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SUSTAINABLE BUILT ENVIRONMENT

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INVESTIGATING THE THERMAL COMFORT EFFECTS OF DAYLIGHTING AS A PASSIVE DESIGN STRATEGY AT McDONALD'S ALOR SETAR BUILDINGS IN KEDAH

Nurul Fatihah Asyiqin Binti Sazali[1], Jamaludin Muhamad[1*]

[1]Architectural Program, Department of Built Environment Studies and Technology, College of Built Environment, Universiti Teknologi MARA, Perak Branch, 32610, Seri Iskandar, Perak, MALAYSIA

2019242406@student.uitm.edu.my, *jamal121@uitm.edu.my

ABSTRACT

This research investigates the thermal comfort perception of passive daylighting strategies implemented in a McDonald's restaurant building in Alor Setar, Kedah. The study explores the relationship between daylighting and users' thermal perception to enhance the dining experience through optimal thermal conditions. Previous studies have suggested that daylighting does not directly impact users' thermal comfort in restaurant buildings but affects the environment's ambient temperature. Therefore, this study utilizes controlled experimental observations to understand the interplay between all relevant factors better. Data collection involved measuring daylight lux levels, ambient and room temperatures, three participants' skin temperatures, and their subjective responses after 30 minutes of daylight exposure. The results indicate that exposure to daylight influences the ambient temperature of the surrounding environment. Higher lux levels result in increased temperatures due to heat gain. The findings reveal that users perceive warmer sensations when exposed to higher temperatures under high daylight illuminance levels (lux levels), compared to medium and low illuminance levels, and vice versa. This study contributes to a deeper understanding of the variable factors that impact users' thermal comfort perception in indoor environments, particularly in restaurant settings where ensuring user comfort is crucial for successful design outcomes.

Keywords: *Daylighting, users' thermal perception, thermal comfort, restaurant buildings.*

INTRODUCTION

The restaurant industry in Malaysia is currently more competitive than ever before. Various restaurant types and concepts are available, including fine dining, family-friendly fast food, and both standalone and chain establishments. As a crucial part of the hospitality sector, restaurant design should be visually appealing, functional and create a relaxed atmosphere. One practical approach to achieving this is incorporating passive design strategies that utilize natural elements on the site, specifically for restaurants. These strategies aim to maintain comfortable indoor conditions and minimize unnecessary heat gain or loss without relying on purchased energy.

Daylighting is the most popular passive design strategy employed in building design. It involves ensuring an even distribution of natural light throughout the building. Scientifically proven to affect human health and comfort positively, natural light also helps mitigate the adverse impacts of the built environment. Design elements such as windows, skylights, solar tubes, and transparent glass walls are utilized to collect and reflect natural light into areas with less illumination. Glass windows and exterior glass walls were commonly found in the facades of most restaurant buildings.

By incorporating these design elements, natural light enters the buildings, reducing energy consumption for mechanical cooling, heating, and lighting systems. Additionally, the thermal performance of the building improves, enhancing the indoor comfort for its occupants. Therefore, it is crucial to understand further how daylight influences the thermal responses of buildings and users, particularly in restaurant buildings where comfort is paramount.

RESEARCH AIMS AND OBJECTIVE

This research aims to explore the connection between passive daylighting strategies implemented in restaurant buildings and their effects on the thermal responses of users. Despite daylighting not being explicitly mentioned as one of the six factors affecting thermal comfort, there is a suggestion that it can indeed influence the thermal comfort experienced by individuals inside these buildings.

The objective was to examine the correlation between passive daylighting strategies employed in the McDonald's restaurant buildings under investigation and the ambient air temperature in the surrounding environment, which ultimately impacts the thermal comfort experienced by users.

PROBLEM STATEMENT

The issue of thermal comfort in restaurants is not a new phenomenon. Many of us have experienced the discomfort of an unsatisfactory thermal environment inside restaurant buildings. It can be scalding due to the climate and inadequate ventilation, causing hot air to circulate into the dining area or too cold with drafts from air conditioning blowing directly on patrons. Thermal comfort is crucial for successful building operations in the built environment. Therefore, precise control of passive design strategies to optimize indoor thermal performance is essential.

While the benefits of passive daylighting strategies for the well-being of buildings and user comfort are widely recognized, a lack of clarity in their implementation can lead to failures in the daylighting design system. Improper planning of natural lighting can result in unwanted heat gain (Rana, 2018). Although some research has examined the impact of artificial lighting on users' thermal responses, few studies have fully explored the relationships between daylighting and thermal comfort levels, specifically in restaurant environments.

EXPLORING THE CONCEPT OF ARCHITECTURAL LIGHTING

Architectural lighting, the marriage of art (architecture), and technology (lighting), play a crucial role in how people perceive and comprehend architecture. It is a medium that adds value to the design and functionality of architectural structures. By enhancing the aesthetic appeal of buildings and structures, lighting creates ambience, evokes feelings, and expresses the essence of a form, as stated by the renowned architect Le Corbusier. Other design elements and technicalities, such as spatial design, material usage, and colour schemes, would lose effectiveness without adequate lighting (Joson, 2022).

Architectural lighting design significantly impacts the well-being of building users by enhancing their spatial experience. According to Munson (2019), in an interview with Alcon Lighting, lighting helps emphasize specific architectural features, as demonstrated in the figure below, showcasing the iconic interior of a church design (Alcon Lighting, 2019). Natural light penetrates the voids carved from thick concrete, providing intimacy and excitement while influencing users' moods and spatial awareness. Therefore, it is essential to integrate good architectural lighting designs into the building's exteriors and interiors, as they play a substantial role in creating the desired atmosphere, particularly in public spaces.

