RESEARCH ARTICLE

Natural Daylighting Simulation of Building Atrium Towards Effective Indoor Artificial Intelligence-Integrated Urban Farming in Malaysia

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Abstract

***Abstract**. The COVID-19 pandemic and land shortage in Malaysia are driving up the cost of local and imported food due to rising holding costs. As food prices rise, urban agriculture grows. Urban farming often occurs in enclosed facilities with little natural light. The standard method of artificial daylighting to maintain photosynthesis illumination uses much energy. Building strategies can include atrium designs to let enough light into the indoor farming area. An atrium with optimal natural daylighting for urban farming reduces energy use and follows sustainable architectural principles. This study seeks the best atrium design for urban farming with artificial intelligence. Simulations of atrium prototypes in Lightstanza software are used in this study. The study found that the circular atrium design provides optimal daylighting at 512.66 lux for tropical climates, exceeding rectangular and square atriums in daylight penetration and distribution and compliance with JKR (Jabatan Kerja Raya), Malaysian Public Work Department and IES (Illuminating Engineering Society) lux standards. As a result, the best atrium design requires optimal daylighting penetration, where the redefinition of atrium design allows efficient integration in tropical climates and provides enough indoor illumination for AI-integrated indoor agriculture.*

***Keywords:** Agriculture, Artificial Intelligence, Atrium, Daylighting, Simulation, Tropical Climate,*

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Introduction

The events of the novel Coronavirus Pandemic have abruptly alerted us to the fragility of supply networks for everyday items that we once considered dependable, especially during times of crisis. Instances of barren store shelves, queues outside grocery shops, and anxious individuals engaging in panic-driven purchases have highlighted Malaysia's susceptibility to food security issues. The outbreak of COVID-19 exposed the nation's weaknesses in maintaining a steady food supply, notably when trade reached a standstill, leading to a loss of access to essential commodities (Cheng, 2022). Some consumers have opted to accumulate supplies of dried and canned food as a precautionary measure in anticipation of potential deterioration. This scenario is driven by concerns over escalating prices and likely scarcity of products (Manjula Bai, 2020). The food crisis in Malaysia serves as a reminder of how vulnerable supply systems may be during emergencies. Unless swift measures are implemented to tackle this concern, Malaysia will face a food crisis within a few years. This predicament arises from the limited land available for food production and the impact of global warming on the food industry (Cheng, 2022). Urban farming is one of the new food supply alternatives necessary to feed the globe in the future (Ali, Zaman & Othman, 2022). Urban farming primarily occurs in neighbourhoods within cities or other heavily populated urban areas (Othman, Latip & Ariffin, 2019).

Modern urban farming is often carried out within a building with an atrium to allow sufficient sunlight for the plants within an indoor setting (Fahim, 2021). The atrium designs can be used for the most regulated interior daylighting (Falkenberg, 2012) but are often not ideal for urban farming. Urban farming will undoubtedly alter how agriculture is produced when combined with Artificial Intelligence (AI). An effective atrium design using artificial intelligence sensors is necessary to optimise daylight penetration (Lorenz et al., 2020) within a tropical setting, particularly in Malaysia, which can be integrated with an indoor farming system. AI is assuming a vital role within the agriculture industry's endeavour to ensure sustainable nourishment for the future amidst the challenges of climate change. Its contributions span monitoring soil and crops to employing predictive analytics (Javaid et al., 2023; Shaikh et al., 2022). Automating processes will improve food output quickly and efficiently (De Abreu et al., 2022). This research will test the strategies of the atrium using simulation to determine the best atrium design from daylight penetration into the atrium. Malaysia finds itself in a favourable position to reassess its current national food security plan, focusing on critical aspects such as increased production, efficient resource utilisation, sustainable consumption practices, resistance to climate change, availability of water resources, and the challenge of limited land availability (Tapsir et al., 2019). The current administration's steadfast dedication to solving issues related to food security establishes a promising basis for this comprehensive examination. A significant transformation might occur by placing greater importance on urban farming, providing farmers with increased options and improved returns on their limited land holdings (Sroka et al., 2023). The integration of cutting-edge technologies, including the Internet of Things (IoT), Big Data, and artificial intelligence (AI), presents an avenue for farmers to cultivate more nutrient-rich and high-value crops, elevate soil quality and unlock expanded prospects by reaping amplified rewards from their relatively compact land holdings (De Abreu et al., 2022).

