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Assessing Daylighting Conditions and Strategies in Residential Workspaces During the COVID-19 Pandemic: A Case Study of Apartment Buildings in Malaysia

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ABSTRACT

Incorporating daylighting strategies in buildings is crucial for enhancing visual conditions, energy efficiency, and productivity. Working in an environment without windows or with limited access to daylight can negatively affect performance and lead to eye fatigue, stress, and headaches. The COVID-19 pandemic and the rapid development of IT capabilities have resulted in an increase in home-based workspaces worldwide, including Malaysia. This emerging trend, accelerated by the pandemic, has prompted people to work from their homes. Therefore, it is essential to ensure visual comfort for home workers by implementing effective daylighting strategies in their residential work environments. This study focuses on evaluating daylighting conditions in existing residential apartment buildings (RABs) in Malaysia, particularly considering their transformation into workspaces during the COVID-19 outbreak. The research methodology consists of three sequential steps; selecting and observing case studies, conducting simulation experiments, and administering a questionnaire survey. Hence, it involved observing 10 contemporary RABs in Johor Bahru, recording their facade and layout characteristics, including window shading. Then, simulation experiments were conducted by the IES-VE software to demonstrate indoor daylighting condition. Additionally, a questionnaire survey was conducted from 360 occupants of the selected RABs, utilizing multiple-choice questions and a five-point Likert scale. The collected data was analyzed using descriptive statistics. The results revealed that the lack of external window shading forced residents to rely on internal shading methods. Moreover, excessive tropical sunlight resulted in visual discomfort and glare issues for users. However, occupants predominantly utilized conventional shading options, such as curtains, leading to poorly illuminated indoor environments and increased reliance on artificial lighting for desk-related tasks. The significant findings from this research emphasize the design of flexible spatial layouts with ample open spaces along with the use of efficient internal and external shading devices in RABs, to create well-lit and healthy working environments.

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1. Introduction

With the development of computers, Internet services, and digital drawing, many people moved their own offices into their residential units (Whitehead, 2009). Technology enables people to arrange their work-life balance in a smart and flexible way, making homeworking a common occurrence today (Acosta et al., 2023). The global pandemic of COVID-19 and its mandatory stay-at-home lockdowns accelerated this trend, resultantly affecting every household's operation (Qarnain et al., 2020). In numerous cases, lockdowns have resulted in homes transforming into workplaces, affecting both social and professional aspects of life (Muñoz-González et al., 2021). Several studies indicate that irrespective of the COVID-19 pandemic, home-based workplaces are going to substantially increase worldwide and persuade people to work from their homes in the near future (Bateman, 2000; Sulaiman & Shariff, 2012). After the COVID-19 outbreak, remote work became essential for many office employees, providing a chance to assess how home office environments impact worker health (Awada et al., 2021). As a result of the COVID-19 pandemic, the need for physical distancing, enforced lockdowns, travel restrictions, and the closure of offices and schools, working from home became the only option for many people (Caligiuri et al., 2021). Despite some benefits for home workers, such as preventing the spread of viruses and saving lives, saving time and reducing expenses of commuting; studies show that the design of living spaces must be altered in the post-pandemic life to make it suitable and flexible enough for home working (Tokazhanov et al., 2021). This makes it essential to reconsider the regulations applied in residential buildings to ensure they are suitable for habitation, especially now that they are commonly being used as both offices and living spaces. In today's landscape, where telecommuting is firmly integrated into society (Micaela, et al., 2020), it is significant to focus on architectural design elements, especially on natural lighting, that can enhance our indoor environmental condition (Jiang et al., 2021). Hence, it is essential not only to design electric lighting effectively but also to ensure an adequate amount of daylight in home workstations.

In the current decade, daylight has been experimented to improve work productivity and mood of people in indoor spaces. It represents the inhabitants a sense of contact to the outside and eye muscles can relax when they focus on distant objects. Studies have confirmed that people have an innate inclination towards daylight as opposed to artificially lit areas within a building (Mousavi et al., 2013). Daylight provides good color rendering which cannot be coordinate by artificial light and also decreases eye fatigue as the human eyes adjust effectively to daylight (Freewan & Al Dalala, 2020). Furthermore, exposure to daylight has been found to have a notable impact on mood by reducing the occurrence of headaches, eye strain, and stress (Morin et al., 2020). Interestingly, daylighting has great impacts on behavioral, physiological, psychological and even spiritual aspects of human being and acts much better than the artificial light to increase productivity and performance of human beings (Boyce et al., 2006). Recent research suggests that low levels of vitamin D, which is produced by Ultraviolet-B exposure from daylight, are linked to an increased risk of COVID-19 infection (Merzon et al., 2020). New data highlights novel connections between daylight, circadian rhythms, sleep, and immune health, especially in the context of the ongoing COVID-19 pandemic worldwide (Ray et al., 2020).

Before the pandemic, residential buildings used 10–15% of their total electricity consumption for lighting, while in office buildings, this figure rose to as high as 50%. As a result, there is significant potential for energy and cost savings through the use of daylighting in residential buildings (Han et al., 2019). Daylighting is particularly vital in residential buildings due to its impact on electricity consumption for lighting and its effects on people's health and well-being (Wirz-Justice et al., 2021; Zhang et al., 2022). It was stated that incorporating daylighting is an effective approach for designing home office workspaces to enhance visual comfort for users (Mousavi et al., 2021). Daylight influences human physiology and behavior, and since people spend over 90% of their waking hours indoors, it is crucial. Yet, daylighting in residential buildings is often not designed to support circadian rhythms (Figueiro et al., 2017). Data from earlier surveys indicate that houses constructed before 1950 typically featured great natural lighting and had significantly lower rates of health problems among residents compared to modern housees (Muñoz-González et al., 2021). As residential buildings are primarily designed for living purposes, they may not be suitable for creating convenient workspaces equipped with all comforts, especially considering the importance of natural light (Acosta et al., 2023). A recent survey has accentuated the importance of daylighting design in residential buildings during the outbreak of COVID-19 worldwide (Mangkuto et al., 2020). Since remote work became more common, the need to study daylighting in home-based workstations grew urgent as it has a direct impact on people's daily physical and emotional well-being. Researchers began exploring this topic to uncover the challenges individuals face when setting up a home workspace (Cuerdo-Vilches et al., 2021).

