RESEARCH ARTICLE

Window Size and Opening Impact on Thermal Comfort Performance of Royal Malaysian Police (RMP) Lockup in Malaysia

Bismiazan Abd Razak[1*], Mohd Farid Mohamed[1], Fatin Atikah Abd Razak[2]

[1]Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

[2]National AI Office Malaysia (NAIO) Level 30-1, MOF Inc. Tower, 9, Persiaran KLCC, Kuala Lumpur 50088, Malaysia

*Corresponding author: bismiazan@ukm.edu.my

Abstract

Issues related to the ineffective design of lockup windows in Malaysia, which contribute to detainees' discomfort, have been frequently highlighted by SUHAKAM. The absence of standardized design guidelines for lockup windows has been identified as a key contributing factor to this problem. This study aims to evaluate the impact of varying window sizes and the percentage of window openings on the thermal comfort performance of lockups through multiple design configurations. A building performance simulation program, Integrated Environmental Solution-Virtual Environment (IES-VE), was utilized to simulate the thermal conditions of a case study lockup over one year. The objective was to determine an optimal window design that enhances thermal comfort performance based on recommendations from prior research, design standards, and Malaysian guidelines. The findings indicate that the 20-A window design, with a 20% opening size, is the most effective configuration, improving operative temperature by 0.8% compared to the existing 4% window opening. In small thermally confined naturally ventilated lockup spaces without mechanical cooling, even 0.1°C to 0.2°C can affect human thermal sensation and perceived acceptability in hot-humid climates. These results provide valuable insights for enhancing the current lockup window design to improve thermal comfort performance and mitigate detainee discomfort.

Keywords: *Thermal comfort performance, natural ventilation, window combinations, Royal Malaysian Police (RMP) lockup, IES-VE*

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Introduction

This paper presents an analytical study on the combination of window designs in Royal Malaysia Police (RMP) lockups to examine the optimal combination for achieving more efficient thermal comfort performance. The study was conducted through simulation processes on a case study lockup model located at the Alor Gajah District Police Headquarters, Melaka. The selection of this lockup as the simulation study model was based on previous research findings by SUHAKAM (2016), which identified it as one of the lockups facing issues and challenges related to inefficient natural ventilation and design.

A total of nine simulation series were conducted on nine different window design combinations, each with varying opening sizes and percentage of openings, based on the maximum allowable improvements to the existing design. The simulation process was carried out using the Integrated Environmental Solution-Virtual

Environment (IES-VE) software, which was selected for its capability to analyze and generate precise and accurate data, as recommended by previous studies on this software.

Several criteria were established for the case study lockup model to ensure the accuracy of the simulation. The physical characteristics of the lockup, as modeled in the simulation program, were required to closely resemble the original conditions in terms of size, dimensions, construction materials, finishes, adjacent spaces and rooms, and both internal and external environments. The selected case study lockup was designed for natural ventilation, with no mechanical ventilation influence applied throughout the simulation process. The window opening sizes and percentages were determined based on the existing design, current guidelines, and recommendations from previous researchers.

The final study results will be analyzed and generated to assess thermal comfort performance based on the operative temperature comfort index, aligned with ASHRAE Standard 55 which is 22.7 ºC to 29.7 ºC (ASHRAE 55, 2023). This analysis aims to evaluate the implication of different window design combinations on thermal comfort performance. Ultimately, the findings will serve as a guideline for designers, policymakers, and lockup standard guidelines to gain a clearer understanding of the optimal window design requirements for achieving more efficient thermal comfort performance in lockups.

Lockup Facilities Conditions in Malaysia

Lockup is frequently associated with police facilities. This association arises because any mention of a lockup often evokes the image of a police detention facility, typically linked to individuals who have committed offences or more precisely detainees. According to Dewan Bahasa dan Pustaka (2017), a lockup is defined as a room designated for the confinement of detainees. Similarly, PDRM (1953) describe a lockup as a temporary detention facility for individuals suspected of committing an offence who are under investigation or for those sentenced by the court to short term imprisonment. Abd. Razak et al. (2020) further defines a lockup as a temporary holding area or confinement cell used for a limited period to detain individuals suspected of wrongdoing but not yet convicted, while awaiting trial or sentencing if found guilty. This definition underscores that lockup detainees are individuals held only on a temporary basis for investigative and information gathering purposes prior to being brought before the court for adjudication, sentencing or imprisonment.

Despite the extensive body of research conducted both in Malaysia and globally on thermal comfort performance aimed at ensuring that buildings operate efficiently while maintaining optimal levels of occupant health and comfort, alongside efforts to promote energy conservation, reduce maintenance costs, and encourage sustainable building practices there remains an evident gap in studies focusing on the thermal comfort performance of lockup facilities. This research gap is particularly significant in regions with hot and humid climates such as Malaysia, where environmental conditions have a substantial impact on thermal comfort performance outcomes. The lack of empirical studies on lockup and detention environments limits the availability of reference materials and design guidelines that could inform post-occupancy evaluations and assist future designers and researchers in assessing the thermal comfort performance of such facilities. Furthermore, existing studies concerning lockups are scarce and often difficult to access especially those addressing critical issues such as ventilation performance, thermal comfort, indoor air quality, and window design both within Malaysia and globally. Table 1 presents several previous studies related to lockup facilities that have been conducted by past researchers including the author at both the national and international levels.

Table 1: Summary of Previous Studies on Security Facility Buildings (Lockup) at the National and International Levels

Research Topic	Author/Year	Research Description and Methodology
Monitoring Human Rights of Persons in Police Lockups: Potential Role of Community-Based Organizations	(Hounmenou, 2012)	This article explores how community organizations can enhance civilian review agencies by monitoring police lockups, examining abuse cases, human rights standards, oversight challenges, and international best practices adaptable to U.S. contexts.
Deaths in Police Custody a Thematic Study on Lockup Conditions and Factors Contributing to the Death	(SUHAKAM, 2016)	A study on the conditions and factors contributing to detainee deaths using qualitative and thematic methods through interviews, surveys, and observations of respondents and the study area.
Added Value to Security Building Design Case Study: Police Station in Malaysia	(Zaharin, 2019)	A study on the design planning and layout of Royal Malaysia Police (RMP) station facilities that comply with standard operating procedures (SOP), conducted through case study observations, literature review, interviews, and semi-structured questionnaires with respondents.
Research on the design typology of the Royal Malaysian Police (RMP) lockups	(Abd. Razak et al., 2020)	This study explores Royal Malaysian Police (RMP) lockup design typology, including definitions, types, infrastructure, standards, and issues highlighted by NGOs, using qualitative methods to provide guidance, references, and comprehensive understanding.
Thermal Comfort Performance of Naturally Ventilated Royal Malaysian Police (RMP) Lockup in Hot and Humid Climate of Malaysia	(Abd. Razak et al., 2021)	This study investigates thermal comfort performance in three RMP lockups during monsoon transition, revealing that Penang's facility exceeds ASHRAE 55 thresholds, indicating inadequate ventilation and informing future architectural design improvements.

