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EXPLORING THE POTENTIAL OF VEGETATION STRUCTURES (VS) AND LANDSCAPE ORIENTATION IN MINIMIZING THERMAL PERFORMANCE IN A TROPICAL CLIMATE: A FIELDWORK STUDY

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Abstract:

The study investigates the impact of vegetation structure within two landscape orientations on thermal performance, a critical consideration in urban planning and environmental management. Given the increasing concerns about Urban Heat Islands and global warming, understanding how vegetation influences thermal regulation is essential. This research employed a quantitative method through field measurement studies, focusing on two single-storey semi-detached houses namely East Landscape Orientation (ELO) and West Landscape Orientation (WLO) located at Seri Iskandar, Perak Malaysia. The snowball technique was utilized to select the case study houses, ensuring a targeted approach to understanding the effects. Thermal Microclimate Data Logger and Indoor Air Quality Monitor Data Logger were used to measure environmental parameters for thermal conditions, ensuring consistent, reliable, and comprehensive data for analyzing thermal performance in both outdoor and indoor environments. The research findings reveal that the orientation of a house relative to the sun's path significantly impacts its thermal dynamics, with vegetation playing a crucial role in moderating these effects. ELO houses benefit from milder morning sunlight and effective afternoon cooling, while WLO houses experience higher outdoor and indoor temperatures due to intense sunlight and less efficient transpiration by vegetation. Vegetation on the west side provides shade and reduces heat absorption, improving comfort and energy efficiency. Understanding these dynamics can help homeowners and architects make informed decisions about landscape design, enhancing thermal comfort and energy efficiency in homes. This research also contributes to the

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expanding knowledge base on sustainable urban design by exploring the use of vegetation to enhance thermal performance.

Keywords:

Vegetation Structure, Landscape Orientation, Thermal Performance

Introduction

The majority of the world's population now resides in urban areas, and this tendency is expected to continue, especially in developing countries (United Nations., 2008). Urbanization has a substantial impact on diversity, ecosystem functioning, local and regional climate, and quality of life. An unanticipated ecological consequence of urbanization is the Urban Heat Island phenomenon, which causes cities to have higher temperatures compared to their suburban and rural environs (Li et al., 2011). Urban temperatures are expected to rise by an additional 2°C by the year 2050. Currently, 60% of the worldwide urban population is experiencing double the average rate of warming (Johnston, 2017). Therefore, it is crucial to address and reduce the impacts of Urban Heat Island (UHI) in order to advance urban sustainability, especially in the context of climate change (Kotharkar et al., 2018).

Urban Heat Islands refer to the observed phenomenon where urban areas experience significantly higher temperatures than their rural counterparts due to human activities and urbanization (Al horr et al., 2016). The urban heat island (UHI) effect is an inadvertent ecological outcome of urbanization, resulting in cities being warmer than the surrounding suburban and rural areas (Li et al., 2011). Antoniadis (2018), provides a foundational understanding of UHIs, attributing them to factors such as reduced vegetation, the absorption and re-radiation of solar energy by urban materials, and anthropogenic heat release. Research by Hirano & Fujita (2012), further quantifies the impact of UHIs on energy consumption, thermal comfort, and even mortality rates during heatwaves, underscoring the urgency of addressing UHI effects in urban planning and design.

Growing concerns about Urban Heat Islands (UHIs) and climate change have highlighted the need to integrate effective cooling strategies into urban planning and design. Among these strategies, vegetative cooling stands out as a sustainable approach to alleviating thermal discomfort in urban areas. Fu et al., (2022), asserted that vegetation serves as an inherent means of cooling urban areas. Generally, an increased presence of vegetation in urban areas leads to a more pronounced cooling impact. This article, entitled "exploring the potential of Vegetation Structures (VS) and landscape orientation in minimizing thermal performance in a tropical climate: a fieldwork study" aims to examine how different vegetation structures and their orientations in urban landscapes help improve thermal performance. This study is based on the hypothesis that strategic placement of vegetation and orientation of the landscape can significantly reduce local temperatures, providing a natural cooling effect in urban areas. By focusing on the thermal benefits of vegetation, this research contributes to the development of sustainable urban environments that can withstand the challenges of global warming and urbanization.

Literature Review

Vegetation is the phrase used to describe plant life in a certain place. Plants do not exist in solitude; rather, they create plant communities comprised of groups of plants that live in the

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same geographical area. The number of vertical height strata of plants is directly correlated with vegetation structure. The natural tropical rainforest environment shows a fully matured vegetation structure (Buyadi et al., 2014). Furthermore, Vegetation Structure (VS) pertains to the tangible attributes of plants and their organization within a certain habitat. The parameters encompassed in this analysis consist of the vertical dimension, horizontal dimension, width, shape, density of plants, leaf area index, canopy, colour as well as the spatial distribution of individuals within a population (Kamarulzaman et al., 2023).