As planning of existing and future residential buildings has to be altered according to the implications of COVID-19 (Spennemann, 2021), such adjustments can be employed while considering the importance of daylighting within residential buildings. This may increase the importance of flexibility in designing the residential setups. Addressing daylight access in existing buildings is challenging due to the diverse climatic conditions around the world and the wide range of architectural styles in residential buildings, which are influenced by regional construction practices (Acosta et al., 2023). The significance of daylighting design is highlighted in tropical regions with a large sunlight abundance, as high as 140,000 lx (Djamila et al., 2011; Lim & Ahmad, 2014; Mousavi et al., 2016b), and severe sky luminance (Dahlan et al., 2009). Although many buildings in tropical climates benefit from ample indoor daylight, they often lack proper daylighting design. Previous research claimed that implementing daylighting strategies through interior retrofitting is crucial for creating energy-efficient and productive home office environments (Mousavi et al., 2021). The home-based workspace has currently become a new focus initiative of the Malaysian government to increase home workers due to its benefits. By expanding this trend in Malaysia, and generally in the world, one of the essential factors to be considered is the availability of daylight and its quality in home offices (Monzón-Chavarrías et al., 2021; Sulaiman, 2011). While studies on daylighting in Malaysia has specifically focused on office buildings, it is essential to create effective daylighting strategies for residential environments to enhance visual comfort for home workers, as there is limited

research on daylight quality in home workspaces in tropical climates.To fill the research gap, this study focuses on daylighting conditions in the existing residential apartment buildings (RABs) which comprised a substantial number of built structures in the tropical climate of Malaysia as a case study of this research, and attempts to come up with suggestions for the existing RABs to create an optimum working environment during lockdowns based on daylight quality. To achieve the above mentioned concerns, this research seeks to answer the following questions:

1- What are the challenges of using natural daylight in RABs for homeworkers in tropical climate, specifically, Malaysia?
2- What are the architectural and spatial solutions to those challanges?

Through answering the above questions, we attempt to provide useful insights that can inform future architectural design and urban planning policies, assuring that RABs are better equipped to support the evolving needs of residents in a post-pandemic world. Providing visual comfort for home workers during the pandemic using the solutions of this study is a novel subject that has been developed in this research.

2. Methodology

The methodology to conduct this research is comprised of three major phases; case study selection and observation, simulation experiment, and questionnaire survey. The initial observation of ten selected case studies supported the primary concern of the research, which was daylight quality and its management within the existing RABs in the Malaysian climate. In the second stage, simulation experiments were conducted to show daylighting conditions in the case studies. In the third phase, the data gathered during observation and daylight simulation experiments were cross-checked through a questionnaire survey to see the subject from the users' perspectives before and after the pandemic. Almost all the data collected during each phase, supported the findings of the previous phase. The conclusion was made based on the analysis and examining the overall results of various stages of this research. Figure 1 shows the research process diagram.

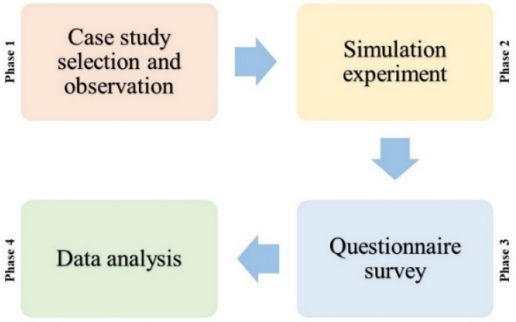


Figure 1. Research process diagram

2.1 Case Study Selection

In the selection process of RABs, it was tried to consider variables effective on daylight quality such as; topography, layout, density of the area, and location of units based on their height. Hence, the selection of 10 RABs in Johor Bahru (JB), Malaysia, was guided by specific criteria to enhance the study's relevance. JB was identified as an appropriate location due to its dense concentration of low-rise to high-rise buildings, providing a useful context for examining daylight effects in residential environments. The chosen case study buildings were evaluated based on the factors such as their orientation, height, window-to-wall ratios, and the number of occupants, all of which significantly influence daylight exposure and its impacts on home-based working. A purposive sampling approach was used to ensure a variety of building features, enabling a more comprehensive analysis of how different characteristics affect the interaction between daylight and homeworking practices. For better generalization, the RABs were chosen from different districts in JB (Figure 2). The buildings represent the typical types of apartment building. To have a better focus on daylight study, all the selected RABs were exposed to sunlight from all four sides and with diverse heights from low-rise to high-rise (Figure 3).