The Essence of Restaurant Lighting: Exploring the Fundamentals

A restaurant is a commercial establishment designed to serve food and beverages to customers. Restaurateurs aspire to create appealing and captivating spaces that attract people. However, architects and designers must recognize that a visually pleasing interior and exterior are only part of the equation. The functionality of a restaurant should be prioritized alongside aesthetics, as they work synergistically rather than in isolation. Lighting and colour, in addition to the building's design, materials, and furniture arrangement, actively contribute to the ambience of the environment (Farooq et al., 2020).

In the above context, lighting is crucial in determining a restaurant's functionality, user experience, and comfort. Two primary sources of lighting are employed in restaurants: artificial and natural. Both sources can be utilized to create three types of lighting—ambient, task, and accent lighting—which serve different purposes through various lighting fixtures and designs (WebstaurantStore, 2018).

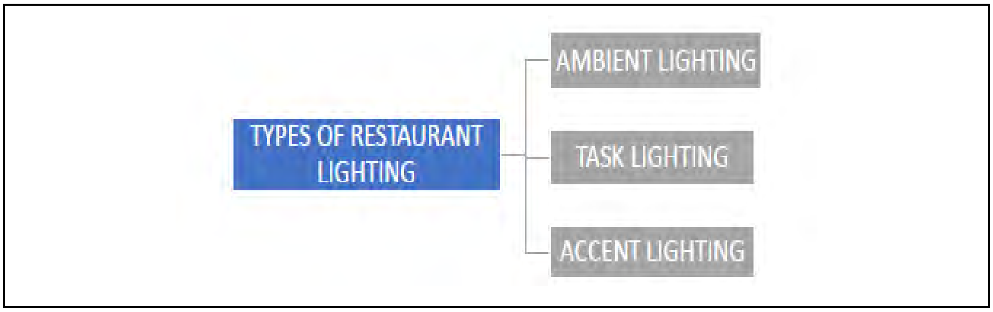


Figure 1: Types of Lighting Used in a Restaurant
Source: Author (2022)

Ambient Lighting:

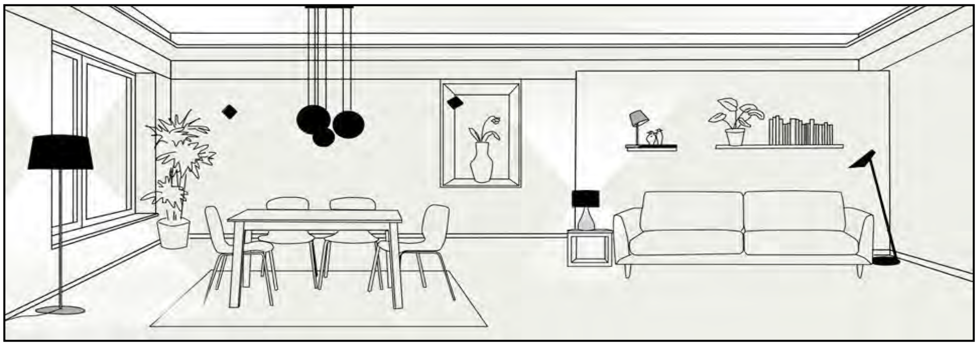


Figure 2: Ambient Lighting in a Space.
Source: Ambient, Task, and Accent Lighting 101 (2018)

Ambient lighting, also known as general lighting, serves as the primary light source in space, establishing the overall lighting framework within a building. It enhances the perception of warmth and depth while providing a comfortable illumination level (What is Ambient Lighting and How to Get It Right, 2017). Typically, ambient lighting is soft, diffused, and often dimmable to accommodate different settings throughout the day and night.

Yilmaz (2018) states that the achievement of the lighting effect can be consistently maintained by arranging them at a strategic distance from each other. This arrangement helps prevent undesirable incidents, such as light glaring directly on users' heads or causing discomfort from misplaced bulbs. By strategically placing lamps and fixtures outside of natural traffic patterns, people can move freely without obstruction, and the lighting can gracefully trace the perimeter of the space.

Task Lighting:

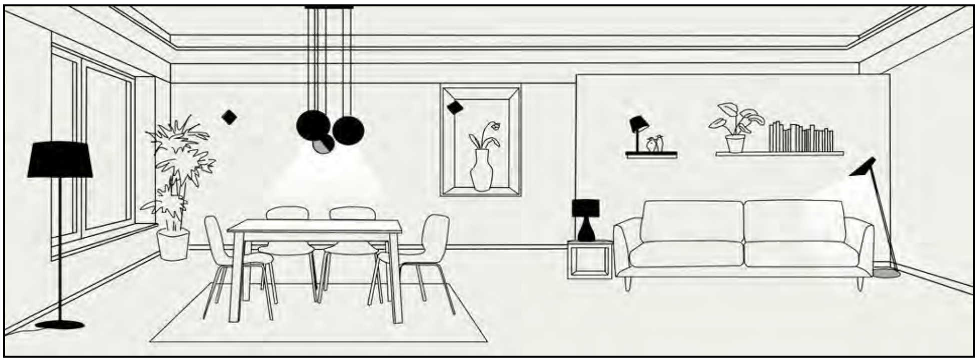


Figure 3: Task Lighting in a Space.
Source: Ambient, Task, and Accent Lighting 101 (2018)

Task lighting refers to intense and direct illumination designed explicitly for detailed tasks such as sewing, reading, cooking, or any activity requiring focused attention on the job (Ambient, Task, and Accent Lighting 101, 2018). It is brighter than ambient lighting and typically focuses on a specific area where the study is performed. However, adequate task lighting should provide appropriate bright light to the workspace without causing eyestrain. Lighting that creates shadows or glare can be distracting and uncomfortable for the eyes.

Task lighting is most effective when it creates contrast. For example, a study lamp over a desk works better in a dimly lit room than in a brightly lit environment. Concentrated light enables users to pay better attention to details, resulting in higher-quality outcomes. Additionally, according to Hogrebe (n.d.), task lighting empowers individuals to control their lighting environment, which has psychological benefits.

Furthermore, it contributes to energy conservation in the overall building lighting system, making it environmentally friendly (Hogrebe, n.d.).