Vegetation plays a crucial role in urban climates, offering natural cooling through shading, evapotranspiration, and wind modulation. Mohd Fairuz Shahidan (2007), demonstrated how individual leaves can react to incoming shortwave radiation by reflecting and transmitting it, as depicted in **Figure 1.** A study by Akbari et al., (2001), highlights how tree canopy cover can significantly reduce surface and air temperatures, leading to reduced cooling loads and energy consumption in urban areas. Further, Yu et al., (2018), explore the concept of green infrastructure as a strategy for urban climate regulation, demonstrating how strategic vegetation planning can enhance urban thermal comfort and resilience to climate change. In accordance with Noorazlina et al., (2023), it has been noted that effective landscape design can minimize the penetration of sunlight into a structure, hence establishing pleasant temperatures for both indoor and outdoor spaces.

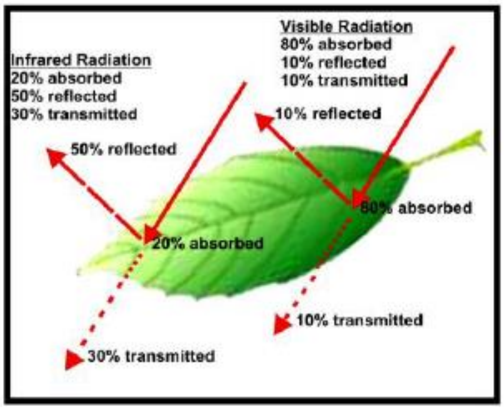

Figure 1: Solar Radiation Response of a Single-Layer Leaf: Absorption, Transmission, and Reflection

Meanwhile, the orientation of urban landscapes in relation to vegetation structure plays a pivotal role in maximizing the cooling benefits of green spaces. Lin Yola, (2018) examine the differential cooling effects of vegetation in various urban orientations, finding that east-west orientations tend to benefit more from vegetative shading than north-south orientations due to the path of the sun. This is corroborated by Fu et al., (2022), who utilized simulation models to show that the spatial arrangement and orientation of green spaces significantly influence the microclimate, particularly in terms of mitigating heat in densely built environments. The relationship between vegetation structure and landscape orientation significantly influences thermal performance in ecosystems. Vegetation structure, which includes the density, height, and layering of plant species, plays a critical role in modulating microclimates by providing shade, reducing wind speed, and increasing humidity through transpiration. Dense canopies, for instance, can lower ground temperatures by blocking direct sunlight and promoting cooler, moister conditions underneath. In contrast, sparse vegetation allows more solar radiation to reach the ground, raising surface temperatures (Misni, 2013; Qiuyan Yu & Yu, 2018).

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Landscape orientation, which includes the direction and slope of the land, interacts with vegetation structure to further influence thermal dynamics. For example, southern slopes in the Northern Hemisphere receive more sunlight and therefore experience higher temperatures, while northern slopes remain cooler and wetter. The vegetation on these slopes responds accordingly: sun-adapted species thrive on warmer slopes, while shade-tolerant species dominate in cooler areas. This interaction ensures a diverse range of microhabitats and promotes biodiversity. Vegetation structure and landscape orientation together form a mosaic of thermal environments that are critical to the survival and distribution of diverse plant and animal species and impact ecosystem functioning and resilience to climatic variability.

Methodology: Case Study, Tools & Instruments, and Data Collection Process

The methodology for assessing the thermal performance of vegetation structures and orientations in urban landscapes was meticulously designed to ensure accuracy and relevance. The study utilized a comprehensive suite of tools and instruments, primarily focusing on field measurement studies to gather empirical data on thermal conditions within the case study houses.

Case Study

This study focuses on the influence of vegetation structures in two different landscape orientations on thermal performance, a crucial consideration in urban planning and environmental management. With increasing concerns about Urban Heat Islands (UHI) and global warming phenomenon, it is important to understand how vegetation influences heat regulation. This research used a quantitative method through field measurement studies and focused on two single-story semi-detached houses, namely East Landscape Orientation (ELO) and West Landscape Orientation (WLO) in Seri Iskandar, Perak Malaysia **(Figure 2).** The details landscape orientation for both research studies are shown in **Figure 3**. The snowball technique was used to select case study houses to ensure a targeted approach to understanding impacts. The selection criteria were carefully chosen to consider different vegetation structures and landscape orientations as stated in **Table 1.**

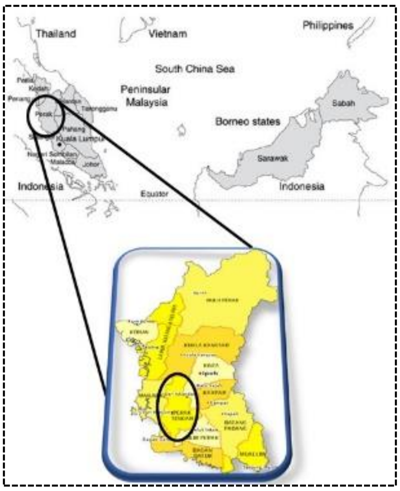

Figure 2: Area of the Research Studies.

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Figure 3: Landscape Orientation for Both Research Studies.