Figure 2. Location of the existing residential apartment buildings (RABs) in Johor as the case studies

Figure 3. Case study of typical RABs in Johor, Malaysia: (a) Kipmart; (b) Skudai Parade; (c) Kolej Perdana; (d) Danga view; (e) Pulai view; (f) Mewa; (g) Lake View; (h) Nusa Perdana; (i) Pangsapuri Jasa; (j) Cempaka

2.2 Daylight Simulation Experiment

Daylight simulation experiments were conducted to detect indoor daylight status in a typical room of the existing RABs in Malaysia. The geometry of the test room was achieved through a survey of the general typology of residential rooms in Malaysia (Mousavi, 2017). As various furniture layouts in a room represent different daylighting conditions (Mousavi et al., 2018), the test room in the simulation experiments was without any furniture inside. Daylight simulation experiments in this study were conducted by the Integrated Environment Solution – Virtual Environment (IES-VE) software which was previously validated in tropical climates (Mousavi et al., 2016a). IES-VE utilizes a Radiance-based engine for daylight simulation, employing a ray-tracing calculation method. It takes into account the distribution of emitted rays and considers the transmission reflection, and refraction surfaces. It is also able to create the geometric models required for this study. Additionally, IES-VE incorporates ASHRAE 90.1 standards, using climate hourly data files for solar energy, temperature, and humidity that are validated by a recognized authority (Lim et al., 2016). Two daylight indices, Work Plane Illuminance (WPI) and Daylight Glare Probability (DGP), were used to analyze daylight quantity and quality in the test room, respectively. To have a better generalization of indoor daylighting, as shown in Fig 4, diverse positions of the sun toward a side-lit room were considered for the simulation experiments (Mousavi, Khan, & Mohammadi, 2021); when the test room is under an overcast sky (position A), when it receives direct sunlight (position B), and when it obtains diffused or indirect sunlight, bright indirect in position C and faint indirect in position D, respectively. Thus, the simulation tests were conducted under an overcast sky (position A), and intermediate skies for the other positions of the sun in the sky. In this case, daylight simulation experiments were performed in the room with the east-facing window on 22 June at 9 a.m., 12 p.m., and 3 p.m. to replicate positions B, C, and D, respectively.

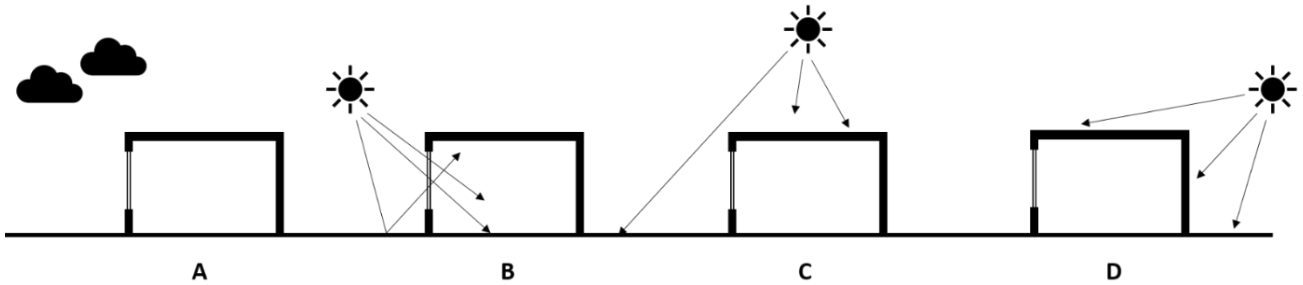


Figure 4. Diverse conditions of daylighting in a building: (A) under an overcast sky, (B) under direct sunlight, (c) under bright indirect sunlight, (D) under faint indirect sunlight

2.3 Questionnaire Survey

The findings of the simulation experiments show the existing daylight behavior in the RABs. To validate these findings, a questionnaire survey was conducted from the residents of the case study buildings to find out the users' responses regarding daylight conditions in their working spaces (the working area stands for a room that contains the desk-related tasks in the RABs). The questionnaire survey consisted of five categories (Table 1). The first category included demographic questions about the respondents and their residential location. The second category contained multiple-choice questions regarding the activities primarily performed by residents in their homes during the daytime, both before and after the COVID-19 pandemic. Only activities that are commonly carried out in residential settings were examined (Mousavi et al., 2016a). The questionnaire aimed to assess changes in functions within residential buildings from a 'before and after the pandemic' perspective. The third category focused on the frequency with which respondents used electrical lighting for desk-related tasks in their homes during the daytime, as well as the time periods during which these tasks were performed, both before and after the pandemic. The fourth category investigated the condition of windows in rooms used for desk-related tasks, specifically regarding the presence of internal shading devices and the extent to which these devices were used during the daytime. The final section of the survey explored respondents' subjective perceptions of daylighting conditions in their home-based work environments using five-point Likert scale questions. Additionally, respondents were asked open-ended descriptive questions about their satisfaction with daylighting in order to explore potential problems and solutions in more detail. After conducting a pilot study and ensuring gender balance, 360 individuals, all of whom were at least partially home-based workers, were selected to respond to the questionnaire survey. The survey was conducted during the lockdown period to evaluate the condition of daylight within the RABs. To achieve this, an online questionnaire survey was administered between 1 August 2021 and 15 September 2021, coinciding with the peak of the COVID-19 pandemic in Malaysia. The questionnaire, comprising 12 self-administered questions, was designed to provide an overview of respondents' perceptions of their housing units. All necessary precautions were implemented to ensure the anonymity of respondents, and no personal data were collected. The statistical methods via applying the SPSS tool (Statistical Package for Social sciences) were conducted to analyze the quantitative data. Later, the results were presented by using descriptive statistics (frequency, percentage, and cross-tabulation).

2.4 Limitations

A key limitation of this methodology is the use of purposive sampling. While this approach is effective in selecting buildings with different characteristics, it may not fully represent the entire range of residential buildings in JB. To address this, buildings with diverse orientations, window-to-wall ratios, and heights were selected to capture a wide range of daylight conditions. Another challenge is the potential variability in individual responses to daylight during home-based working, which could be influenced by factors beyond the building's design. To mitigate this, participants from diverse demographic backgrounds were recruited, and the survey questions were specifically designed to focus on daylight-related factors. Furthermore, although daylight simulations were used for analysis, field measurements were conducted to validate and enhance the reliability of the results.