The fusion of urban farming with AI is poised to reshape the landscape of agricultural production. Automating critical processes promises to swiftly and efficiently augment food yield (De Abreu et al., 2022). In pursuing sustainable food production in the face of climate change, the agriculture industry relies on artificial intelligence (AI) to fulfil several critical roles, including monitoring soil and crops and conducting predictive analytics. Simultaneously, the effectiveness of urban farming structures, namely the atrium, is significant, as it is directly linked to sunlight. Striking the right balance is crucial since insufficient exposure to sunlight can inhibit plant growth, whilst excessive sun exposure might hinder healthy development.

Research Aim and Objectives

This research aims to determine the best atrium design that allows optimum daylighting penetration as an element that complements artificial intelligence-integrated agricultural buildings. These are the objectives for this study that contribute towards achieving the aim of this research are:

a. To identify the typical atrium design typologies in Malaysia.

b. To analyse the criteria, benefits and constraints of atrium design.

c. To simulate the different atrium design typologies based on the identified criteria.

Literature Review

Understanding the challenges associated with ensuring food security, elucidating the concept of artificial intelligence, exploring the idea of urban farming, and examining the process of planning and executing atrium architecture are all fundamental components necessary for mimicking the infiltration of natural light into building atriums to integrate AI technology into agricultural practices. Food security concerns are generally characterised by the need for cheap and nutritious food at minimal expenses.

Food Security

Food security is the capacity to consume sufficient calories and nutrients for a healthy lifestyle (Sulaiman et al., 2021), which deals with access, usage, stability, and food security (Abdullah, Mersat, & Wong, 2021). The COVID-19 pandemic led to the suspension of operations in most sectors. However, specific economic fields, notably agriculture and interconnected industries along the goods supply chain, were categorised as essential or noteworthy (Dardak, 2021). Ensuring the security of food supplies stands as a critical priority for any nation grappling with a pandemic, urban development and overpopulation (Baharudin et al., 2018). Research indicates that the agricultural and food industry experienced a significant impact from the pandemic, affecting an estimated 91.1% of business proprietors (Apostolopoulos et al., 2021). In the agricultural sector, numerous agri-food crops have remained unharvested due to labour shortages and declining consumer demand (Dardak, 2021). Poverty and food security exhibit a mutually beneficial interdependence. Food insecurity poses a substantial concern that can pose a problem in emerging nations such as Malaysia (Syafuddin Tan, Bakar & Ahmad, 2021; Manjula Bai, 2022) if not addressed accordingly.

Artificial Intelligence

The invention of artificial intelligence (AI) aims to reconstitute, if not improve, human intelligence where necessary (Dellermann et al., 2019). The study of artificial intelligence (AI) revolves around how machines can gain knowledge, like human learning and its capacity to respond to various behaviours. Artificial intelligence has witnessed notable advancements, such as the emergence of software capable of dynamically adjusting hardware configurations to cater to user requirements and the development of computerised diagnostic systems. Since artificial intelligence (AI) was introduced into the market, it has been accountable for rapid transformations within business and technology (Zhaoyu & Dolah, 2023).

Artificial intelligence (AI) considers the aspects of perception, interaction, manipulation, interpretation and learning (Westphal et al., 2023). Perception entails constructing mental representations of the physical environment from sense data. Manipulation involves the articulation of appendages such as robotic arms or mobility aids towards physical universe alteration. Interpretation encompasses planning, diagnosing, and designing (Ahmed & Nabi, 2021). According to computer scientists, by 2020, an estimated 85% of customer interactions will be managed through automated means (Wang & Abdullah, 2021). This projection suggests that computers and artificial intelligence will effectively manage routine human necessities, such as inquiring about the current weather temperature.