Accent Lighting:

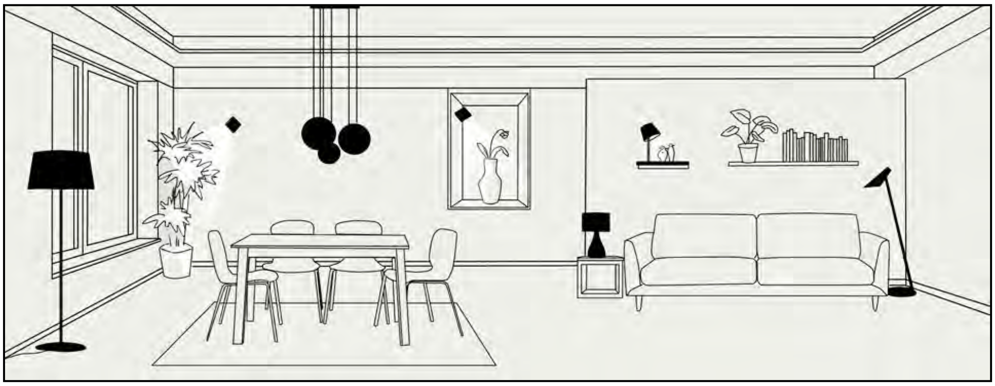


Figure 4: Accent Lighting in a Space.
Source: Ambient, Task, and Accent Lighting 101 (2018)

Accent lighting is the illumination directed towards a particular object or area, intended to emphasize, and highlight its details. It is typically three times brighter than ambient lighting. Unlike other types of lighting, accent lighting aims to create visually appealing focal points and enhance aesthetics (Ambient, Task, and Accent Lighting 101, 2018). It functions similarly to makeup, drawing attention to specific features and making them more visually appealing and desirable. Designers often use accent lighting to add drama and character to their designs.

Commonly used fixtures for accent lighting include wall sconces, recessed spotlights, track lighting, and floodlights. Adjustable fittings are preferred for accent lighting as they can be angled and directed to create highlights, focusing on specific areas or objects.

BENEFITS OF NATURAL LIGHT IN RESTAURANTS

The lighting in a restaurant plays a crucial role in shaping the dining experience for customers. It significantly impacts their perception of the establishment and influences whether they will return (Feuling, 2021). Therefore, maintaining appropriate lighting is essential to create a comfortable and welcoming atmosphere for patrons. According to renowned fashion designer Oscar de la Renta, perfect lighting is the most critical factor in design.

Natural light has a natural appeal and is beneficial for individuals' well-being, productivity, and overall satisfaction. Research studies have shown that exposure to natural light in restaurants or cafes creates a bright and uplifting ambience, leaving customers feeling refreshed and comfortable. This is because natural light emits bright blue light during the day, which makes a sense of spaciousness and keeps people awake and alert. In contrast, dimmer lighting in the evening signals relaxation and prepares the body for sleep, creating a smaller and more intimate atmosphere (Konrad, 2017).

Figure 5: The Effect of Blue Light Emitted by Natural Light (Left), The Effect ofRed Light Emitted by Natural Light (Right) Source: Kenjar (n.d.) (Left). Courtesy of The Fulton (2022) (Right)

As mentioned earlier, restaurants that incorporate ample windows or openings to allow natural light into the premises will experience varying brightness levels throughout the day, with brighter conditions during the daytime and dimmer lighting in the evening. This brightness is well-suited for fast-food or family-friendly restaurants, while dimmer lighting creates a more suitable ambience for fine dining establishments. Some restaurants serve breakfast, lunch, and dinner throughout the day. Considering this, it is advisable to have adjustable lighting designs that cater to the different meals served. Bright lighting is ideal for breakfast as it helps keep patrons awake and alert. Moderate lighting works well during lunchtime, while dimmer lighting creates a more intimate atmosphere for dinner (Rossi, 2020). Achieving these different lighting intensities can be easily accomplished by harnessing natural light.

Passive Daylighting Strategies in Restaurant Buildings:

The passive daylighting strategy is a popular architectural practice used to design low-energy buildings. It is vital for the development of a sustainable design that improves the quality of users' lives. The goal of daylighting is to collect and distribute enough natural light throughout the buildings to reduce the consumption of energy as much as possible. The design elements do not require any special mechanical equipment or power supplies, making this a "passive" strategy (Passive Daylighting System Could Transform the Architecture of Natural Light | Thought Leadership, 2019).

The direction of light entering the building is an important aspect to consider before the design and construction process. Buildings have traditionally been designed with fewer and smaller windows or openings on the polar side (East and West), but more and larger windows or openings on the equatorial side (South and North). As said by Vujovic (n.d.), building orientation has a big impact on passive design operations (Marro, 2018). The figure below shows the proper building orientation for an effective passive design.

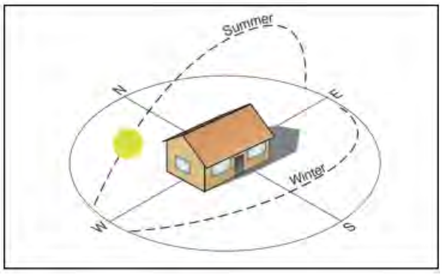
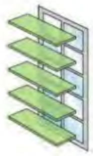
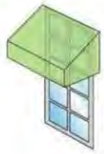


Figure 6: Building Orientation in Relation to the Sun Path.
Source: Nick and Ben Gromicko (n.d.)

A shading system is essential for controlling daylighting for an effective passive design strategy. It also functions as a design element on the building's envelope. They can be installed on either the exterior or interior of the building (Jarrad, 16 n.d.). However, the exterior shading system has more advantages than the interior shading system. It could block and prevent direct light especially from East and West at certain times of the day, from entering the building as well as reduce unwanted solar heat gain. Table below explains the various types of external shading devices commonly used in the architectural field.