The methodology used in this study is complemented by alternative approaches explored by other researchers that could enhance the current analysis. For instance, some have employed more advanced daylight simulation methods, such as climate-based daylight modeling, which enables a dynamic assessment of daylight throughout different times of the year. Incorporating such methodologies into future research could provide a more nuanced and time-sensitive understanding of how daylight influences home-based working, offering deeper and more detailed insights.

3. Results

3.1 Lack of Efficient External Shading on Windows in Residential Buildings in Malaysia

A detailed observation of multiple case studies reveals that the vast majority of residential buildings in Malaysia lack external shading devices on their façades (Figure 5). External shading is a critical architectural element, particularly in tropical climates such as Malaysia, where high solar exposure and heat are persistent environmental factors. Shading devices - such as overhangs, fins, or louvers - help mitigate solar heat gain by blocking direct sunlight from entering the building, thereby reducing indoor temperatures and also the reliance on mechanical cooling systems. However, Mousavi (2017) examination shows that instead of using external shading for thermal management, the facades of many RABs feature window frames designed substantially for aesthetic purposes. These outer frames, while breaking the visual monotony of the buildings' façades, fail to perform any environmental function, such as controlling excessive solar radiation. They are decorative rather than functional, serving to enhance the visual appeal of the buildings without addressing the environmental challenges associated with tropical climates. This conventional approach to façade design, characterized by a lack of external shading, has become widespread in many of the existing RABs in Malaysia.

Despite the growing awareness of environmental sustainability in architecture, the continued use of these façade designs reflects deeper systemic issues within the design and construction processes in the region. The adoption of external shading devices remains limited, and the primary reasons for this, according to interviews with architects familiar with RAB design and construction are twofold: the additional costs involved and the perceived unattractiveness of shading structures (Mousavi, 2017). The financial expenses associated with external shading devices are an important deterrent for builders and developers. Frequently, shading structures require additional materials, design complexity, and labor, which can boost the overall cost of construction. In the competitive property development market of Malaysia, where cost efficiency is paramount, these added costs are often viewed as unjustifiable. Developers prioritize reducing upfront costs and maximizing profits, even when the long-term savings from energy efficiency, such as reduced air conditioning use, would outweigh the initial investment. From the developer's

view, investing in shading devices is seen as an expense that does not offer prompt financial returns. As a result, cost-driven decisions favor the elimination of shading, despite its advantage for environmental sustainability and occupant comfort. In addition to cost concerns, architects and developers have also cited the unfavorable shapes of shading devices as another reason for their exclusion from RAB façades. Modern architectural trends, especially in urban environments, often emphasize clean, minimalistic designs that are sleek and visually appealing. Many external shading devices, particularly conventional ones such as large overhangs or bulky external louvers, are perceived to conflict with this contemporary aesthetics. Hence, architects and developers are mostly hesitant to incorporate shading structures that may disrupt the streamlined look of a building's façade or that are considered inelegant. This aesthetic bias against shading devices makes a remarkable challenge in convincing stakeholders to adopt these environmentally beneficial elements. The focus on visual appeal, sometimes at the expense of environmental considerations, reflects a wider tension in architectural practice between form and function.

3.2 Internal Shading Solutions as an Effective Alternative to External Devices in Residential Buildings

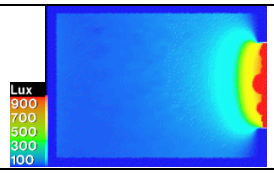
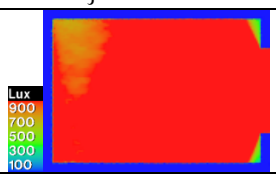
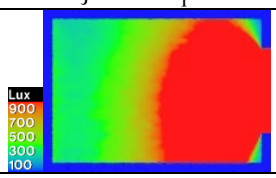
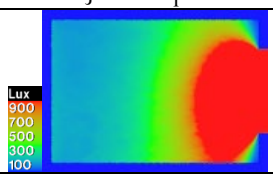
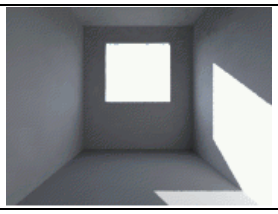
Table 2 shows the results of the daylight simulation experiments in the test room with an east-facing window. Under an overcast sky, the mean WPI in the room is higher than the recommended upper threshold of 500 lx, which was considered for the desk-related tasks (Dubois, 2001; Mousavi, Khan, & Mohammadi, 2021). In addition, the glare probability in the room is higher than 0.35, which represents 'perceptible' glare in the test room (Costanzo et al., 2018; Pierson et al., 2018). Under the three statuses of the intermediate sky, the mean WPI is recorded as extremely higher than the acceptable range with 8,043 lx, 1,961 lx, and 783 lx in the morning, at noon, and in the afternoon, respectively. The DGP values are recorded higher than 0.45 in the morning and at noon, which has shown 'intolerable' glare incidence in the test room. In the afternoon, a DGP of 0.41 represents 'disturbing' glare condition in the test room. The results of the simulation experiments reveal that both the quantity and quality of daylighting are crucial in residential buildings, particularly those that lack external shading on their facades. In tropics, where solar availability is intense, buildings without adequate shading are prone to excessive sunlight penetration. This can lead to a variety of problems, including inconvenient indoor environments due to overheating and increased glare, both of which negatively impact the well-being of the occupants. In the absence of external shading devices, achieving balanced daylighting becomes a major challenge. This challenge is compounded in tropical contexts where the sun's angle and intensity vary throughout the day, requiring dynamic and adaptable solutions to manage daylight and heat gain. The findings highlight that using internal shading devices on windows could be a highly effective remedy for managing daylighting in residential buildings that lack external shading. This is in accordance with research indicating that internal shading devices, such as adjustable light shelves integrated with blinds, offer flexibility by allowing residents to regulate the amount of daylight entering the room based on different sky conditions such as overcast, intermediate, or clear skies (Mousavi, Khan, & Mohammadi, 2021). In tropical climates, where sunlight penetration can fluctuate dramatically throughout the day, having the potential to adjust internal shading devices provides a practical means of optimizing daylight while minimizing glare and excessive heat. Internal shading can be tailored to meet the specific lighting requirements of different rooms, allowing for more localized control. Furthermore, when combined with proper window orientation and glazing, internal shading systems can significantly improve thermal comfort and reduce energy consumption related to cooling and artificial lighting.