Urban Agriculture

Urban agriculture produces food in backyards and communal gardens of cities and suburbs. Consequently, it defies statistical analysis and trend detection. Urban agriculture includes raising common species like cattle and chickens and regional species like guinea pigs on a modest scale. It also includes raising fruit, vegetables, and speciality crops like medicinal and ornamental plants (combined fish and plant culture). By integrating AI, farmers can cultivate healthier crops, exterminate pests, monitor soil and plant growth, and labour less (Rizou et al., 2020).

Urban agriculture utilises city water resources and recycles organic waste, contributing significantly to managing natural resources for a sustainable environment (Islam & Chamhuri, 2017). This practice is often situated near city areas, and due to the scarcity of available land, it thrives within limited spaces. Unlike many other transient activities, urban agriculture is poised to become a lasting fixture in developing and developed cities.

Traditionally, agriculture has been associated with rural landscapes, with its related activities predominantly confined to these areas (Chagomoka et al., 2017). It was commonly believed that rural crop production alone would nourish urban populations. However, this notion is proving inaccurate for many developing cities, mainly due to deficiencies in essential infrastructure like transportation, roads, and markets, further exacerbated by the limited purchasing power of the underprivileged population (Chagomoka et al., 2017). Over time, escalating poverty and elevated unemployment rates, coupled with urban advantages like robust food demand and market proximity, have fostered the emergence of diverse crop and food systems within cities and their outskirts. This emphasis often centres on cultivating fresh vegetables and producing milk, eggs, and poultry.

Integration of A. I. into Urban Farming

The food sector encompasses many responsibilities that heavily rely on agriculture. Artificial intelligence technology plays a transformative role in augmenting and enhancing traditional practices. AI technologies assist farmers in cultivating healthier crops, managing pests, monitoring soil conditions, tracking plant growth, and reducing labour-intensive workloads (Vijayakumar et al., 2022).

Neglecting field variability and treating agricultural land as a uniform entity in numerous developing nations leads to several issues, including inefficiency in input use, heightened environmental contamination, and diminished farm returns (Vijayakumar et al., 2022). Overcoming these challenges requires site-specific crop management, demanding extensive data and information. IoT and AI integration can provide farmers with real-time, comprehensive information, encompassing weather conditions, temperature, humidity, and market prices. By fully grasping the available local resources, these technologies can propose tailored farming strategies suited for various specific environmental conditions (De Abreu et al., 2022).

Technological advancements in AI support precision agriculture through factors such as soil quality assessment, weather forecasting, optimised seed variety selections, and localised pest presence, exemplifying how technological progress can facilitate the selection of crops and enhance the availability of hybrid seed choices that align with farmers' requirements. The internet can be harnessed to educate artificial intelligence about the diverse responses of seeds to distinct climatic and soil conditions. Numerous plant sensors exist to oversee plant growth and identify diseases. Unmanned Aerial Vehicles (UAVs) have introduced a range of innovative prospects for agriculture, encompassing the capacity to observe the well-being of crops (nutrient imbalances, insect or disease harm), assess irrigation machinery efficiency, recognise weeds infestations, monitor livestock, and manage emergencies (Vijayakumar et al., 2022). This implementation aids in identifying problems before the manifestation of evident signs of insufficiency or infection in the plants, enabling proactive interventions and reducing crop loss. Artificial intelligence holds numerous applications within agriculture, potentially enhancing farming practices. For instance, agricultural robots can identify and manage pests and diseases in crops, boost efficiency, and automate specific farm tasks, among other benefits. Additionally, machine learning algorithms enable crop mapping, providing farmers with insights into their fields' most economically productive areas. Moreover, agricultural AI can illuminate crop yields, empowering farmers to tailor their strategies. Furthermore, automated identification and proactive management of plant diseases by agricultural artificial intelligence (AI) systems can significantly contribute to minimising wastage. Artificial intelligence's swift data processing and decision-making abilities suggest its imminent prominence in shaping the future of agriculture.