Table 1: Various Types of External Shading Devices
Source: Author (2022)

ELEMENT	DESCRIPTION
 **Figure 2.11:** Horizontal Louvers Source: External Shading Devices (n.d.)	**Horizontal Movable and Fixed Fin** Horizontal louvers work best on the building's south façade. This is because it can block and reduce the heat gain of sunlight during the hot season while also reducing the energy used for the building's cooling system.
 **Figure 2.12:** Vertical louvers Source: External Shading Devices (n.d.)	**Vertical Movable and Fixed Fin** Vertical louvers are ideal for the west and east building's façade. By acting as a windbreaker, this type of shading device can also improve the insulation value of glass during the colder seasons.
 **Figure 2.13:** Awning Source: External Shading Devices (n.d.)	**Awning** An awning is a device that provides shade from the sun and snow (Shah, 2019). It is a dynamic shading device as it can be rolled and folded back to be stored when not in use. It is usually made from a flexible material.
 **Figure 2.14:** External Recessed Window Source: External Shading Devices (n.d.)	**Recessed Windows** Recessed windows are installed within a recess or alcove in the wall which resulted in the gap between the window and the surrounding wall. Because it reduces solar heat gain, a deeply recessed window can be used to control and lower room temperature (Canada, 2020). It is also referred to as the opaque envelope of the building envelope (building skin).
 **Figure 2.16:** Extended Overhang Source: Cewiche Canyan Bar & Restaurant (2018)	**Overhang** A sufficient depth of roof overhang is typically used in the design of a single or two-story building. It is straightforward and efficient as an energy-saving shading device. The width of the overhang will vary depending on the building site analysis (Rinka, 2022).
 **Figure 2.17:** Trellis and Vines Source: Living Awning (n.d.)  **Figure 2.18:** Tree Shade Source: Living Awning (n.d.)	**Living Awnings** Living awnings, such as trees and shrubs or trellises with vines are excellent natural shading devices. They block direct sunlight that causes glare, but allow the sun to warm the building in the winter. They also lower the air temperature of the heat transfer between the outside to the building envelope and interior.

The mentioned design elements below are commonly used to allow daylight into the building to brighten the indoor darker areas. By using these techniques, a great amount of energy consumption on artificial lighting can be reduced.

Table 2: Various Types of Design Elements that Allow Penetration of Daylight Source: Author (202

ELEMENT	DESCRIPTION
 **Figure 2.19:** Large Restaurant Windows Source: Large Restaurant Window (n.d.)	**Window** Architects use windows with high head heights to let in as much light as possible. Sometimes, horizontal ribbon windows which are uniform windows with the same height and width are placed across the entire façade. Bilateral window placement is used to light the space from every angle. The windows will face each other from opposite or adjacent sides (Passive Daylighting Systems Could Transform the Architecture of Natural Light, 2019).

 **Figure 2.20:** Skylight in a Restaurant Source: Skylight (n.d.)	**Skylight** Skylight is a light transmitting fenestration that allows natural light to enter from above. This method is useful and effective to light the areas where light from the windows cannot reach. Uniform placement of skylight will result in uniform lighting. They are the most effective source of daylight.
 **Figure 2.21:** Clerestories Source: Clerestory (n.d.)	**Clerestory window** Clerestories are windows that are high above eye level. Usually, clerestories are combined with reflective roof materials or paints. The natural light that entered through the clerestories is collected and reflected off the roof, illuminating the room below in a very diffuse manner (Passive Daylighting Systems Could Transform the Architecture of Natural Light, 2019).

 **Figure 2.22:** Light Shelves in a Cafeteria Source: Light Shelves (n.d.)	**Light Shelves** A light shelf is a horizontal reflective shelf placed above windows. 'Bouncing' light off the horizontal surfaces distributes it more evenly and deeply into the space. It also reduces glare which causes eyestrain.
 **Figure 2.23:** Solar Tubes Source: Solar Tube in Home (n.d.)	**Solar Tubes** Solar tubes direct natural light from the sun through the small opening of the tubes from the roof. They appear to be conventional ceiling bulbs powered by electricity from the inside. Solar tubes operate well when installed directly above the areas where users require ample and direct lighting, such as working desks (Passive Daylighting Systems Could Transform the Architecture of Natural Light, 2019).

Definition of Thermal Comfort Study:

Thermal comfort is described subjectively as the human satisfactory perception of the thermal environment under given room conditions. According to the Health and Safety Executives, it is also known as “the person state of mind whether they feel too hot of too cold” (HSE, 2015). Thermal comfort is consistently rated as one of the most critical elements for improving users’ comfort and satisfaction with their indoor environment. Nonetheless, it is based on personal experience that will be determined by a variety of factors. It will differ from person to person, even within the same room (Thermal Comfort in Buildings – Designing Buildings Wiki, 2013). There are numerous techniques that can be used to estimate thermal comfort levels, but Guenther proposed that human thermal comfort was determined by balancing two variables within a narrow range of acceptability: skin temperature and sweat secretion (Guenther, 2021). According to the figure below, there are six basic factors that affect the thermal comfort perception of building users, which can be divided into two categories: personal factors and environmental factors.

Figure 7: Factors Affecting Human Thermal Comfort
Source: Praveen Kumar (2019)

First and foremost, the types of clothing a person wears act as an insulator, influencing heat exchange between the human body and the surrounding environment (Wei Zhao et al., 2019). Clothing is commonly known as a protective layer that shields the wearer from feeling too hot or too cold. In some cases, certain professionals such as doctors or firefighters are required to wear specific uniforms, such as Personal Protective Equipment (PPE). However, wearing too many layers of clothing that do not provide adequate insulation may be the leading cause of heat stress. ‘Clo’ is a unit of measurement for clothing thermal insulation.