Table 1. Questions requested in the survey for evaluation

Category	Questions
Sociodemographic features:	1. Gender 2. Age 3. Location 4. Type of home
General data of respondents' home:	5. Type of activities done by the respondents during daytime before and after the covid-19 pandemic
Desk-related Tasks:	6. Using artificial lighting for the desk-related tasks during daytime 7. Duration of time to do desk-related tasks during daytime before and after the covid-19 pandemic
Condition of Windows	8. Status of windows in the desk-related rooms in terms of internal shading devices during daytime 9. Windows' coverage by shading devices during daytime before and after the covid-19 pandemic
Daylighting condition:	10. Daylight avaiability in the desk-related rooms during daytime 11. Glare rate in the desk-related rooms during daytime 12. Subjective responses about daylighting satisfaction in the desk-related rooms during daytime

Figure 5. Lack of external shading controls on the facades of case studies: (A)Pulai View, (B)Kipark, (C)Danga View, (D)Kolej Perdana, (E)Mewah View, (F)Skudai Parade, (G)Pangsapuri Jasa, (H)Nusa Perdana, (I)Lake View Suite, (J)Flat Cempaka

Table 2. Results of the daylight simulation experiments in the test room

Sky type	Overcast	Intermediate	Intermediate	Intermediate
Position	A	B	C	D
Date/time	.....	22 June / 9 a.m.	22 June / 12 p.m.	22 June / 3 p.m.
Indoor Daylight Quantity Image				
Mean WPI	578 lux	8043 lux	1961 lux	783 lux
Indoor Daylight Quality Image				
DGP	0.36	0.54	0.46	0.41

3.3 Impact of the Pandemic on Daytime Occupancy and Desk-Related Activities in Residential Buildings

The data showed in Figure 6 provides a clear illustration of how the daily routines of users in their residential buildings have evolved, particularly in the context of the pandemic. Specifically, it presents the percentage of residents engaged in various daytime activities within their homes, both before and after the pandemic. The findings indicate a substantial shift in how people utilize their residential spaces, especially during the daytime. The pandemic, which forced many people to work and study from home, has triggered a significant increase in indoor activities, most notably those related to desk-related tasks. Before the pandemic, residential environments were primarily used for leisure and household chores, while activities like working, studying, or paperwork were typically conducted in external settings such as offices, schools, or libraries. However, with the widespread implementation of remote working and learning, homes have increasingly become multifunctional spaces. The study highlights this transition by presenting that activities such as computer-based work saw a dramatic rise, with 95% of respondents reporting engaging in such activities after the pandemic, a notable increase compared to pre-pandemic times. Similarly, other desk-related activities like writing and paperwork increased to 83%, while reading and studying, which were already common, saw a surge to 76%. This shift indicates a redefinition of residential buildings, which have now absorbed functions traditionally associated with external work and study spaces. The rise of desk-related tasks also reflects the broader societal adaptation to new working and learning conditions, where digital tools and virtual communication have become integral to daily life. Basically, the pandemic has accelerated the transformation of residential units into hybrid spaces that accommodate both personal and professional tasks, reshaping how users interact with and utilize their living spaces.

Through the cross-tabulation method in the descriptive statistics (Table 3), it was found that 61.9% of the respondents, who engaged in writing and paperwork activities during the daytime, turned on electrical lighting to ensure adequate illumination for these tasks. This suggests that although a common preference for natural daylight exists, many users found it insufficient for detailed work such as writing and paperwork, leading them to supplement with electrical lighting during daytime hours. The results also indicate a remarkable reliance on electrical lighting for various desk-related tasks, even during the daytime, when daylight is available. Specifically, 58.4% of occupants who read or studied in their residential place used electrical lighting to ensure sufficient illumination. This suggests that, despite the availability of daylight, natural light may not always be adequate for detailed visual tasks such as reading or studying, possibly due to factors like the positioning of windows, the quality of daylight, or personal preferences for brighter environments while engaging in focused activities. For computer-related tasks, 51.5% of occupants also opted for electrical lighting during the daytime. This is particularly important given that screens already emit light, yet more than half of users still found it essential to supplement with additional lighting. This could be elaborated by the need to reduce eye strain or improve visibility in spaces that might not receive consistent daylight throughout the day, such as rooms with limited window exposure or different weather conditions. The overall findings reveal that electrical lighting plays a major role in enabling effective work and study environments within homes, especially for desk-related tasks. The pandemic's influence is particularly evident when comparing pre- and post-pandemic behaviors. Before the pandemic, fewer participants reported engaging in desk-related activities in their homes. However, after the onset of the pandemic, a considerable shift occurred, with a majority of users now performing these activities in their homes during the daytime. This shift reflects the broader trend of remote work and education, where residential units have transitioned into primary workspaces. The increased use of artificial lighting highlights how users have adapted their environments to support productivity, often compensating for any shortcomings in natural lighting with artificial sources. Thus, the pandemic not only redefined the purpose of residential environments but also brought about changes in lighting preferences, with a main portion of the population turning to electrical lighting to facilitate their daily activities. This points to the significance of designing homes with flexible lighting solutions that can support a range of tasks, especially in a world where remote work and study have become more prevalent.