Source: (Author, 2025)

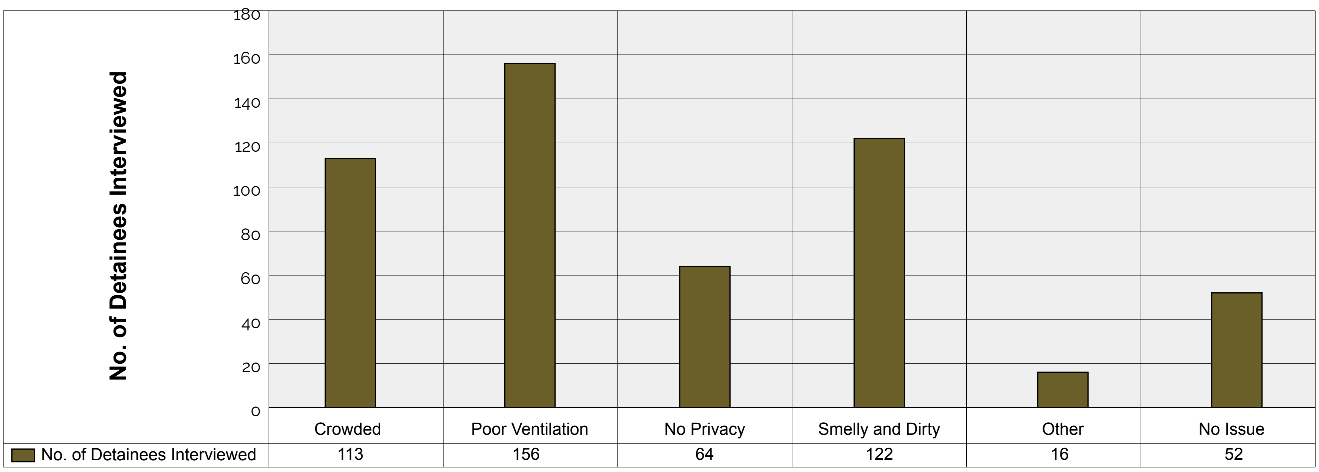
From the related studies, the research conducted by Hounmenou (2012) mentioned that standards and civilian oversight agencies alone cannot effectively prevent police abuse due to resource limitations and restricted cooperation. It proposes community-based monitoring as a proactive approach highlighting independent visitor groups capacity to investigate systemic misconduct, improve conditions in police lockups and enhance public trust in fair police practices. Meanwhile, the study by SUHAKAM (2016) was a qualitative or thematic study based on observations and interviews that were conducted. No scientific measurement instruments were recorded at the study site. On the other hand, the study by Zaharin (2019) focused on the planning, design and layout of Royal Malaysia Police (RMP) station facilities designed in accordance with PDRM standard operating procedures (SOP). This was achieved through case study observations, literature reviews, interviews and semi-structured questionnaires administered to respondents.

Recent research related to lockups was also conducted by the author in 2020 and 2021. The study by Abd. Razak et al. (2020) identified several lockup typologies covering definition, type, standards, and design across various security agencies, revealing structural similarities. It emphasizes the need for agency-specific adherence to SOPs, improvement of weaknesses, and preservation of strengths. The research recommends developing comprehensive RMP lockup design guidelines, highlighting future studies on natural ventilation, thermal comfort, and detainee health. Research by Abd. Razak et al. (2021) investigates the thermal comfort performance of Royal Malaysia Police (RMP) lockups to assess indoor comfort levels. Field studies were conducted in three lockups located in Penang, Melaka, and Kuala Lumpur during the hot, humid monsoon transition. Measurements were compared with ASHRAE 55 standards and previous building comfort studies, as no prior Malaysian lockup research exists. Selected lockups featured full natural ventilation with fans turned off to capture true environmental conditions. Cells were chosen for size and finishing consistency and tests were performed in vacant spaces. Findings focus on understanding each lockup thermal comfort performance relative to window openings and spatial volume.

The window design of police lockup has also been a persistent concern raised by non-governmental organizations (NGOs) and independent commissions both at the national and international levels particularly regarding human rights and detainee welfare. This issue arises because the window design in many police lockups is often considered ineffective, resulting in inadequate natural ventilation within detention cells. Factors such as insufficient number of windows, inadequate window dimensions, and improper orientation have been repeatedly identified as key contributors to poor ventilation which in turn lead to significant thermal discomfort among detainees. In more severe cases, ineffective window design and poor ventilation systems have been associated with critical incidents including detainee deaths attributed to inadequate airflow and thermal stress as reported by the Human Rights Commission of Malaysia (SUHAKAM, 2016).

Based on Figure 1, which was adapted from the findings of SUHAKAM thematic study on several Royal Malaysia Police (RMP) lockup across the country, various infrastructural issues have been identified concerning the condition of lockup facilities (SUHAKAM, 2016).

Figure 1: A Thematic Study on the Detainee Lockup Infrastructure of the Royal Malaysia Police (RMP)



Source: (SUHAKAM, 2016)

The thematic study which involved 523 respondents comprising detainees interviewed during the investigation revealed that the most significant issue reported within lockup was poor ventilation, cited by 156 respondents. This was followed by unpleasant odors and unhygienic conditions, reported by 122 respondents. These two factors are closely interrelated as both directly influence the overall comfort and health of detainees within the lockup environment.

The ineffective size and design of lockup windows often being too small, insufficient in number, or obstructed are frequently cited as the primary causes of poor ventilation within detention cells. Inadequate internal airflow prevents proper air exchange, resulting in stale, humid and odorous indoor conditions that create hot and uncomfortable environments for detainees. This situation is further exacerbated by the presence of in-cell toilets that are poorly maintained. Poor ventilation, characterized by excessive heat, unpleasant odour and unsanitary conditions contributes to significant discomfort due to unhealthy and low-quality air circulation and in extreme cases, has been linked to detainee fatalities. This issue is not confined to local contexts alone but has also been a recurring concern raised by international human rights and detainee welfare organizations such as the United Nations (UN) and the World Health Organization (WHO) in global conventions. However, given Malaysia's climatic conditions as a hot and humid tropical country, achieving an acceptable level of thermal comfort performance within lockup is particularly challenging if the design does not adequately consider all relevant climatic factors.

The Implication of Window Design on the Thermal Comfort Performance of Buildings

As widely known, windows are one of the essential and complex components in the design of any building (Christian et al., 2015). This is because windows play a crucial role in providing and regulating ventilation and natural lighting within a building to ensure the comfort of its occupants through air circulation and exchange. The window component is also of greater importance and is carefully considered in various aspects, such as dimensions, percentage of opening, positioning, window type, and more (Talarosha & Marisa, 2018). This is especially crucial for buildings that rely on natural ventilation and are in hot and humid climates year-round, such as in Malaysia. An effective window design for a building can create a well-regulated indoor environment while enhancing the occupants' work performance, emotional well-being, and physical comfort (Talarosha & Marisa, 2018; Tamaskani Esfahankalateh et al., 2021).

As a country with a hot and humid climate throughout the year, characterized by low ambient wind speeds and fluctuating conditions due to monsoonal variations, achieving optimal thermal comfort performance in buildings solely through natural ventilation via windows remains a significant challenge (Abd. Razak et al., 2021; Lim, 2014). This is because naturally ventilated buildings rely heavily on pressure differences between the surrounding and indoor air, as well as the direction of airflow, to facilitate effective ventilation (Khalit et al., 2023; Mohammad Yusoff, 2020; Saadatjoo et al., 2018). Although various parameters and aspects are commonly considered to enhance ventilation systems through window design such as dimensions, percentage of opening, window placement and window type, the window size remains one of the simplest and most effective strategies that designers can adopt to achieve optimal ventilation levels (Elshafei et al., 2017).

In Malaysia, various guidelines have been introduced as references for designing appropriate windows for buildings. For example, the Street, Drainage, and Building Act (SDBA) and the Uniform Building By-Laws (UBBL) mandate that window designs for any space must have a minimum size percentage of 10% or 1/10 of the total floor area, with at least 5% of the total floor area remaining unobstructed (Uniform Building By Law (Amendment 2012), 2012; UPE JPM, 2024). Based on this regulation, every building design must incorporate natural ventilation through windows that meet the specified minimum percentage to ensure a comfortable indoor environment for its occupants. According to Tamaskani Esfahankalateh et al. (2021), ensuring adequate window sizing and appropriate positioning is crucial to preventing issues related to insufficient ventilation and lighting. Inadequate provisions in these aspects can negatively affect occupants, leading to discomfort and health problems due to poor air circulation and ineffective airflow. However, according to a study by Lim (2014), the recommended opening percentage of 10% or 1/10 of the total floor area, with at least 5% unobstructed, is insufficient to achieve a comfortable and healthy indoor environment for occupants. Therefore, this statement must be considered in this study to verify and determine whether it is indeed accurate.