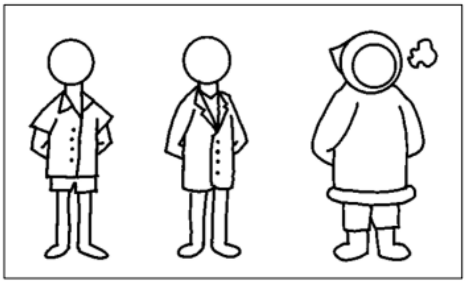


Figure 8: Different Types of Clothing Resulted in Different Total Clothing Thermal Insulation (Clo)
Source: Author (2022)

The work rate or metabolic heat of a person is also important in determining the user's thermal comfort level. The metabolic heat rates of humans vary according to activity levels and environmental conditions. The human body will generate more heat if the work requires a lot of physical activity, therefore, affecting their thermal comfort levels. The more heat a user generates, the more heat must be lost in order to prevent overheating (HSE, 2015). Physical characteristics such as height and weight, age, level of fitness, and gender can also impact a human's thermal comfort even if the environmental factors are all constant.

Air temperature is a common component of thermal comfort. The temperature of the air surrounding the body will determine how hot or cold the user feels. Air 26 temperature is also known as dry-bulb temperature simple because it is measured in degrees Celsius (°C) using a dry-bulb thermometer (Thermal Comfort, 2022). In addition, air temperature is easily influenced by passive and mechanical heating and cooling, with respect to location and time.

The second environmental factor that influences human thermal comfort is the mean radiant temperature (MRT). Nate Adams defined MRT as the uniform and constant temperature of all the surfaces around us (Gutowski, 2021). As an illustration, while air temperature measures the temperature a person received from contact with air, mean radiant temperature measures the temperature from the radiant heat exchange from a human body to all the objects and surfaces in the room. But it depends on the temperature difference and emissivity of both temperatures. A globe thermometer, which is a hollow copper sphere painted black in the center and contains a temperature sensor, can be used to measure MRT (Mean Radiant Temperature, 2020). The heat from a warm object, which is in a form of energy, is transferred to another object with a lower temperature to achieve thermal equilibrium. This is because, the mean radiant temperature is the average temperature of all the objects in the vicinity (Thermal Comfort, 2010). For example, building components that face a hot and sunny orientation, such as a window facing the heat source (sunlight) will significantly raise the MRT level. Meanwhile, a cold building component, such as a cold floor that is located far from the heat source (sunlight) will lower the MRT level.

Another essential factor is air velocity, which refers to the air movement distance travelled per unit of time in m/s. The rate of heat transfer is affected by the dynamic relationship between the temperature and the temperature of the adjacent surfaces. This explains how heat transfer is proportional to the velocity of air movement across a surface. Unfortunately, draught complaints may arise due to the result of rapid changes in air velocity (Thermal Comfort, n.d.). On the contrary, in some hot weather conditions, a higher air velocity can be used to speed up the heat loss rate from the user's body to the surrounding environment. For example, turning on the fan to full speed will result in a higher air velocity. Figure below illustrates the types of body heat loss that happen around high air velocity (wind). Furthermore, air movement within a building is critical to avoid artificially heated still or stagnant air, which can make users feel stuffy. It can also lead to the accumulation of bad odour (HSE, 2015.).

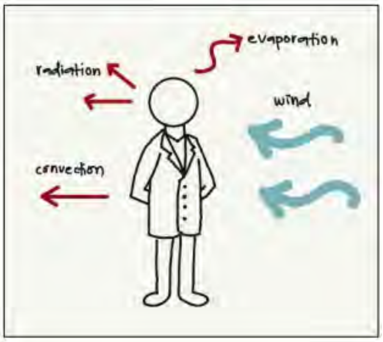


Figure 9: Body Heat Loss Due to High Air Velocity
Source: Author (2022)

Most of the time, moisture in the form of water vapour is present in the air. This occurs when water evaporated into the surrounding environment due to heat. Humidity levels are based on the amount of moisture content that gets evaporated in the air (HSE, 2015). When the temperature rises, the air can hold more water vapour, implying that the humidity level is affected by the climate temperature. Humidity measures the amount of water vapour in the air, whereas the ratio of the actual amount of water vapour in the air to the maximum limit of water vapour that air at its normal temperature can hold is the relative humidity. Relative humidity of 70% or higher can cause discomfort to the users. This is because higher humidity in the air will prevent body sweat from evaporating (Basic Factors Influencing Thermal Comfort, 2015). Buildings and properties can sustain extensive damage from high humidity levels such as dampness and mold. Excessive dryness caused by low humidity levels, on the other hand, is hazardous to the environment and human health. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends keeping the facility's indoor relative humidity (RH) between 40 and 60 percent (Peng, 2021).

RESEARCH APPROACH AND DESIGN

This research employs a quantitative research methodology aimed at investigating the thermal comfort perception of users and passive daylighting strategies in McDonald's restaurant buildings. The methodology involves systematic data collection, analysis, comparisons, and literature reviews. The research conducted on-site observations at three McDonald's restaurant buildings in Alor Setar, Kedah, over a three-month period from May to July 2022. The selected branches were McDonald's Alor Mengkudu in Jalan Alor Mengkudu (Restaurant A), McDonald's City Plaza in Jalan Tuanku Ibrahim (Restaurant B) and McDonald's Shell Kota Setar in Jalan Sultanah (Restaurant C). This timeframe allows for capturing data across different seasons, potentially affecting thermal comfort and daylighting conditions. The research methodology focuses on two main areas: the thermal comfort perception of the restaurant buildings' users and the passive daylighting strategies employed in these buildings. The three McDonald's restaurant buildings were selected to represent a diverse sample of existing restaurant buildings in the Alor Setar vicinity.