The data presented in Figure 7 highlights a significant shift in the way people utilized their residential units for desk-related activities before and after the COVID-19 lockdowns. Prior to the pandemic, only 36% of the residents engaged in desk-related activities within their homes typically for more than three hours during the daytime. However, the onset of the pandemic and the subsequent lockdowns led to a dramatic increase in this behavior, with 89% of occupants performing such tasks for at least three hours per day at their home. This shift reflects the widespread adoption of home-based work and the necessity for people to adapt their living environment into more functional work environments. Additionally, this change underscores the growing reliance on home-based workspaces and the extended hours many individuals dedicated to professional tasks during the pandemic.

3.4 Low Satisfaction with Daylighting Among Home Workers in Residential Buildings During the Pandemic

Figure 8 illustrates the condition of internal shading devices installed on the windows in the living spaces of the case study buildings. Overall, the majority of respondents (83%) reported that the windows in their living spaces had some form of internal shading, such as curtains, drapes, Venetian blinds, vertical blinds, etc. Of these respondents, 59% stated that before the pandemic lockdowns, they would close the internal shading devices completely to block out intense sunlight during the daytime. However, this percentage significantly increased to 94% during the COVID-19 lockdowns, when occupants spent more time engaged in various activities inside their homes during the day.

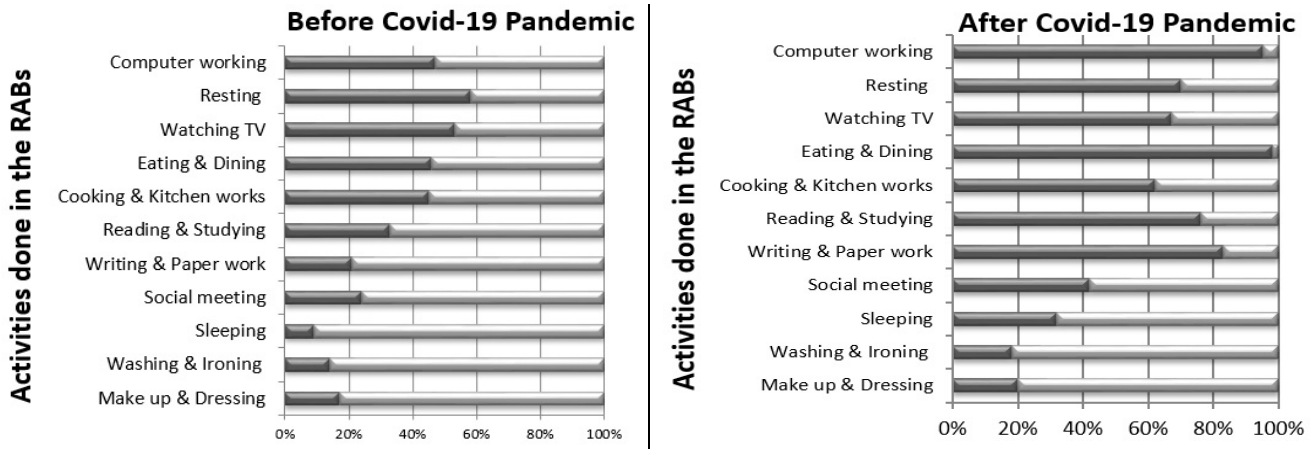


Figure 6. Percentage of the activities done by the occupants during the daytime (n = 360)

Table 3. Cross-Tabulation of the desk-related tasks with the usage of electrical lighting during the daytime

				Using Electrical Lighting		
				No	Yes	Total
Desk-related Tasks	Writing & Paper work	No	Count *(n)*	---	---	61
			% Usage during daytime	---	---	100.0%
		Yes	Count *(n)*	114	185	299
			% Usage during daytime	38.1%	61.9%	100.0%
		Total	Count *(n)*	61	299	360
			% Usage during daytime	17 %	83 %	100.0%
	Reading & Studying	No	Count *(n)*	---	---	86
			% Usage during daytime	---	---	100.0%
		Yes	Count *(n)*	114	160	274
			% Usage during daytime	41.6%	58.4%	100.0%
		Total	Count *(n)*	86	274	360
			% Usage during daytime	24%	76%	100.0%
	Computer working	No	Count *(n)*	---	---	18
			% Usage during daytime	---	---	100.0%
		Yes	Count *(n)*	166	176	342
			% Usage during daytime	48.5%	51.5%	100.0%
		Total	Count *(n)*	18	342	360
			% Usage during daytime	5%	95%	100.0%