A Study on the Window to Wall Ratio (WWR) and Opening Impact on Thermal Comfort Performance of Buildings with Natural Ventilation

In addition to the guidelines introduced and recommended by relevant agencies, previous studies conducted by academics, professionals, and industry experts have also explored the effectiveness of window design in buildings across various aspects. Numerous studies have been conducted to identify the best methods and solutions for addressing building ventilation issues, ensuring that indoor environments achieve optimal thermal comfort and indoor air quality. Among the studies that have been conducted are as presented in Table 2.

Table 2: Summary of Selected References on the Implication of Window Design on Thermal Comfort Performance in Naturally Ventilated Buildings in Tropical Climate

Author/Year	Country and Koppen Climate	Research Parameters	Research Description and Methodology
(Talarosha & Marisa, 2018)	Indonesia (Tropical rainforest)	Type of window usage Window opening percentage Window positioning	A qualitative study on 58 school classrooms to determine which design provides the best thermal comfort performance, indoor air quality, and natural lighting for students and teachers.
(Lim, 2014)	Malaysia (Tropical rainforest)	Window opening size	A survey-based study on terrace housing in Malaysia to investigate the thermal and visual comfort performance of residents, influenced by window opening constraints and environmental factors, particularly low wind speed in the country's climate.
(Christian et al., 2015)	Ghana (Tropical monsoon)	Window size Window positioning	A parametric simulation study on residential rooms to analyze the effects of window size and positioning on the indoor temperature of the studied building space.
(Sacht & Lukiantchuki, 2017)	Brazil (Tropical climates)	Window opening size	A simulation-based study on the effect of natural ventilation flow on thermal comfort performance and indoor air quality in the study room, based on window size and opening angle.

Source: (Author, 2025)

A qualitative study by Talarosha & Marisa (2018), conducted through field observations on 58 classrooms from 40 schools in Indonesia, examined the thermal comfort performance, indoor air quality, and lighting for teachers and students. The study suggested that a window opening percentage of 20% is ideal for sufficient daylighting, with a fixed opening for ventilation ranging from 6% to 10%. Additionally, it recommended positioning windows at a height of 1.0 meter to 1.4 meter from the floor level to ensure fresh air circulation. Lim (2014), through a study of 31 terraced houses with various designs from 12 residential areas around Johor Bahru, Malaysia, using survey and statistical methods, focused on examining the thermal comfort performance and visual comfort performance of the residents. This study also states that each residential room should be equipped with natural ventilation and lighting through windows, with a minimum area of 10% of the floor space, of which at least 5% should be operable or unobstructed, as stipulated in the UBBL. However, the findings of this study also indicate that the natural ventilation and lighting requirements stipulated by the UBBL are insufficient to ensure a comfortable and healthy indoor environment.

Christian et al. (2015) conducted a study using the Tas Tool parametric simulation process on residential rooms in Ghana to observe the effects of window size and position on indoor temperatures, influencing thermal comfort performance in residential buildings in the country. The effective window size recommended for this study (residential buildings) ranges between 10% and 30% of the floor area, as it contributes to the thermal comfort performance of the space. Meanwhile, a window opening size of 40% is still considered acceptable. Sacht & Lukiantchuki (2017), through a study conducted using Computational Fluid Dynamics (CFD)-Ansys CFX simulations on a test room, examined the effects of natural ventilation flow on the indoor environment, influencing thermal comfort performance and indoor air quality based on window size. Based on the overall study increasing the window size from 10% to 25% enhances the air change rate per hour by allowing a greater volume of air to circulate within the space.

In addition to studies focusing on parameters such as window size, percentage, position, and building orientation, previous researchers have also investigated the effectiveness of window design in influencing a building's thermal comfort performance through various alternative approaches and design improvements. These include the use of different window types in studies (Liu & Lee, 2019), variations in window configurations (Wang et al., 2018), user behavior concerning window openings in buildings (Lai et al., 2018), comparisons of different window types and their effect on indoor environmental conditions (Gao & Lee, 2011), and the effects of window shading usage and placement (Othman et al., 2021).

However, each proposed design improvement and technological advancement in these studies must align with the objectives and functional requirements of a building to ensure that the suggested modifications are appropriate and relevant to the intended goals. In this study, a lockup building is specifically designed for natural ventilation using iron grille windows combined with expanded metal. These windows remain constantly open, allowing for continuous and unobstructed airflow. For security and privacy reasons, lockup windows are designed in this manner, ensuring that all materials used are secure and resistant to manipulation, preventing detainees from turning them into potential weapons (Abd. Razak et al., 2020).

From a review of previous studies, it can be summarized that window design contributes to various implications on a building's thermal comfort performance. Factors such as window size, percentage, position, orientation, window type, and other design elements all play a significant role in shaping indoor thermal conditions. The significance of window design is more pronounced in buildings that rely entirely on natural ventilation without support from mechanical, automated, or hybrid systems. This is because ventilation potential depends entirely on external environmental factors, such as prevailing wind speed and indoor environmental conditions.

In this study, the significance of window design on a building's thermal comfort performance will focus primarily on natural ventilation, specifically considering window size and percentage of opening. These two factors are key elements outlined in national building design guidelines, including requirements set by Local Authorities (PBT) and regulations such as the Uniform Building By-Laws (UBBL) and the Street, Drainage, and Building Act (SDBA) (Act 133). Additionally, they are practical for designers to implement and cost-effective, as they do not require significant modifications to existing windows or buildings. Additionally, these two factors are the focus of this study because lockup window designs follow standardized specifications which is iron grille windows with expanded metal to ensure security and alignment with the functional requirements of a detention facility. The proposed alternative designs will also consider the rationale behind security and privacy factors for detainees within the lockup. Therefore, the proposed improvements in this study will focus on window size and window size percentage without altering the existing window materials or types. The determination of each proposed alternative will also consider the recommendations made by previous researchers to obtain the best solutions and suggestions for optimizing window design. This will be based on window size and size percentage to ensure effectiveness.

Methodology

Case Study Lockup Model located at the Alor Gajah District Police Headquarters, Melaka

Located at longitude 102° 14' 25.80" E and latitude 5° 24' 59.99" N, the selection of the case study lockup was based on findings from SUHAKAM (2016), which identified ventilation issues and challenges as contributing factors to detainees health conditions and mortality rates. Table 3 shows finding about lockup with ventilation and window design issues by SUHAKAM in 2016.