Table 1: Criteria for Selecting the Research Studies Houses.

No	House Labelled	Criteria Selection: Building Construction & Material	Building Design & Opening	Built-Up Area	Landscape Size	Landscape orientation	Landscape design	Landscape density	Climatic condition	Housing Area
1	Eastern Landscape House (ELH)	*	*	*	*	ø	ø	ø	*	*
2	Western Landscape House (WLH)	*	*	*	*	ø	ø	ø	*	*

* *Similar criteria selection*
ø *Different criteria selection*

Tools and Instruments

In order to precisely collect and document thermal microclimate data, this study utilized two sets of portable instruments with data loggers and sensors, specifically designed for outdoor and indoor measurements as shown in **Figure 4.** Thermal Microclimate Data Logger, Model Delta Ohm HD32.1 (Program A), served as the primary outdoor instrument for measuring various environmental parameters such as temperature(°C), relative humidity (%), and air

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velocity(m/s) for understanding thermal environments. Several probes were used in conjunction with this data logger to gather comprehensive data. The Globe Thermometer Probe was employed to measure Mean Radiant Temperature (MRT) and Wet Bulb Globe Temperature (WBGT), providing insights into overall thermal radiation exposure and the combined effects of temperature, humidity, wind speed, and solar radiation. An Air Velocity Probe was used to assess the speed of air movement, a critical factor in thermal comfort. Additionally, sensor probes measured natural ventilation's wet-bulb and dry-bulb temperatures, helping to evaluate cooling effectiveness. A Relative Humidity and Temperature Combined Probe measured both moisture content in the air and ambient temperature.

For indoor measurements, an Indoor Air Quality (IAQ) Monitor Data Logger, Model Delta OHM (HD37AB1347), were utilized to monitor parameters affecting indoor air quality, such as temperature, relative humidity, CO2 levels, volatile organic compounds (VOCs), and particulate matter (PM2.5 and PM10). This comprehensive approach allowed for a thorough assessment of the interior thermal comfort. **Table 2** presents the tools utilized in the field measurement investigation. Both the outdoor and indoor instruments were positioned at a height of 1 meter above the ground. The data logger was programmed to record data from 9am to 6pm every day for a duration of three days. This setup ensured consistent, reliable, and comprehensive data collection, providing a robust dataset for analyzing thermal performance and air quality in both outdoor and indoor environments.

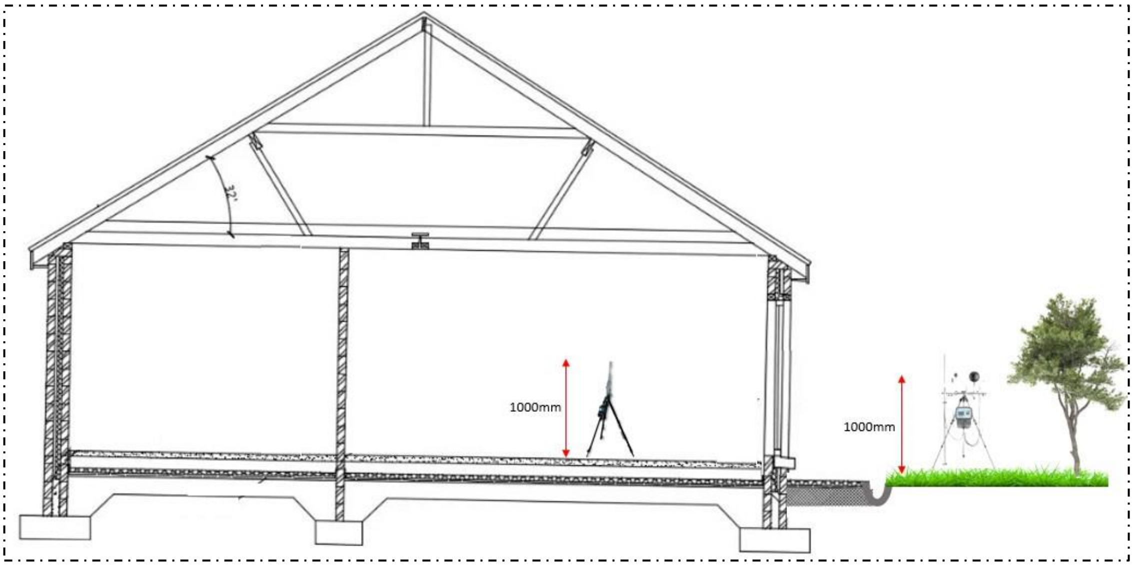

Figure 4: Both Outdoor and Indoor Measuring Instruments were Positioned at a Height of 1 Meter.

Table 2: The Instruments Used for Measuring in Outdoor and Indoor Environments.