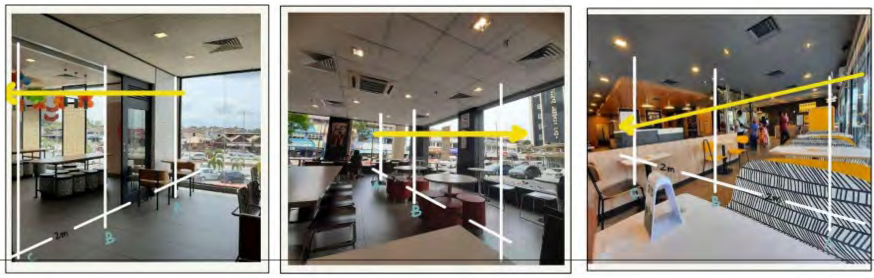


Figure 10: Dining Interior Conditions of Restaurant A, Restaurant B, and Restaurant C (from left to right)
Source: Author (2022)

During on-site observations, primary data were collected through instrument readings, including daylighting lux levels, temperature, and humidity. This quantitative data provides concrete measurements for analysis, allowing for a detailed understanding of the thermal conditions and daylighting strategies. Visual data in the form of photographs were taken during on-site visits. These images serve as supplementary evidence, aiding in the analysis and comparison of passive daylighting strategies across the selected case studies. documents related to the restaurant buildings, such as architectural plans, were annotated to provide context and additional insights into the passive daylighting strategies employed. These documents offer a comprehensive view of the building design and its impact on thermal comfort and daylighting.

This on-site observations and primary data collection are essential to capture real-world conditions and experiences within the selected McDonald's restaurant buildings. This approach ensures that the research findings are grounded in the actual context of the study. The systematic collection of primary data through instrument readings and photographs enhances the research's validity and reliability. Precise measurements and visual evidence contribute to the credibility of the findings. Secondary data were also gathered through extensive literature reviews encompassing books, journals, and internet articles. This step contributed a theoretical foundation to the research by incorporating established knowledge and research findings related to thermal comfort, passive daylighting strategies, and building design principles. Through the combination of primary and secondary data collection methods enriches the research's depth and breath. While primary data offers firsthand information, the secondary data on the other hand provide a broader perspective and theoretical foundations.

There are two data analysis method used in this research study, which is the quantitative analysis and comparative analysis. In quantitative analysis, the collected numerical data, including temperature, humidity, and lighting lux levels, were subjected to statistical analysis. Descriptive statistics and other data were computed to identify patterns and relationships within the data. By comparing the quantitative data from the three McDonald's restaurant buildings, the study aims to highlight variations in thermal comfort perception and passive daylighting strategies. This comparative approach allows for insights into the effectiveness of different strategies and their impact on users' comfort. Both methods align well with the research objectives of investigating thermal comfort perception and passive daylighting strategies, since the study can provide precise insights into these aspects, contributing to a comprehensive understanding.

Procedure of Data Collection During Research Study:

The study took place in the dining areas of the selected McDonald's restaurant buildings. Each session had three participants, and they followed a predetermined clothing ensemble. The session lasted around 30 minutes as per normal mealtime duration. Daylight levels and room temperatures were measured at 12 p.m. at distance of 0m, 2m, and 4m from the windows using a lux meter, and an infrared room thermometer. Participant skin temperature was also measured before the session. Participant A sat at 0m from the windows, Participant B at 2m, and Participant C at 4m. All participants stayed seated for the entire 30 minutes session, engaging in their meals. During the session, participants' skin temperatures and ambient room temperatures were monitored. The researcher remained present to guide participants. After the 30-minute exposure, skin temperatures and room temperatures were re-measured. Participants shared their perceptions of the indoor environment and their feelings during the exposure. This procedure was repeated for all selected McDonald's restaurant buildings.

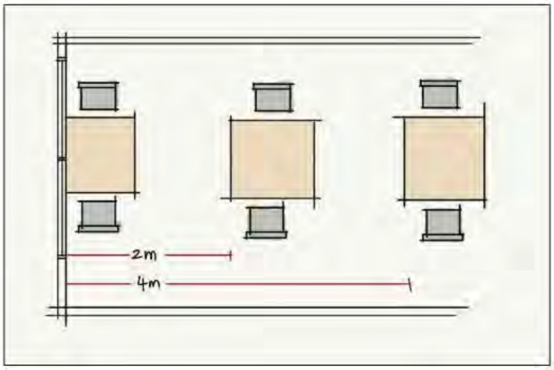


Figure 11: Assigned Seating Distance between All Participants.
Source: Author (2022)

FINDING

Indoor Dining Area Temperatures and Thermal Comfort Analysis:

Indoor dining area temperature were meticulously assessed across the three selected McDonald's restaurant buildings. Guided by the standards of EN ISO 7726, the recorded data was adjusted to yield an average room temperature value for each restaurant building, in accordance with their specific thermal conditions.

Utilizing Air Conditioning for Thermal Comfort:

The evaluation factored in the implementation and operation of air-conditioning system, a widely employed cooling method for fast-food restaurant buildings. The established room temperature values for all investigated restaurants ranged between 24.0 to 27.0 degrees Celsius. These room temperature benchmarks were pivotal in gauging the subsequent variations in indoor dining area temperatures within the chosen buildings.

Challenges and Considerations in Maintaining Standard Room Temperatures:

However, it should be noted that maintaining temperature uniformity, as set for each restaurant building, is a challenging task. The air conditioning systems do not introduce fresh air into the spaces but instead recycle the indoor air by cooling it and removing excess moisture to improve its quality. Each McDonald's restaurant building faces unique challenges in maintaining the desired room temperature. Hence, ambient temperature values were collected during the site observations to analyse the actual air temperature of the surrounding environment. The measured values were relatively close to the standard room temperatures specified for each restaurant building.