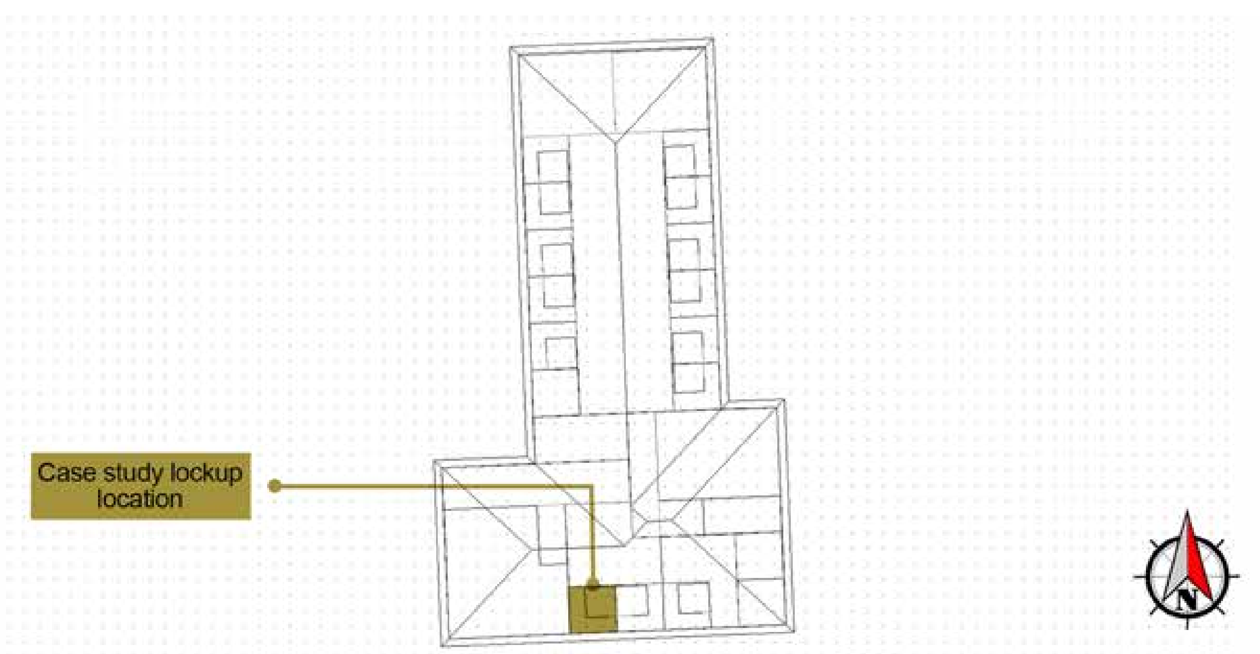
Table 3: SUHAKAM Findings Related to Problematic Lockups in Malaysia

Northern and Central Zone Lockups	Southern and East Coast Zone Lockups	Sarawak and Sabah Zone Lockups
Jalan Patani	**Alor Gajah**	Lahad Datu
Datuk Keramat	Batu Pahat	Ranau
Kota Setar	Tanah Merah	Tabuan Jaya, Kuching
Kepala Batas	Rantau Panjang	Lokap Berpusat Kontijen Sabah
Kubang Pasu	Tampin	Penampang
Pelabuhan Klang	Melaka Tengah	Bintulu
Kepala Batas	Balai Pontian	Kuching
	Kuala Terengganu	Lahad Datu
	Kluang	

Source: (SUHAKAM, 2016)

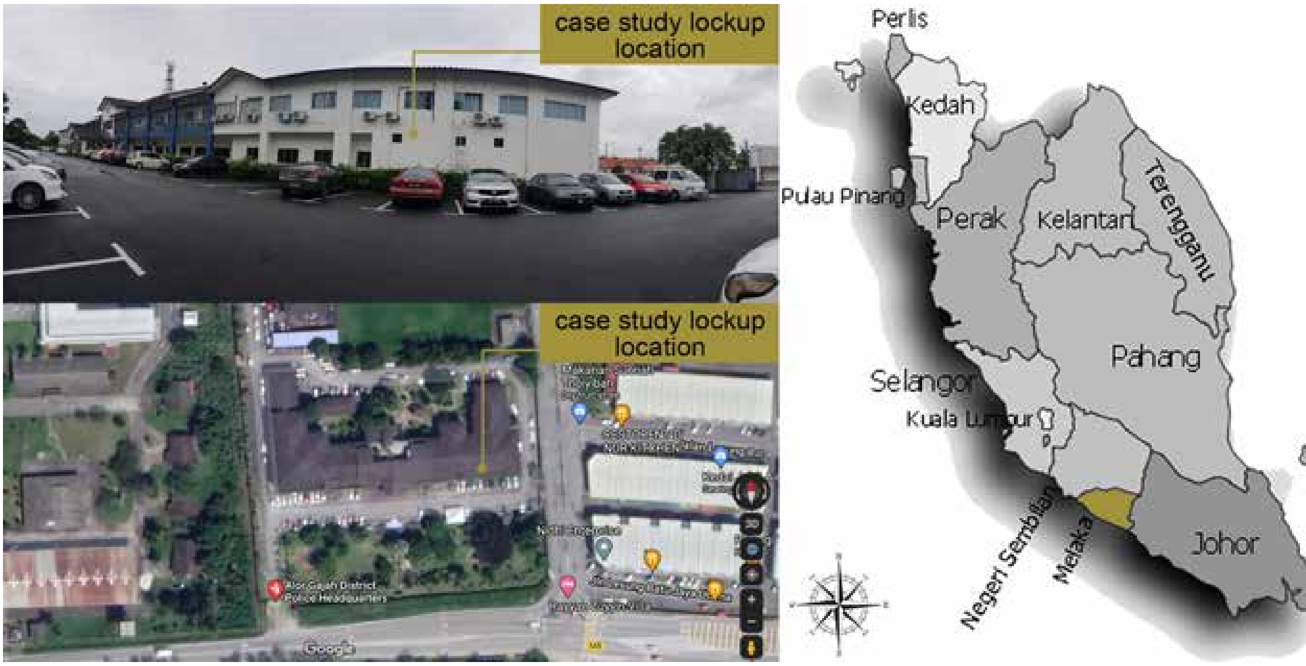
Figure 2 and Figure 3 shows the selected lockup, which is in Alor Gajah District Police Headquarters, Malacca situated in the southern section of the lockup building. The front section of the lockup cells consists of an overflow or recreation area that can be used to accommodate additional detainees when the lockup cells are full as well as to serve as a space for detainees' recreational activities. The building is designed with a cross-ventilation concept with 16 lockup cells positioned along the outer perimeter walls, cells designed for three detainees and others for six detainees while the central area functions as the overflow or recreation space. All the cells share the same window design, which consists of medium-hard steel bar grilles layered with expanded metal. On the left side are the lockup cells, all built with the same design while the right side contains other rooms such as offices and inspection areas that use standard sliding windows. The upper window space of the lockup cells accommodates the office area. The exterior surroundings of the lockup in this case study show no significant obstructions and are mainly surrounded by roads, parking spaces, and small to medium-sized trees.

Figure 2: Case Study Lockup Cell Location and Floor Plan



Source: (Author, 2025)