	Outdoor Instrument: ***Thermal Microclimate data logger, model Delta OHM (HD32.1)*** (a) Thermal Microclimate Data Logger (HD32.1) (b) Globe thermometer probe for MRT and WBGT (TP3275)

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(c) Air Velocity probe (AP3203 /A3203-F)
(d) 2 sensor probes for natural ventilation wet and bulb temperature (HD3217DM)
(e) Radiant Temperature Probe (TP3207TR)
(f) Relative Humidity and Temperature combined Probe (TP3217R)
(g) Briefcase and probes
(h) Tripod (VTRAP32)

(Delta OHM Manual, 2009)

Indoor Instrument: ***Indoor Air Quality (IAQ) Monitor data logger; model Delta OHM (HD37AB1347)***

Data logger (HD37AB1347)

Tripod (VTRAP30)


Combined Probe for IAQ (P37AB14)

Directional Hotwire Probe (AP471S3)

(Delta OHM Manual, 2022)

Data Collection Process

Thermal performance sensors were strategically positioned both inside and outside the selected houses. These sensors have been programmed to record data at 30-minute intervals, allowing detailed analysis of temperature differences and fluctuations over time. This interval is chosen to balance the need for detailed temporal data with the practical considerations of data storage and battery life. The aim of the study is to elucidate the interplay between building design, external factors, and indoor thermal comfort by collecting data from both the indoor and outdoor environments.

Meticulous daily weather records were taken for each house for three days to ensure a consistent and reliable data set. It is noteworthy that each study house experienced consistent daily weather conditions throughout the field measurement period. This consistency was characterized by an average of six to eight hours of sunlight and the absence of rain during the data collection phase, providing an ideal context for studying the thermal influence of vegetation structures and orientations. Mean meteorological records were prepared to complement the field data. The parameters were obtained from the Malaysian Meteorology Department at Pusat Pertanian Titi Gantong, the closest meteorological station to the field

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measurement area. These data provided broader climatic context and supported the analysis and interpretation of the site-specific measurements collected by the thermal microclimate data loggers and sensors. **Figure 5** shows the Flowchart of the summary Data Collection Process.

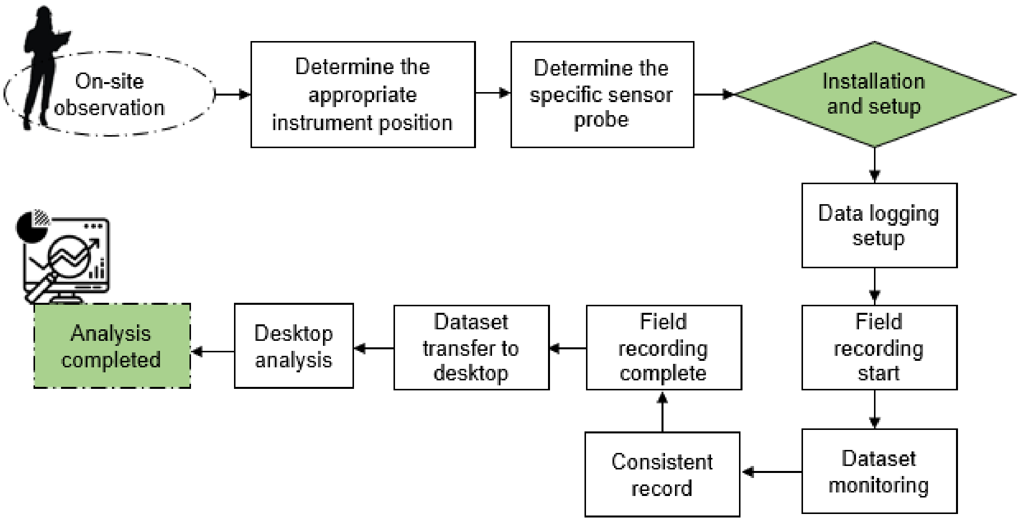

Figure 5: Flowchart Illustrating the Process of Collecting Field Measurement Data.

Results and Discussion

The field measurement results in this study are classified into three primary parameters: ambient temperature (°C), air velocity (m/s), and relative humidity (%). These factors are crucial for comprehending the environmental circumstances being studied. During the initial stage of data presentation, the daily results for each case study are delivered over a period of three days. This approach provides a thorough overview of the range of values observed in the measured parameters, enabling an understanding of how they change over time.

After conducting a thorough study of the daily findings, attention is now directed towards analyzing the average data collection. In this stage, the information collected during the three-day period is combined to obtain typical values for each parameter. Through the process of computing averages, the study eliminates the temporary fluctuations noticed in the daily observations, so establishing a more consistent foundation for comparison and analysis.

After completing the average data collected for each case study, the research next proceeds to compare the conclusions acquired from different scenarios. This comparative analysis is an important step in understanding the similarities and differences in environmental conditions in different contexts. Through the comparison of data from each case study, the research obtains valuable insights into the influence of various causes or conditions on the measured parameters.

3-Days Analysis of Measured Parameters

This research uses field measurements to understand environmental conditions. It focuses on three parameters: ambient temperature, air velocity, and relative humidity. Daily data is presented over three days and provides an overview of changes over time. The results of the analysis of the 3 days of data collection for each measured parameter are shown in **Figures 6, 7 and 8.** The fluctuation pattern of the data in 3 days is recorded for both research study houses for the entire field study. To analyse the result of the measured parameters, average data

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collection is used to obtain typical values for each parameter. A comparative analysis is then carried out to understand similarities and differences in environmental conditions in different scenarios and to gain insights into the influence of different factors.