Table 3: Data Record Conditions of Restaurant A, Restaurant B, and Restaurant C (from left to right)
Source: Author (2022)

Window Orientation	North-oriented		
Participant	A	B	C
Distance from Windows (m)	0 m	2 m	4 m
Lux Levels (lux)	2899.0	1125.0	823.0
Participant Skin Temperature Before 30 Minutes (°C)	36.6	36.3	36.1
Participant Skin Temperature After 30 Minutes (°C)	37.5	36.9	36.3
Ambient Temperature (before 30 minutes) (°C)	26.8	26.6	26.5
Ambient Temperature (after 30 minutes) (°C)	27.2	26.8	26.6
Thermal Sensation / Perception of Participant	Warm	Comfortable	Slightly Cold

Window Orientation	South-oriented		
Participant	A	B	C
Distance from Windows (m)	0 m	2 m	4 m
Lux Levels (lux)	1502.0	761.0	568.0
Participant Skin Temperature Before 30 Minutes (°C)	36.3	36.4	36.5
Participant Skin Temperature After 30 Minutes (°C)	37.1	36.7	36.5
Ambient Temperature (before 30 minutes) (°C)	26.6	26.3	26.1
Ambient Temperature (after 30 minutes) (°C)	26.9	26.5	26.2
Thermal Sensation / Perception of Participant	Comfortable	Comfortable	Slightly Cold

Window Orientation	East-oriented		
Participant	A	B	C
Distance from Windows (m)	0 m	2 m	4 m
Lux Levels (lux)	3486.0	1553.0	713.0
Participant Skin Temperature Before 30 Minutes (°C)	36.3	36.8	37.1
Participant Skin Temperature After 30 Minutes (°C)	38.0	37.1	36.7
Ambient Temperature (before 30 minutes) (°C)	27.2	26.8	26.6
Ambient Temperature (after 30 minutes) (°C)	27.6	27.0	26.6
Thermal Sensation / Perception of Participant	Too Hot	Comfortable	Slightly Cold

The three tables above display the collected data from all three restaurants, around 12 p.m. The measurements were recorded from 0m, 2m, and 4m, away from each restaurant building's window that face different orientations.

Influence of Daylight Exposure on Ambient Temperature:

Ambient temperature, signifying the actual air temperature of the surrounding environment, emerged as a dynamic influenced by daylight exposure. Measurements were conducted before and after a 30-minute interval at specified distance, employing thermometer and a lux meter. The outcomes unveiled a distinct rise in ambient temperature following the daylight exposure period. The effect was particularly pronounced at the 0m distance from the windows, with a slightly lesser impact at 2m, and least at 4m. This highlights the tangible impact of daylight exposure on environmental temperature inside a restaurant. A clear correlation was evident: heightened illuminance levels at proximity to windows translated into elevated temperatures. This is because, building components that face a hot and sunny orientations, such as a window facing the heat source (sunlight) will significantly raise the mean radiant temperature level. Meanwhile, a cold building component, such as a cold floor that is located far from the heat source (sunlight) will lower the mean radiant level (Thermal Comfort, 2010). The graph below illustrates the average room temperature and ambient temperature values before and after 30 minutes of daylight exposure for each McDonald's restaurant building.

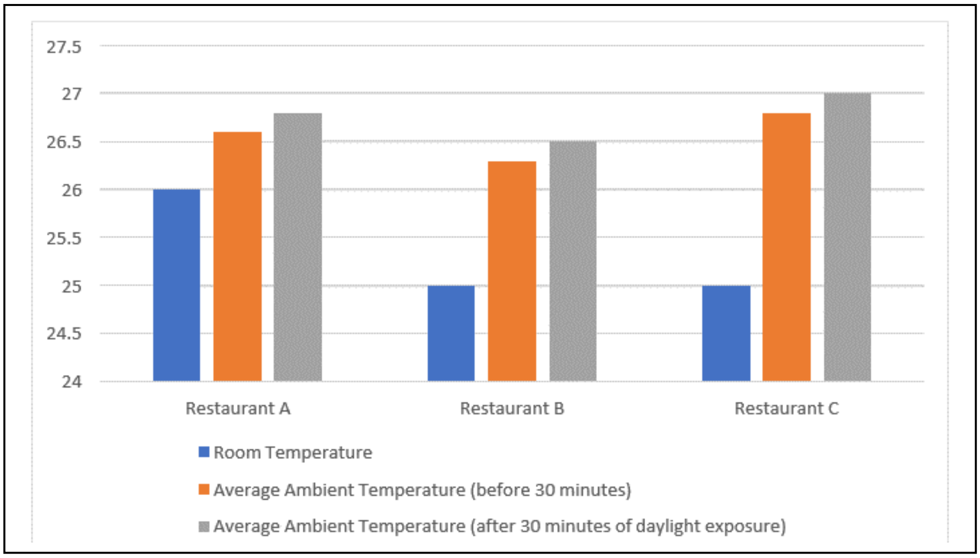


Figure 12: Differences between Room Temperature and the Average Ambient Temperature Measured (°C)
Source: Author (2022)

Influence on Thermal Sensation and Perception:

Although direct daylight exposure did not directly dictate user's thermal comfort (Thermal Comfort, 2010), it still emerged as a factor influencing the surrounding ambient temperature that ends up impacting the users in the vicinity. This is because this indirect influence triggered users' thermal sensations and perceptions. According to the Health and Safety Executive, it is also known as "the person state of mind whether they feel too hot or too cold" (HSE, 2015). The study findings revealed that users tended to feel warmer when seated in high temperatures with high daylight illuminance levels (lux levels) compared to medium and low illuminance levels, and vice versa.

During the study, participant A, sitting at 0m from the windows in all the restaurant buildings, experienced a gradual increase in skin temperature, leading to slight discomfort and sweating due to the heat. Participant B, who sat 2m away from the windows, experienced a slight increase in skin temperature and remained comfortable without sweating or shivering. In contrast, participant C, seated farther from the windows, expressed feeling slightly cold due to the air conditioning. Participant C's skin temperature slightly increased at Restaurant A, remained constant at Restaurant B, and gradually decreased at Restaurant C. The graph below illustrates the changes in participants' skin temperature before and after session.