Figure 3: Case Study Lockup Location

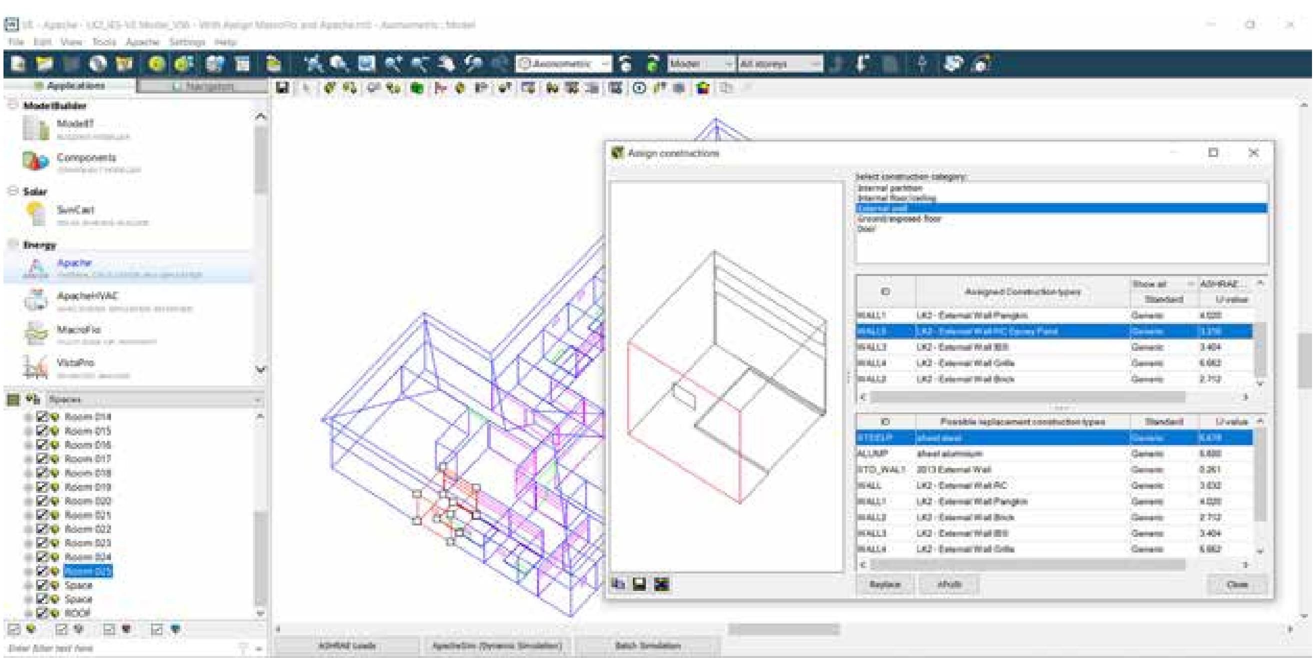


Source: (Author, 2025)

Lockup Model (Standard Size and Design Model)

To complete this study, a simulation process using the Integrated Environmental Solution-Virtual Environment (IES-VE) building performance simulation software was conducted on the Case Study Lockup Model located at the Alor Gajah District Police Headquarters, Melaka as shown in Figure 4.

Figure 4: The Modelling Process of the Case Study Lockup Using Integrated Environmental Solution-Virtual Environment (IES-VE) Software

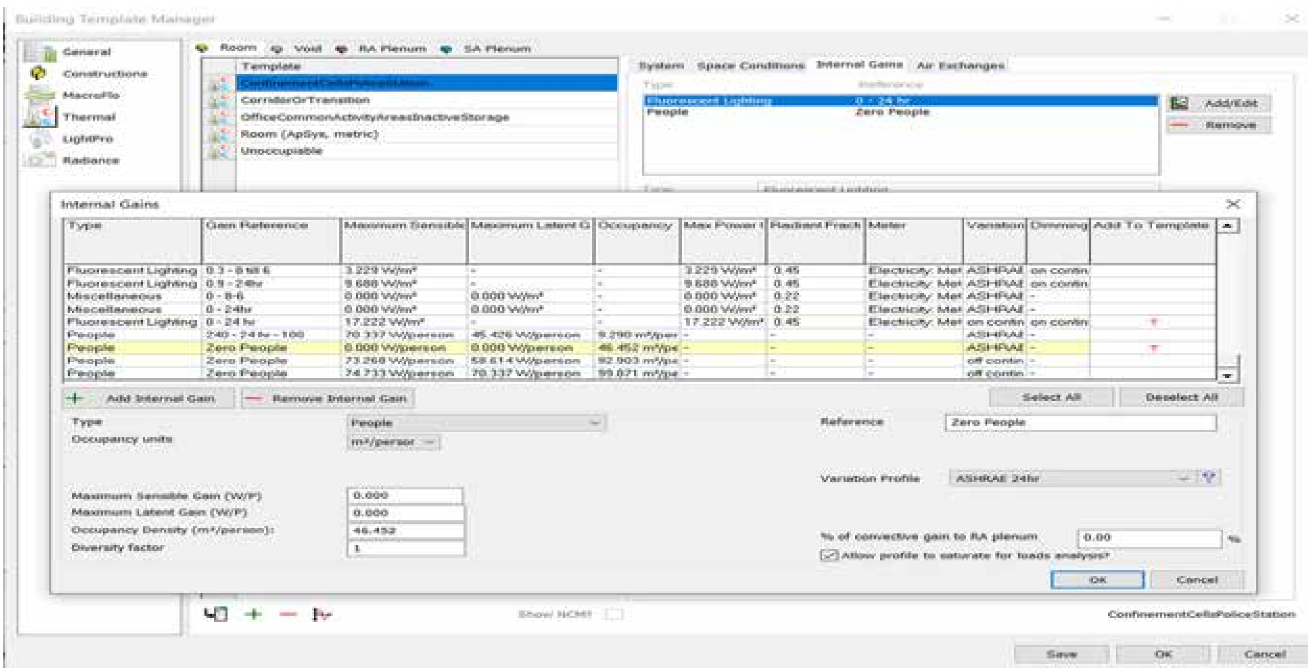


Source: (Author, 2025)

The model follows standard dimensions of 3.0 m (width) × 3.0 m (length) × 4.2 m (height), incorporating window openings and direct natural ventilation as a reference. This lockup model represents a standard detention cell designed to accommodate one to three detainees at a time. The selection of this lockup model was made because it represents a basic lockup design that meets the standard width, length, and height criteria commonly used in the design of detention complexes or zones, particularly for police stations and centralized detention facilities.

Table 4 and Figure 5 show the list of material specifications that include U-Value data and other thermal influence factors determined in the simulation process such as Internal Gains and Air Exchanges which encompass the input parameters like Type, Occupancy Density (m2/person), Maximum Sensible Gain (W/P) dan Minimum Sensible Gain (W/P).

Figure 5: Building Material Configuration and Thermal Influences in Simulation Process



Source: (Author, 2025)

Table 4: Building Material Specifications for the Lockup Building Performance Simulation Process

Category	Construction	Thickness (mm)	U-Value (W/m^2-K)
External wall	Reinforced concrete c/w cement plaster and rendering	150	3.83
Internal partition	Cast concrete (IBS) c/w cement plaster	150	2.61
Exposed floor	Reinforced concrete c/w screed	150	3.59
Internal ceiling	Reinforced concrete c/w cement plaster and screed	150	2.99
Door and internal grille panel	Iron grille	20	6.67
Window	Iron grille c/w expanded metal	25	6.66
Bed	Reinforced concrete c/w gravel and hard wood on top (tongue and groove)	150	2.00

Source: (Author, 2025)

The simulation methodology employed conservative assumptions including minimal internal heat gains from 1 to 3 sedentary occupants and low lighting/ equipment loads representative of single cell use fixed window openings precluded behavioral variation. A detailed building materials table specifies thermal properties (e.g., wall U-value = 2.83 W/m²K), solar parameters and site context (unobstructed facade with open field and parking area with minimal trees).

The selection of the IES-VE simulation program is also based on previous studies by Leng et al. (2012); Qays Oleiwi et al. (2019) and Razak et al. (2023), which indicate that the percentage difference between 0% and 20% is minimal and acceptable for simulation process. Leng et al. (2012) in a previous study recommended that the acceptable percentage difference between field measurements and simulation programs ranges from 0% to 15% for studies involving air temperature and relative humidity. This statement is also supported by validation studies comparing the accuracy differences between field measurements and simulation programs conducted by Qays Oleiwi et al. (2019) and Razak et al. (2023) which reported percentage differences ranging from 0% to 20% for studies involving air temperature, relative humidity, mean radiant temperature and operative temperature. This confirms that IES-VE is among the most accurate, flexible, and validated programs for simulating building thermal performance.