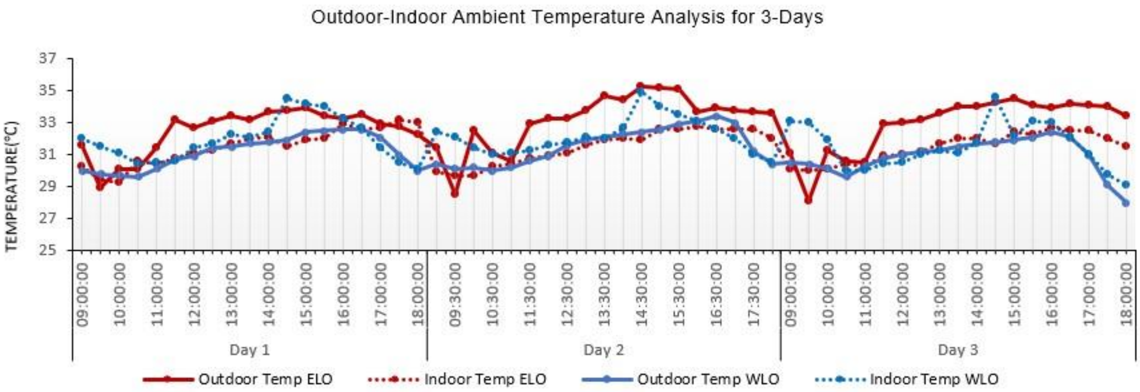

Figure 6: Analysis of Outdoor-Indoor Temperature for Both Research Studies Over 3 Days of Fieldwork Measurement

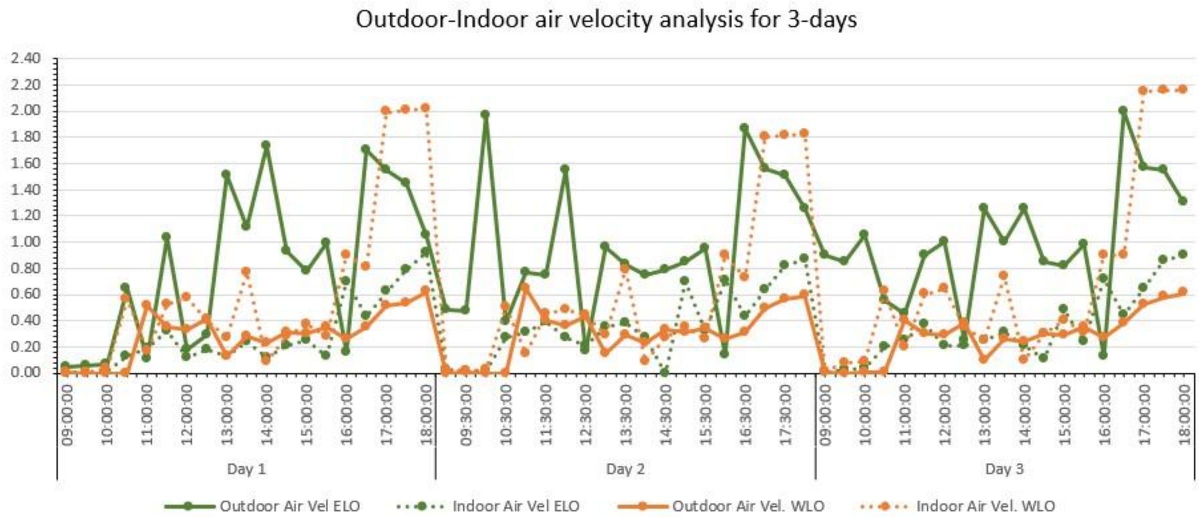

Figure 7: Analysis of Outdoor-Indoor Air Velocity for Both Research Studies Over 3 Days of Fieldwork Measurement