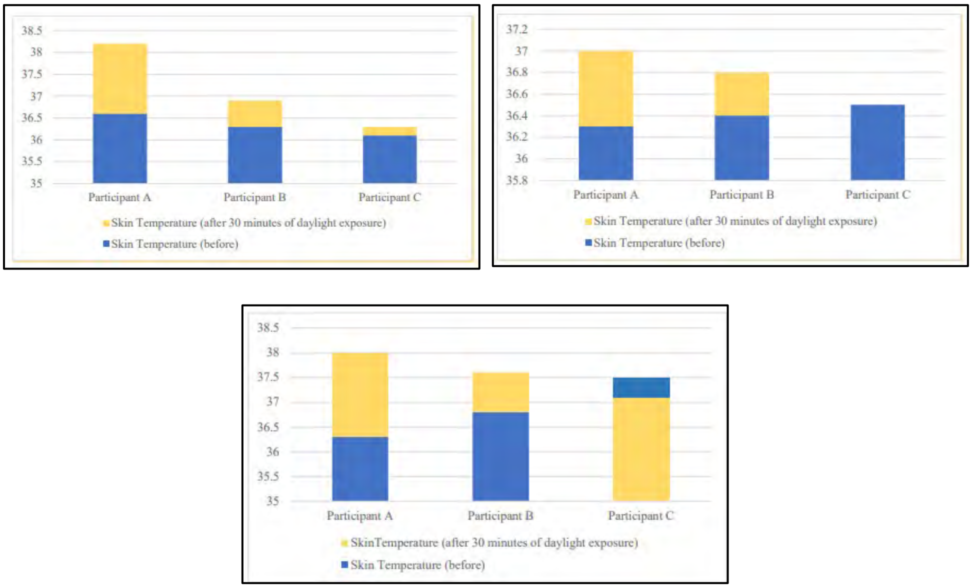


Figure 13: Changes of Skin Temperature of Participants in Restaurant A, Restaurant B, and Restaurant C (from left to right)
Source: Author (2022)

Influence of Building Orientation and Daylight Exposure

As expected, changes in temperature levels played a significant role in determining users' thermal sensations and perceptions, given the impact of daylight on temperature and a suitable control system should be implemented to maintain an acceptable level of daylight illuminance. For example, Restaurant A, which faces the north, utilizes large windows to maximize daylight intake since it receives less daylight than other orientations. At restaurant B, the building was south-oriented and benefits from an extended second floor that acts as an overhang, protecting against excessive daylight exposure. However, Restaurant C recorded high lux levels, causing Participant A, seated near the windows, to experience discomfort from heat and glare. It was suggested that Restaurant C lacked proper shading devices, resulting in higher recorded lux levels than other restaurants.

Figure 14: Large windows on North-Oriented Façade of Restaurant A (left), Large windows on South-Oriented Facades of Restaurant B (middle), Large windows on East-Oriented facades of Restaurant C (right)
Source: Author (2022)

The intensity of daylight illuminance entering the buildings and its impact on users was evident, with closer proximity to windows resulting in higher lux levels. The short-wavelength light from daylight was converted into heat, warming nearby objects or surfaces, and leading to changes in ambient temperatures. Since windows significantly contribute to heat transfer between indoor and outdoor environments, proper control measures such as external shading are necessary. Without adequate control, users may experience heat gain and glare, negatively affecting their dining experiences. These findings demonstrate that passive daylighting strategies can influence users' perception of thermal comfort on a psychological level and slightly impact skin temperature, albeit varying among individuals. Changes in skin temperature were attributed to heat gain and loss resulting from the interaction between daylight and the surrounding thermal environment.

CONCLUSION AND RECOMMENDATION

In conclusion, this research has effectively delved into the intricate relationship between passive daylighting strategies and their consequential impact on users' perceptions of thermal comfort. The investigation has substantiated that daylighting plays a significant role in influencing both indoor dining areas' air temperature and ambient temperatures, consequently shaping users' comfort, and overall dining experiences. Although the direct influence of daylighting on users' thermal comfort may be limited, given its primary effect on ambient temperature, its indirect influence should not be overlooked.

The comprehensive findings and thorough analysis of this study offer compelling evidence of the nuanced interplay between daylighting and users' thermal comfort, even though this connection might not have been traditionally acknowledged as a core driver of thermal comfort (Praveen Kumar, 2019). By shedding light on this relationship, this study contributes substantively to the broader field of research dedicated to enhancing human thermal comfort in restaurant's industry. As a result, it is imperative to incorporate daylighting as a variable of utmost significance when assessing users' perception of thermal comfort – both in practical design implementation and in the planning of future research endeavours.

Moving forward, it is evident that while daylighting stands as an exceptional method for creating an inviting, well-lit ambiance within dining areas, the avoidance of excessive daylight illuminance emerges as a pivotal consideration to avoid potential discomfort and glare for users. Restaurant owners strive to provide a comfortable dining experience, and therefore, implementing a well-designed external shading system is essential to maintain an optimal room temperature. Such a system is instrumental in ensuring an optimal indoor room temperature while simultaneously preserving the desired aesthetic and ambience.

To guide the successful incorporation of external shading, the following recommendations should be put forth. Firstly, integrating a comprehensive site analysis into the design process stands as an indispensable measure. By thoroughly assessing the site's orientation, solar exposure, and surrounding environment, designers can ascertain the most effective and tailored external shading solution to mitigate excessive daylight illuminance and its subsequent thermal effects. Next, employing an innovative approach to external shading design allows for the creation of visually appealing shading elements, that seamlessly complement the architectural aesthetics. Strategic design will ensure a harmonious blend of functional shading and aesthetic excellence. Implementing adaptive shading systems that respond to changing daylight conditions also can provide a dynamic solution to maintaining optimal indoor temperature throughout the day. These systems can automatically adjust the shading elements to regulate daylight ingress and prevent temperature spikes.

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