Determination of Environmental Climate Conditions

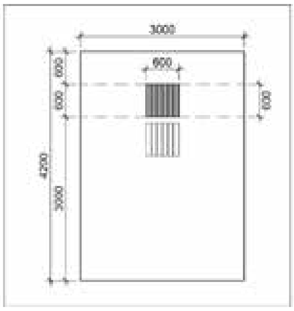
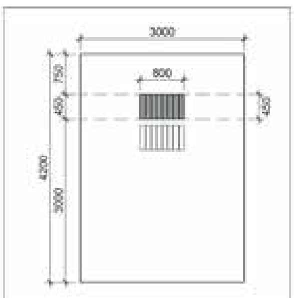
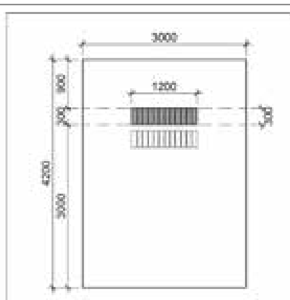
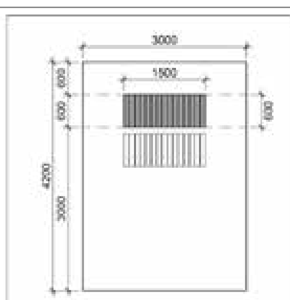
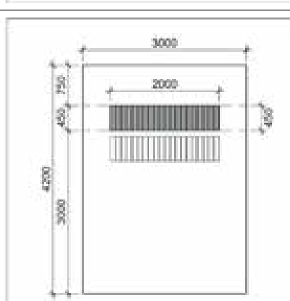
The environmental climate conditions for this extended simulation have been set to reflect Malaysia's climate, which is characterized by hot and humid conditions throughout the year. This selection was made because previous studies have highlighted ventilation issues in case study lockups located within this climate zone. Additionally, the weather data for the simulation process has been configured to represent year-round conditions in Malaysia, enabling the analysis of monthly and annual average readings for each required study parameter.

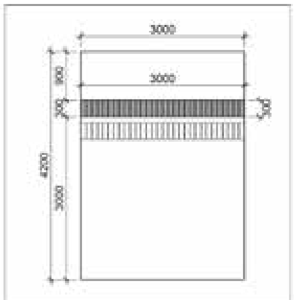
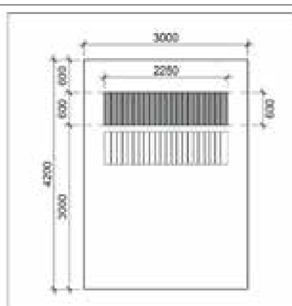
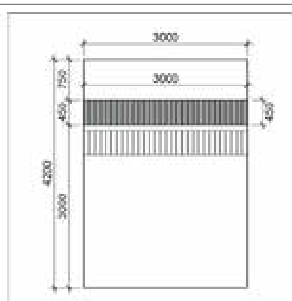
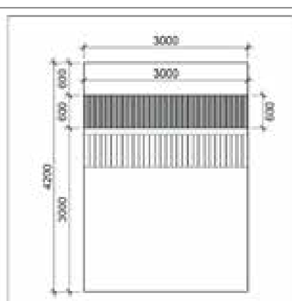
The climate condition in Melaka experiences an average minimum daily temperature ranging from 22.7 °C to 23.7 °C, while the average maximum daily temperature ranges from 31.1 °C to 33.1 °C. The average annual rainfall is 1,971.8 mm, and the humidity level is 81% (World Meteorological Organisation, 2025). The simulation utilized the IES-VE TMY weather file for Malaysia (baseline configuration representative of 2024 conditions). As specific data for Malacca were unavailable in IES-VE, Kuala Lumpur was selected as the nearest equivalent weather station. The dataset was cross-verified against the Malaysian Meteorological Department (Met Malaysia) records for the nearest Alor Gajah station (2018–2023 averages) to ensure climatic representativeness and consistency of temperature, humidity and solar radiation profiles for the study location.

Model Setting and IES-VE Simulation

Several window design combinations for the lockup space will be tested to evaluate the thermal comfort performance generated. This approach aims to analyze the differences in thermal performance for each proposed combination. The selection of these window design combinations considers findings and recommendations from previous researchers, existing standard designs, and national guidelines and regulations. The designated window size percentages include 4% (existing design), 10% (Christian et al., 2015; Uniform Building By Law (Amendment 2012), 2012; Lim, 2014; Sacht & Lukiantchuki, 2017; UPE JPM, 2024), and 20% (Christian et al., 2015; Elghamry & Hassan, 2020; Sacht & Lukiantchuki, 2017; Talarosha & Marisa, 2018). An additional combination with a 15% window size percentage is also introduced as an alternative in this study. The proposed combinations are illustrated in Table 5.

Table 5: The Combination of Window Size Dimensions, Percentage of Dimensions, and Window Openings

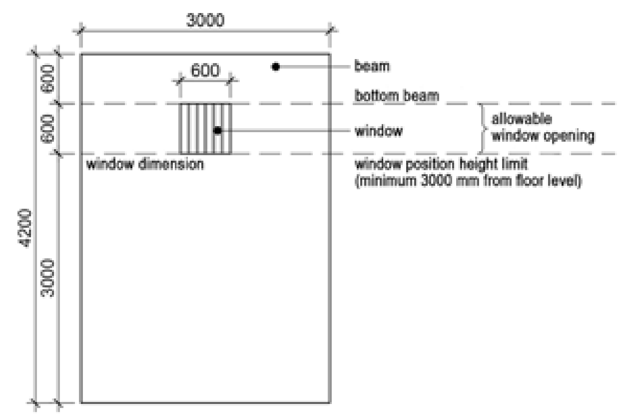
Size Code	Illustration of Window Combinations (wall facade)	Window Dimension	Percentage of Window Opening	Percentage of Ventilation Openings	Example of Recommendations Based on Window Size Percentage
		Height (m) x Width (m)	(%)	(%)	
4-A		0.6 m x 0.6 m	4% (0.36 m²)	83.33%	Standard Design (Existing)
4-B		0.45 m x 0.8 m	4% (0.36 m²)	83.33%	Standard Design (Existing)
4-C		0.3 m x 1.2 m	4% (0.36 m²)	80.55%	Standard Design (Existing)
10-A		0.6 m x 1.5 m	10% (0.90 m²)	81.11%	(Uniform Building By Law (Amendment 2012), 2012) (UPE JPM, 2024) (Lim, 2014) (Christian et al., 2015) (Sacht & Lukiantchuki, 2017)
10-B		0.45 m x 2.0 m	10% (0.90 m²)	81.11%	(Uniform Building By Law (Amendment 2012), 2012) (UPE JPM, 2024) (Lim, 2014) (Christian et al., 2015) (Sacht & Lukiantchuki, 2017)

Size Code	Illustration of Window Combinations (wall facade)	Window Dimension	Percentage of Window Opening	Percentage of Ventilation Openings	Example of Recommendations Based on Window Size Percentage
		Height (m) x Width (m)	(%)	(%)	
10-C		0.3 m x 3.0 m	10% (0.90 m^2)	81.11%	(Uniform Building By Law (Amendment 2012), 2012) (UPE JPM, 2024) (Lim, 2014) (Christian et al., 2015) (Sacht & Lukiantchuki, 2017)
15-A		0.6 m x 2.25 m	15% (1.35 m^2)	81.48%	Alternative Design of This Study
15-B		0.45 m x 3.00 m	15% (1.35 m^2)	80.74%	Alternative Design of This Study
20-A		0.6 m x 3.00 m	20% (1.80 m^2)	80.55%	(Talarosha & Marisa, 2018) (Elghamry & Hassan, 2020) (Christian et al., 2015) (Sacht & Lukiantchuki, 2017) (Christian et al., 2015)

Source: (Author, 2025)

Although several combinations have been established for the purpose of this simulation process, the window height has been fixed at a maximum of 3.0 meters from the floor level due to safety factors and the privacy of detainees in the lockup. This specification also aims to ensure that the proposed design improvements do not exceed the standard operating procedures and regulations of relevant security agencies, while also upholding the human rights of detainees. Since the lockup model selected for the simulation process is based on case study lockup with standard dimensions of 3.0 m (width) × 3.0 m (length) × 4.2 m (height), the remaining maximum allowable space available is 3.0 m (width) × 0.6 m (height), considering the height limit of 3.0 m from the floor level. Based on the available maximum allowable space, the maximum percentage ratio of the window area to the floor area is only 20%. This percentage can be further increased if modifications are made to the height of the lockup, as a taller would provide a larger allowable space, thereby contributing to a higher window size percentage. The position of the window opening will be set within the allowable space between the window height limit and the bottom level of the beam, as illustrated in Figure 6.