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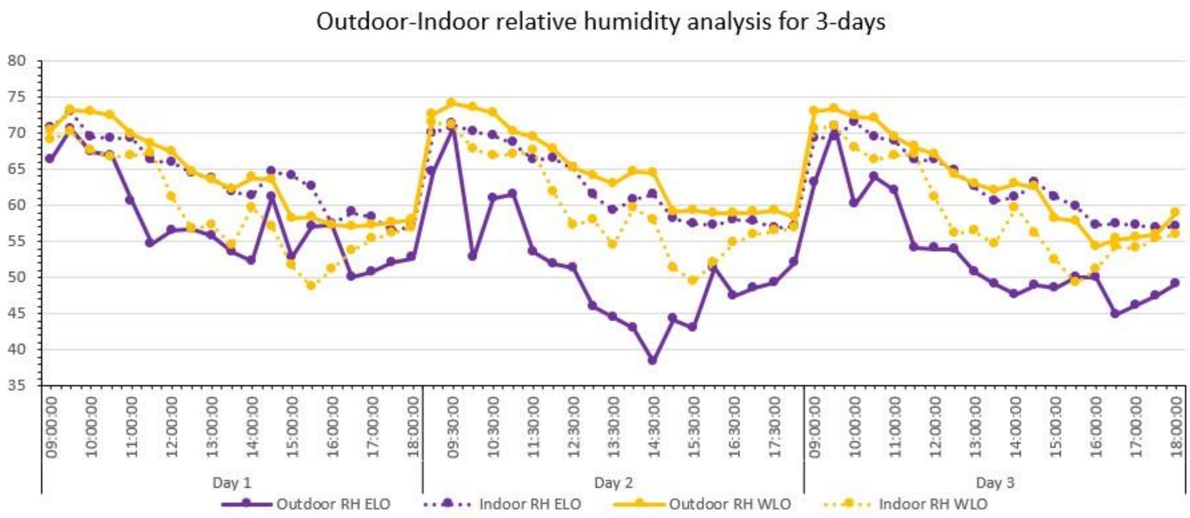

Figure 8: Analysis of Outdoor-Indoor Relative Humidity for Both Research Studies Over 3 Days of Fieldwork Measurement

Average 3-Days Analysis of Measured Parameters

The analysis of the average data indicating that houses with landscapes facing east (ELO) experience higher outdoor temperatures compared to houses with landscapes facing west (WLO), while indoor temperatures ELO are lower than WLO house, can be explained by relating it to the direction of sunrise and sunset. **Table 3 and 4** shows the summary result of the outdoor and indoor data analysis on average over a 3-day field study.

Table 3: Average of 3-Days Outdoor Analysis for Measured Parameters

	EAST LANDSCAPE ORIENTATION (ELO)			WEST LANDSCAPE ORIENTATION (WLO)		
	Temp(°C)	AV(m/s)	RH(%)	Temp(°C)	AV(m/s)	RH(%)
Max	35	1.99	71	33	0.65	74
Min	28	0.05	38	28	0.00	54
Average	33	0.91	54	31	0.29	64

Table 4: Average of 3-Days Indoor Analysis for Measured Parameters

Criteria	EAST LANDSCAPE ORIENTATION (ELO)			WEST LANDSCAPE ORIENTATION (WLO)		
	Temp(°C)	AV(m/s)	RH(%)	Temp(°C)	AV(m/s)	RH(%)
Max	33	0.92	73	35	2.16	71
Min	29	0.00	57	29	0.00	49
Average	31	0.33	63	32	0.64	59

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i) Outdoor-Indoor Ambient Temperature Results

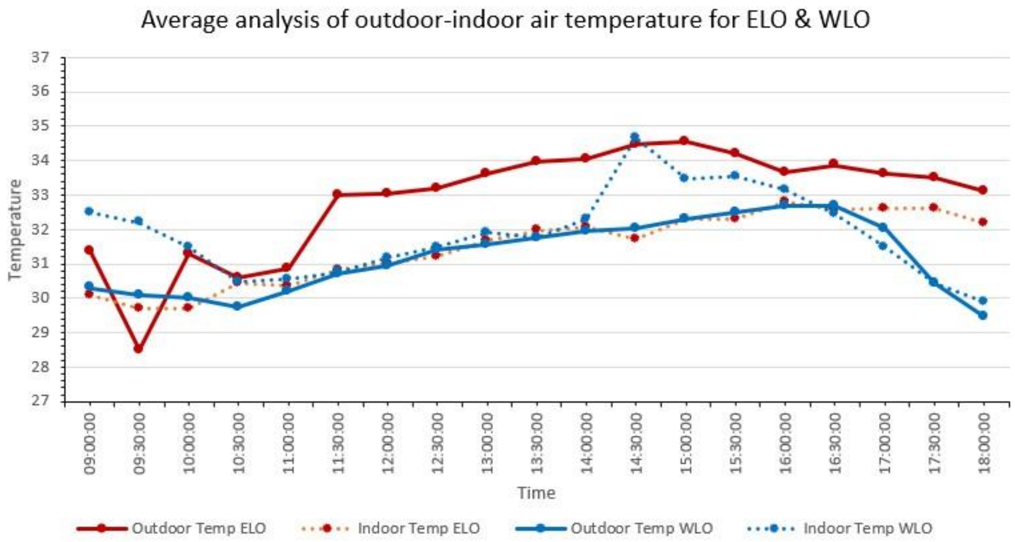

Figure 9: Average Analysis of Outdoor-Indoor Temperature of Study Houses

The direction of sunrise and sunset plays a significant role in the difference in outdoor and indoor temperatures of houses, and vegetation orientation further influences these dynamics. ELO houses receive direct sunlight in the morning when the air temperature is still relatively low. This early sunlight gently warms the exterior surfaces, resulting in higher outdoor temperatures compared to WLO houses, which are still shaded in the morning. Vegetation on the east side can provide additional shading in the morning, helping to moderate the warming effect and keep outdoor temperatures slightly cooler. As the day progresses and the sun moves westward, ELO houses fall into shade by the afternoon. This shading allows the exterior surfaces to cool down, and since they no longer receive direct sunlight, the interior also starts to cool. Natural ventilation often improves in the afternoon, especially if prevailing winds blow from west to east, further reducing indoor temperatures. By evening, ELO houses have had several hours to cool, resulting in lower indoor temperatures at night due to the lack of direct sunlight and the reduced amount of residual heat stored in the walls and roof. Vegetation on the east side also helps in cooling down the area more quickly by providing a buffer against the heat and enhancing the cooling effect through evapotranspiration.

