with similar climates. However, it may be less relevant in places with cooler seasons or more variable weather.

Compared to previous studies that focus on just one factor, this research offers a more complete approach by tying simulation results directly to design decisions. Going forward, future studies could build on this by including real user behavior, testing in actual buildings, or exploring automation and AI for decision-making and optimization.

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