Figure 6: Example of Window Opening Positions in the Allowable Space



Source: (Author, 2025)

The simulation process was conducted over a one-year period, starting from January to December, to comprehensively assess thermal comfort performance throughout the year. During this period, variations in weather conditions, monsoon changes, and environmental climate fluctuations are expected to occur, all of which may affect the recorded thermal comfort performance. The findings of this simulation will focus on analyzing the results of the operative temperature thermal comfort index for each design combination, serving as the comfortable temperature reference for the studied lockup. The recorded readings will be based on the monthly and annual average simulation results. Table 6 shows information on the environmental conditions of the lockup studied, including temperature, air velocity, relative humidity, and wind direction. These parameters were recorded as monthly averages over a one-year measurement period.

Table 6: Environmental Conditions of the Case Study Lockup Over a One-Year Period

Parameters	Reading/Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Prevailing Temperature (°C)	26.9	27.0	27.5	27.6	27.6	27.9	27.3	27.1	27.2	26.7	26.7	26.4
Prevailing Air Velocity (m/s)	1.1	1.8	1.3	1.8	1.6	1.4	1.6	1.6	1.9	1.5	1.3	2.0
Prevailing Relative Humidity (%)	81.2	79.9	83.9	80.3	81.5	79.3	82.3	82.9	80.1	84.2	83.7	83.0
Prevailing Wind Direction (Azimuth) (°)	97.1°	205.5°	125.6°	171.1°	183.0°	91.6°	131.2°	125.7°	196.0°	143.0°	119.3°	213.9°

Source: (Author, 2025)

Table 7 presents the average environmental conditions of the lockup studied over a one-year measurement period, including the minimum, maximum, and average recorded values. The minimum recorded prevailing temperature was 27.2°C at 11:00 on April 6, with a reading of 20.9°C, while the maximum prevailing temperature was recorded at 35.8°C at 17:00 on July 6. The average recorded monthly prevailing air velocity was 1.6 m/s. The minimum air velocity was recorded at 00.0 m/s at 13:00 on January 1, while the maximum air velocity was recorded at 20.6 m/s at 11:00 on February 1. The average recorded monthly relative humidity was relatively high, with a recorded reading of 81.9%. The minimum recorded humidity was 36.0% at 17:00 on July 3, while the maximum humidity reached 100.0% at 5:00 on July 21.

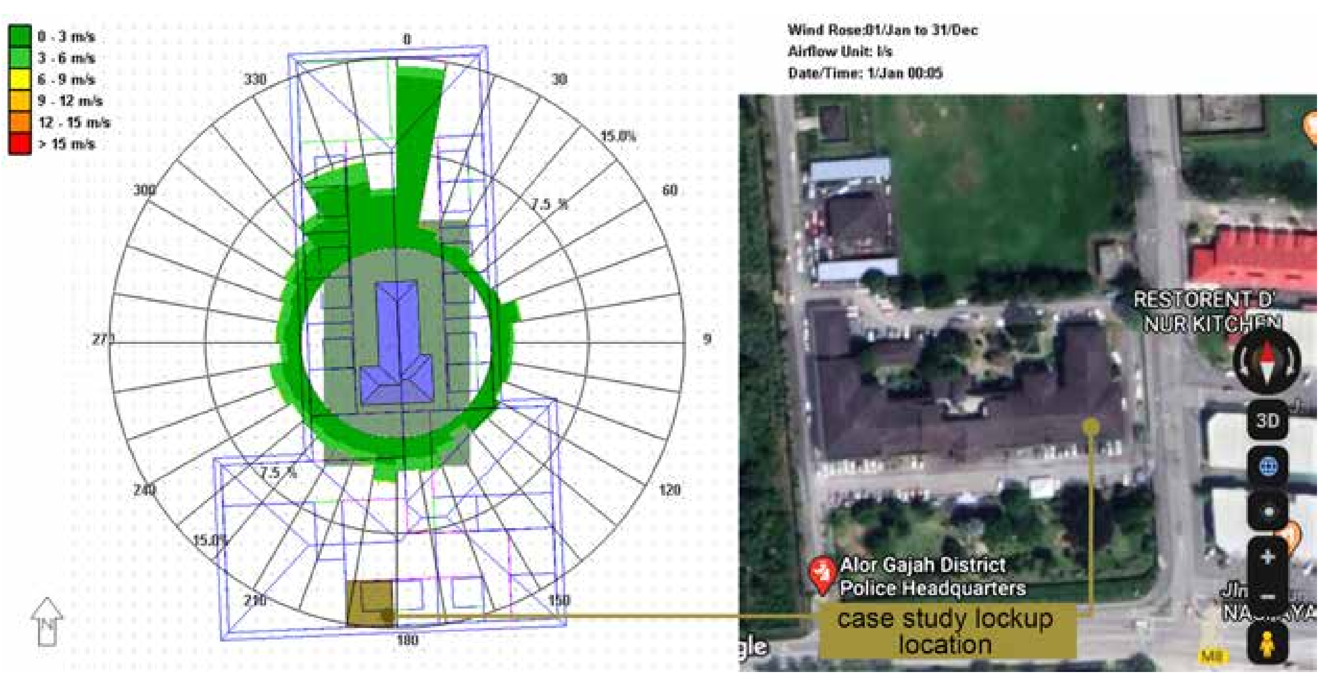
Table 7: Comparison of the Average Environmental Conditions of the Case Study Lockup Over a One-Year Period

Parameters	Reading/Month						
	Minimum			Maximum			Average
	Reading	Date	Time	Reading	Date	Time	Reading
Prevailing Temperature (°C)	20.9	6 Apr	11.00	35.8	6 Jul	17.00	27.2
Prevailing Air Velocity (V_a) (m/s)	0.0	1 Jan	01.00	20.6	1 Feb	11.00	1.6
Prevailing Relative Humidity (%)	36.0	3 Jul	17.00	100.0	21 Jul	05.00	81.9
Prevailing Wind Direction (Azimuth) (°)	0.0	1 Jan	02.00	350.0	5 Jan	20.00	344.0

Source: (Author, 2025)

The average prevailing wind direction recorded throughout the measurement period ranged between 344° and 30°, originating from the Northwest to the Northeast, as shown in **Figure 7**. This prevailing wind direction is not aligned at all with the orientation of the case study lockup windows, which are located on the southern side of the detention block.

Figure 7: Prevailing Wind Direction Over a One-Year Measurement Period



Source: (Author, 2025)

Results and Discussion

At this stage, nine series of simulation processes were conducted to examine the effect of varying window size percentages and dimensions on the thermal comfort performance of the case study lockup. This process aims to identify the window design combination that has the most significant effect on thermal comfort performance. It also refers to past studies and references, ultimately proposing the optimal design that can serve as a robust guideline. Table 8 presents a comparison of the annual average operative temperature for window percentages of 4%, 10%, 15%, and 20% over a one-year measurement period.