In contrast, West Landscape Orientation (WLO) houses receive direct sunlight in the afternoon when the sun is at its hottest. The intense afternoon sunlight significantly raises the temperature of the exterior surfaces, penetrating more deeply and for a longer period, leading to greater heat absorption by the walls, roof, and interior spaces. Vegetation on the west side can provide crucial shading during this peak heat period, reducing the amount of solar radiation that directly hits the house and thereby lowering the exterior and interior temperatures. This prolonged exposure means that WLO houses accumulate more heat in their structures, which is then gradually released into the interior, causing higher indoor temperatures. Even after sunset, the stored heat continues to radiate into the indoor spaces, keeping temperatures elevated well into the night. With less time to cool down before nightfall, the combination of stored heat and limited natural cooling results in higher indoor temperatures for WLO houses. Vegetation on

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the west side can mitigate this effect by providing shade and reducing the overall heat load on the house.

ii) Outdoor-Indoor Air Velocity Results

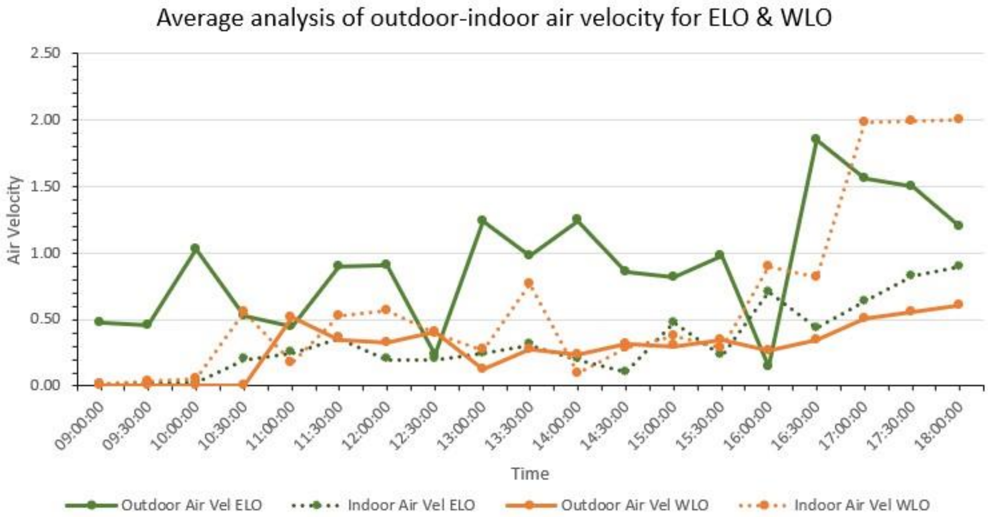

Figure 10: Average Analysis of Outdoor-Indoor Air Velocity of Study Houses

The analysis demonstrates that houses with vegetation landscapes facing east have greater outdoor air velocity than houses with west-facing landscapes, while indoor air velocity is lower in east-facing houses compared to those facing west. This can be attributed to factors such as the positioning of vegetation, landscape orientation, the movement of the sun, and other related factors.

The orientation of a house in relation to the path of the sun and the placement of vegetation have a substantial effect on the speed of air movement both outdoors and indoors. East-facing houses, also known as ELO, experience direct sunshine in the morning, which leads to the warming and upward movement of the air. This, in turn, causes cooler air from the surrounding areas to flow in and replace it. This movement increases the outdoor wind speed. In addition, the vegetation on the eastern side may lack sufficient density in the morning to impede the airflow, so enabling the wind to move with greater freedom. In contrast, houses that face west (WLO) do not receive sunlight in the morning, resulting in less windy conditions and reduced outdoor air velocity. The vegetation on the western side may exhibit a higher density, therefore creating a more effective obstacle to the movement of wind.

ELO houses employ vegetation as a windbreak to diminish the inflow of wind into the house, hence decreasing indoor air velocity. The presence of this vegetation acts as a barrier, reducing the speed of the wind before its reach to the house. Conversely, WLO houses experience intense sunlight during the afternoon, leading to higher indoor temperatures. In order to lower the temperature, these houses frequently depend on natural ventilation, such as the act of opening windows, which in turn enhances the speed of air movement indoors. The vegetation on the western side, having accumulated heat during the day, may not adequately obstruct the wind, resulting in increased airflow into the home.