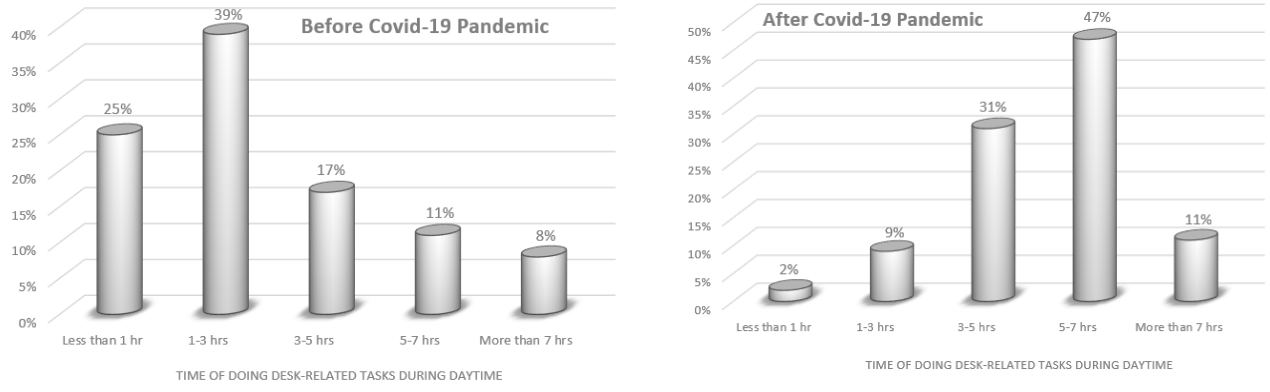


Figure 7. Percentage of time devoted to the desk-related tasks by the respondents before and after the Covid-19 pandemic

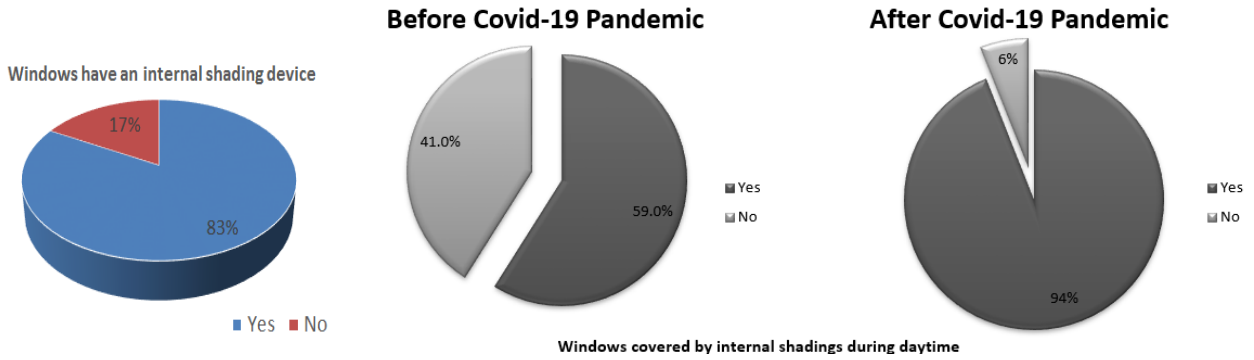


Figure 8. Status of internal shading devices in the case study buildings during the COVID-19 lockdown

Figure 9 depicts the subjective responses of occupants regarding daylighting conditions when the windows in their living spaces were not covered by internal shading devices during the COVID-19 lockdowns, particularly while performing desk-related tasks during the daytime. As shown, about 52% of respondents reported a high availability of sunlight in their desk areas during the day (with a mean score of 3.86). Additionally, a majority, approximately 61%, indicated that the brightness of their desk surfaces was high, leading to glare issues while they worked (mean score of 3.79). Overall, around 42% of respondents expressed dissatisfaction with the daylighting conditions in their homes (mean score of 2.40). While this score falls between low and medium, it indicates that most occupants were generally dissatisfied with the daylighting in their residential units. Although, according to guidelines, the availability and brightness of sunlight were deemed sufficient for desk-related tasks, the respondents were not satisfied with the daylighting conditions in their homes. This may be due to their preferences and the way they had adapted to their existing living environments.

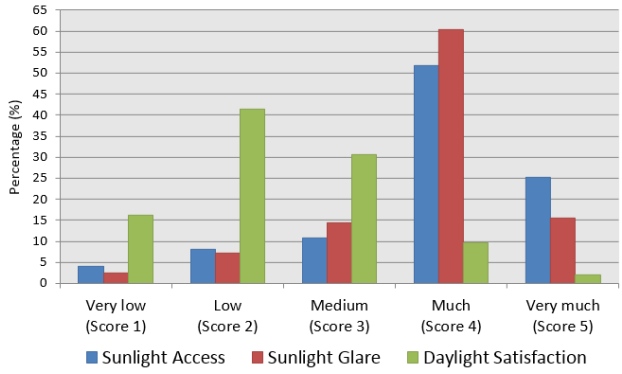


Figure 9. Responses of the occupants about daylighting conditions in their apartments during the COVID-19 lockdown (n = 342)

4. Discussion

This study sought to answer the following questions through sequenced identified methodology:

1- What are the challenges of using natural daylight in RABs for homeworkers in tropical climate, specifically, Malaysia?
2- What are the architectural and spatial solutions to those challanges?

In order to answer the first question through a general observation and survey of the contemporary RABs in Johor Bahru, it was noticed that one of the challenges was the quality of daylight within the spaces which was not adequate and sufficient for home offices and desk-related activities. With the outbreak of COVID-19, this issue became more serious, as working from home had increased considerably. The study revealed that the average working hours of residents from their homes increased from 1-3 hours a day before the pandemic, to 5-7 hours a day after the pandemic. Further investigation confirmed the problem of excessive sunlight availability, as well as, the lack of any suitable external shading devices to control the extreme tropical daylight. The last section of the questionnaire, investigated the users' satisfaction regarding light quality in their working room through open-ended descriptive questions. The results revealed that the preference of users is to have more options to opt for the appropriate daylight, than only having windows with controlled light. The descriptive questions of the surveys indicated that residents were willing to have more options to choose from when it came to control daylight quality in their home-working spaces. This fact was directly related to the level of flexibility in RABs' layout planning, as well as, their spatial quality in terms of openness degree. In order to answer the second question, the study had to recheck the case study buildings in case of their planning according to the survey results of questionnaires. Finally, the observation and review of all the plans almost confirmed three main findings:

1) "*Implementing external and internal shading devices for the windows of buildings*": The incorporation of external awnings to residential buildings for effective window design and implementation is not commonly practiced. This lack of consideration often leads to an aversion to sunlight indoors, prompting residents to rely on

curtains or blinds as a quick fix to prevent glare and excessive heat. Unfortunately, this approach completely blocks natural light, resulting in the increased use of artificial lighting. To address this issue, it is recommended that architects give careful attention to the design of optimal external shading devices for windows, taking into account the specific climate of the region, particularly in the early stages of building design. While this suggestion can be effectively applied to newly designed buildings, it may not be a viable solution for existing structures due to the high costs involved. In such cases, the use of internal shading devices such as light shelves can be a practical alternative. Light shelves not only minimize eye glare but also ensure the distribution of daylight throughout the room, providing a more uniform and healthy lighting environment. This is in accordance with a study by Mousavi et al. (2021) that proposed adjustable internal shading devices to enhance daylighting in home offices within the tropical context.

2) "*Lack of appropriate open or semi-open spaces within the planning of the RABs*": The absence of appropriate open and semi-open spaces in almost all the plans showed that residents did not choose, but to use and manage a fully light-up space with proper ventilation and access to fresh air while working from home. There were only some apartments with terraces; however, they were small and not well proportioned, as shown in Figure 10. Resultantly, they could not be considered an option to be converted into an efficient light-up space for work within the apartments. This is in accordance with a study on the COVID-19 lockdown, housing, and habitability found that many people in Spain expressed a great desire to improve natural lighting in their homes and enhance their connection to the outdoors through terraces (Cuerdo-Vilches et al., 2020). In addition, a study by Zarrabi et al., (2021) showed that the elements such as open or semi-open space in apartment buildings are of particular importance to the mental and physical health of residents during lockdowns, as residents live in and work from their homes. Thus, to maximize the capture of daylight and even ventilation, it is beneficial to incorporate open and semi-open spaces such as terraces and greenhouses into the design of residential apartment buildings. This approach allows for a greater utilization of natural light and fresh air within the building environment.

Figure 10. A typical plan of the case study RABs in Malaysia with inoperable terrace

3) "*Limitation of the plans concerning flexibility*": almost all the plans were rigid. They were not giving a chance for setups for efficiently converting an existing space to a working environment, which could help in the better natural lighting of desk surface and working space. Given the necessity of the apartments to modify to the emerging changes according to pandemic precautionary measures, developing housing flexibility by different means seems the best approach for future designs (Bettaieb & Alsabban, 2021). On the one hand, flexibility seems an essential factor in designing residential apartment buildings based on before and after pandemic situations; on the other hand, daylight quality is equally important in increasing the attribute of home offices. Thus, residential apartments with open-plan layout are suggested to enhance the adaptability of interior spaces, allowing for optimal utilization of natural light, particularly when working from home. Hence, decision-makers in the building industry of tropical regions can modify building codes to make home-office workspaces suitable and flexible for the post-pandemic life.

Consequently, an intriguing point to highlight for architects is that a significant portion of our lives is spent indoors due to weather conditions and work obligations. Hence, it becomes even more crucial for architects to prioritize the design of residential buildings that offer therapeutic levels of illumination, preferably incorporating daylight. Residential buildings should be conceived not merely as structures for shelter and essential activities, but also as environments that promote healing and well-being. The focus of this study on Johor Bahru may introduce certain minor limitations that authors acknowledge, however, Johor Bahrus's urban, social and economic characteristics is representative of many other similar regions in Malaysia. Hence, the findings can be generalized to similar geographic contexts with minor considerations. Additionally, efforts were made to ensure a representative sample, which its demographic and socioeconomic makeup fully captures the diversity of the broader population in Malaysia, so that any influence by local cultural norms or respondent biases may be neutralized.

5. Conclusion

This study reveals that the majority of individuals have a preference for the quality and diverse characteristics of daylight. They particularly value and require the views that are often associated with daylighting, however, due to excessive tropical sunlight in Malaysia, which causes visual discomfort and glare problems for the residents, and also lack of external shadings for the windows, residents had to use internal shading devices, instead. This reliance resulted in a high dependency on the artificial lighting and increase in electricity consumption. The findings suggest that the existing RABs in Malaysia fail to cater to the home workers' physiological and psychological needs in terms of visual comfort. To address these challenges this research recommends several strategies including: a) appropriate implication of external or internal shading devices to control the quality and amount of natural light within the spaces; b) adopting open-plan-layout in apartments can enhance the flexibility of the interiors in order to achieve the best of natural light while working from home and; c) incorporating more open and semi-open spaces such as terraces and greenhouses, in the

planning of RABs to improve natural light access and ventilation. These recommendations offer a practical guide for designers particularly in early stage of design or renovation of RABs in all tropical climates to achieve efficient daylighting and visual well-being. In addition to psychological effects, particularly during a task, favorable lighting quality is consistently valued and associated with human comfort and performance. However, establishing a definitive correlation between daylight and productivity is challenging because numerous other factors must be considered, such as noise level, air quality, and temperature. Thus, future studies can explore these factors to further enhance the productivity and mood of home workers in residential buildings. Additionally, this study highlights the need for further research, particularly focusing on how daylighting affects various age groups and its potential long-term implications for health and productivity in residential buildings. This constructive approach underscores the potential for enhancing the design of RABs, ultimately creating healthier and more comfortable living environments in tropical regions.

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