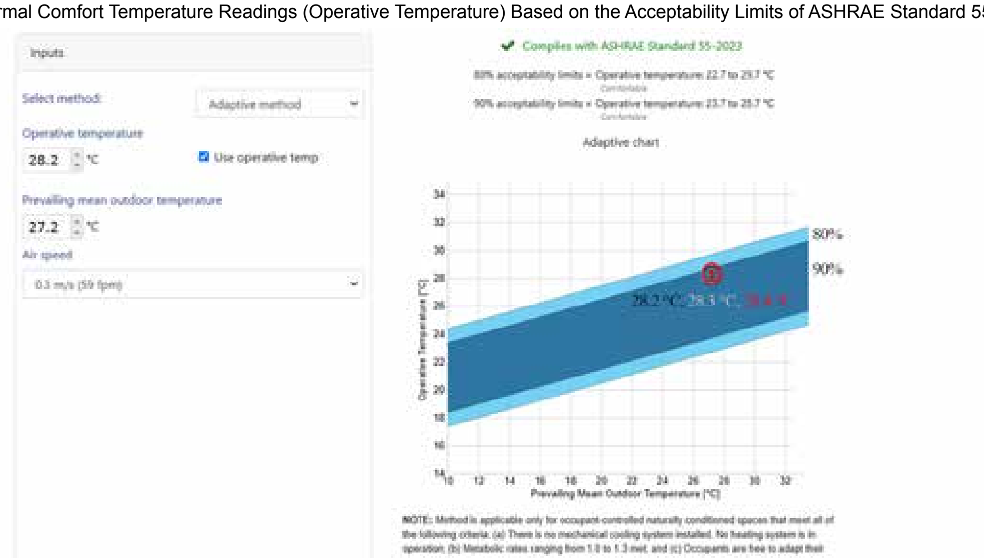
Table 8: Comparison of the Annual Average Operative Temperature for a 4%, 10%, 15% and 20% Window Opening Percentage Over a One-Year Measurement Period

Window Size Code	Operative Temperature (°C)		
	Minimum Reading (°C)	Maximum Reading (°C)	Average Reading (°C)
4-A	26.8	32.4	28.4
4-B	26.8	32.4	28.4
4-C	26.8	32.3	28.4
10-A	26.8	32.5	28.4
10-B	26.8	32.5	28.4
10-C	26.8	32.6	28.3
15-A	26.8	32.6	28.3
15-B	26.8	32.6	28.3
20-A	26.8	32.8	28.2

Source: (Author, 2025)

Based on the analysis of the obtained simulation data, the optimal operative temperature recorded was for the 20-A design combination, with a reading of 28.2°C. In comparison, other design combinations recorded slightly higher temperatures of 28.3°C and 28.4°C. The recorded annual minimum average operative temperature for all design combinations was 26.8°C, while the recorded annual maximum average operative temperature ranged between 32.4°C and 32.8°C. Changes in window design combinations impact on the thermal comfort performance, as recorded for the 20-A design combination, with a difference of 0.2°C or an improvement of 0.8% in operative temperature. However, all recorded readings remain within the acceptable or recommended range specified by ASHRAE 55 (2022), as shown in Figure 8.

Figure 8: Thermal Comfort Temperature Readings (Operative Temperature) Based on the Acceptability Limits of ASHRAE Standard 55



Source: (Author, 2025)

Based on design modifications related to window size and percentage, the recorded result can reach up to 0.4% for every 0.1°C temperature change in each window design combination, as determined through the simulation process. The existing window design with a 4% size proportion recorded lower thermal comfort performance compared to the 20% window design combination, which demonstrated better performance and represented the maximum feasible combination in the study model. The significance of the design modification from 4% to 20% resulted in a more significant change, with an improvement of 0.8% and a temperature difference of 0.2°C between the two design combinations. Each modification made to the window design combinations clearly contributes to the thermal comfort performance of the study model. The lockup's thermal mass, enclosure characteristics, and consistently high humidity contribute to these marginal differences. This finding is further supported by previous studies Christian et al. (2015); Elghamry & Hassan (2020); Sacht & Lukiantchuki (2017) and Talarosha & Marisa (2018), which state that a window size proportion of 20% is more optimal and ideal for the thermal comfort performance of a space.

The recorded minimum to maximum operative temperature readings, serving as an index for preferred thermal comfort performance, remain within the comfortable temperature range recommended by ASHRAE 55 (2022). The recorded values range from 28.2°C to 28.4°C, with the optimal comfort range for this study model being best represented by an average of 28.2°C, as recorded through the 20-A window design combination. Based on the findings from the overall simulation process across all design combinations, the design that has the most significant impact and enhances the thermal comfort performance of the study model, compared to the existing design, is the 20% window size proportion with the 20-A dimensions (0.6 m in height × 3.0 m in width) and an opening area of 1.8 m². The recorded operative temperature for this design combination is 28.2°C, and the results align with the recommendations from previous studies by Christian et al. (2015); Elghamry and Hassan (2020) and Sacht and Lukiantchuki (2017).

The marginal differences in operative temperature are primarily attributed to the lockup high thermal mass, enclosure characteristics and humid environment. The reinforced concrete walls and high surface to volume ratio dampen transient temperature fluctuations, while high ambient humidity limits sensible cooling effectiveness in the hot-humid tropical climate. Furthermore, single-sided ventilation with fixed south-facing openings constrains airflow, resulting in diminishing returns from increased aperture areas. Despite misalignment with prevailing winds (NW–NE), the 20% opening configuration performs best due to its larger effective air exchange area, which enhances buoyancy-driven and convective flows. The 20-A geometry (0.6 m × 3.0 m) promotes improved façade level air exchange achieving a modest operative temperature reduction (- 0.2 °C).

Conclusion

To assess the thermal comfort performance of the case study lockup model, the comfort range recommended by ASHRAE 55 (2022) was used, specifically the minimum and maximum operative temperature range. This benchmark was established to determine whether the recorded readings from the simulation process fall within the recommended range or not. To evaluate the significance of window design on the thermal comfort performance of the study model based on window size and proportion, several findings from previous researchers were selected as a reference. This approach serves as a response to existing recommendations, aiming to determine whether the findings from this simulation process align closely with or differ from those of previous studies, particularly regarding window size and proportion.

From the nine window design combinations analyzed through nine thermal comfort performance simulations, it is evident that design modifications significantly impact thermal comfort performance. The best recorded operative temperature was observed in the design with a 20% percentage of opening, which proved to be the most effective window design in enhancing the thermal comfort performance of the case study lockup model.

The ventilation requirements for window design should not be strictly limited to the existing guideline of 10% or 1/10 of the floor area, as stated in the Uniform Building By Law (Amendment 2012) (2012) and UPE JPM (2024). A larger window size results in better thermal comfort performance, as evidenced by the recorded findings in this study. Window design should be implemented with the maximum possible dimensions based on the available open space rather than being restricted to a specific percentage. This approach ensures adequate ventilation while also positively impacting the thermal comfort performance of a study model. For example, better thermal comfort performance can be achieved by increasing the percentage of window to 30% or 40% through improvements in the ceiling height of the study model, ranging from 4.5 m to 6.0 m. This adjustment allows for a larger allowable space, enabling the provision of more extensive window openings.

For new Royal Malaysia Police (RMP) lockup, a window of exceed 20% is recommended for single-sided naturally ventilated cells, where security window geometry permits, alongside increased ceiling heights (more than 4.5 m) to accommodate larger openings within security constraints. For retrofit applications, structural conditions permitting, increasing the effective opening area toward 15–20% should be prioritized over superficial shading measures. It is further recommended that RMP and PWD incorporate provisions in local design standards allowing cell-specific window adjustments up to 20%, subject to supporting thermal simulation and security evaluations.

The findings of this study can be considered as an additional reference to the existing guidelines provided by Local Authorities (PBT), the Economic Planning Unit (EPU), and regulations such as UBBL, as well as previous research. These findings serve as a potential standard for future window design in detention facilities and as a reference for improving existing standard window designs. Enhancing window design can help achieve better thermal comfort performance, ultimately reducing discomfort among detainees. Further detailed research on the overall design of detention facilities is expected to contribute to improved thermal comfort performance in the future.

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