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iii) Relative Humidity Results

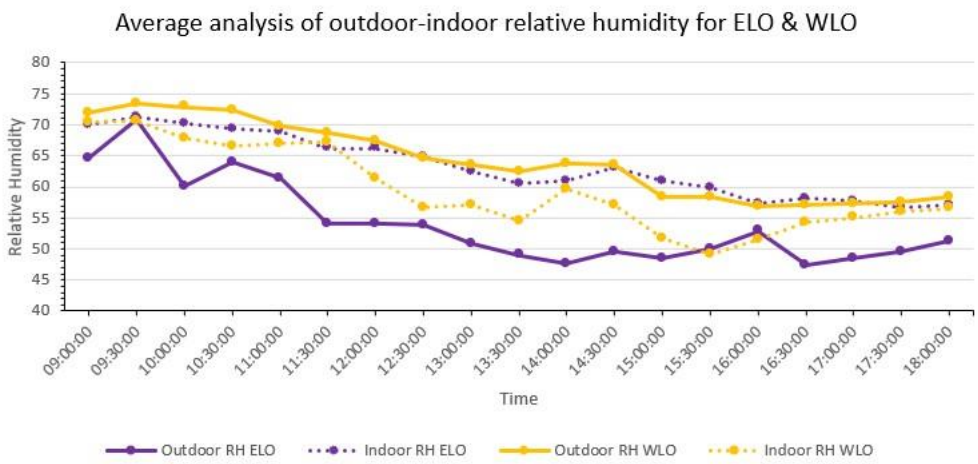

Figure 11: Average Analysis of Outdoor-Indoor Relative Humidity of Study Houses

The data analysis reveals that houses with east-facing landscapes have lower outdoor relative humidity than houses with west-facing landscapes. Conversely, houses with east-facing landscapes have higher indoor relative humidity compared to houses with west-facing landscapes. This can be attributed to the positioning of vegetation and the orientation of the landscape.

The orientation of sunrise and sunset has a considerable impact on the levels of relative humidity, and the placement of vegetation also plays a role in shaping these patterns. Houses oriented towards the east (ELO) receive direct sunshine in the morning, which aids in the evaporation of dew and moisture from the ground and vegetation, resulting in reduced outdoor relative humidity. On the east side, the vegetation begins to release moisture into the air earlier, but the increase in warmth caused by sunshine reduces the relative humidity at the same time. In contrast, houses that have landscapes oriented towards the west (WLO) do not receive direct sunshine in the morning. This causes the moisture and dew to persist for a longer period, leading to higher levels of outdoor relative humidity. As the sun reaches its highest point in the afternoon, residences that face west start to get strong sunshine. This leads to a rise in temperature and a consequent fall in interior relative humidity because of increased evaporation.

Vegetation also has an impact on indoor relative humidity. In ELO houses, vegetation aids in maintaining elevated indoor relative humidity by emitting moisture into the air through transpiration, particularly during the morning when the temperatures are lower. Moreover, because to the absence of direct sunlight, these houses have a faster decrease in temperature during the afternoon and evening, resulting in a higher indoor relative humidity. Conversely, WLO houses, which are exposed to intense afternoon sunlight, experience elevated indoor temperatures that enhance evaporation, resulting in reduced indoor relative humidity. The vegetation on the western side, having accumulated heat during the day, experiences less efficiency in releasing moisture in the evening, so causing a decrease in indoor relative humidity.

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Conclusion

In conclusion, the orientation of a house relative to the sun's path has a profound impact on its thermal dynamics, and vegetation plays a critical role in moderating these effects. ELO houses benefit from milder morning sunlight and effective afternoon cooling, resulting in lower overall indoor temperatures. Vegetation on the east side enhances this cooling effect. WLO houses, exposed to intense afternoon heat, experience higher outdoor and indoor temperatures later in the day, with retained heat keeping indoor temperatures elevated even after sunset. Vegetation on the west side is essential in providing shade and reducing heat absorption, thereby improving comfort and energy efficiency.

Meanwhile, the orientation of a house relative to the sun's path and the placement of vegetation and landscape also play crucial roles in determining outdoor and indoor relative humidity levels and air velocity. ELO houses have lower outdoor but higher indoor relative humidity due to the early evaporation of moisture and effective transpiration by vegetation. WLO houses exhibit higher outdoor relative humidity in the morning and lower indoor relative humidity in the afternoon and evening due to intense sunlight and less efficient transpiration by heated vegetation. In the context of air velocity,

ELO houses experience higher outdoor air velocity due to morning sun-induced air movement and less obstructive vegetation but have lower indoor air velocity because vegetation acts as a windbreak. WLO houses have lower outdoor air velocity due to calmer morning air and denser vegetation but higher indoor air velocity in the afternoon due to natural ventilation needs and less effective wind blocking by heated vegetation. Understanding the dynamics of vegetation and house orientation can aid homeowners and architects in making informed decisions about landscape design, thereby enhancing thermal comfort and energy efficiency in homes.

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