Technological progress has already catalysed transformations in the agricultural sector, yet there remains a plethora of untapped potential where AI could exert substantial influence. In an architectural context, particularly within AI-integrated indoor urban farming systems, AI complements design solutions by enhancing environmental control and resource efficiency, such as irrigation systems, whereby farms have the potential to enhance cost efficiency and maintain output goals by employing artificial intelligence (AI) algorithms to identify and analysing plant water preferences and adjust watering schedules accordingly. Similarly, artificial intelligence (AI) can provide accurate suggestions for fertilisers, achieved by considering the precise nutrient requirements of plants at various stages of their life cycle, considering factors such as nutrient scarcity during early growth phases and lower water requirements at night. Integrating AI with architectural elements supports sustainable farming practices by reducing energy and resource consumption.

Artificial intelligence has the potential to function as an advanced sensor system for gauging the extent of natural light infiltration (Kazanasmas et al., 2017) to ensure optimal light distribution for plant growth within indoor farming environments. Through AI software, calculations for illuminance can be performed through tools like artificial neural networks, complex daylight simulations can be performed, and architectural features such as the influence of atrium design towards daylight penetration can be evaluated. This capability aligns with this research, where AI enhances Lightstanza simulation outcomes by providing dynamic feedback on daylight performance, heat dissipation, and environmental conditions. Ultimately, AI supports operational efficiency and reinforces architectural strategies, creating adaptive, data-driven indoor farming environments that are resilient, productive, and sustainable.

Atrium Design

Atriums are large, open-air chambers in the middle of buildings (Wang et al., 2022). Some have glass roofs designed by building designers and owners for daylight, circulation, and landscaping surfaces. Tropical climates feature a lot of sunlight, glare, and heat, which raises the need for energy consumption. Malaysia is building more atriums because atriums are a popular choice of ecologically sustainable architectural form. The best criteria of an atrium should be that it successfully filters the excessive solar heat while allowing natural daylight to penetrate the building (Wang & Abdullah, 2018). In this research, daylight penetration and heat dissipation are the sole criteria for evaluating efficiency due to their critical impact on plant growth and the indoor environmental quality of AI-integrated urban farming systems. Daylight penetration is essential because plants rely on natural light for photosynthesis, making sufficient light intensity and spectral quality vital for healthy growth and productivity. Optimising daylight penetration also reduces dependency on artificial lighting, aligns with sustainability goals and minimises operational costs in urban farming environments.

Furthermore, effective daylight distribution ensures uniform crop development, reducing variability in growth patterns caused by uneven lighting. On the other hand, heat dissipation is crucial in maintaining thermal comfort and plant health. Excessive heat from solar gain can lead to thermal stress, negatively affecting plant metabolism and water retention. Efficient heat dissipation helps maintain optimal temperature ranges conducive to plant growth, reducing the need for mechanical cooling systems, lowering energy consumption and supporting eco-friendly practices. Additionally, since AI algorithms optimise environmental controls, their effectiveness is heavily influenced by stable baseline conditions. A well-managed thermal environment enhances the accuracy and efficiency of AI-driven climate management systems, addressing the fundamental environmental parameters that influence the sustainability, productivity, and energy efficiency of urban farming systems in Malaysia's tropical climate. The six typical typologies of atrium design identified and found across Malaysia are centralised, semi-enclosed, attached, linear, long horizontal opening, and centralised circular form (Yunus, Ahmad & Zain-Ahmed, 2019).

In the International System of Units (S.I.), lux is a metric for quantifying daylighting illuminance. A single lux, derived from the Latin "light," signifies the illumination generated by distributing one lumen uniformly across a one-square-meter surface. Urban agriculture's vertical farms necessitate an illuminance range of 400 to 700 lux (Song et al., 2019). However, due to the surpassing daylight illuminance levels in tropical regions, it becomes essential to regulate lux to an optimal quantity suitable for effective plant growth (Song et al., 2019). By adhering to the recommended illumination standards outlined in the guides by JKR (Jabatan Kerja Raya) and IES (Illuminating Engineering Society), the atrium's illumination can be aligned with laboratory settings. This recommendation encompasses a luminous intensity of 750 lux according to IES standards and 500 lux as per JKR, harmonising with the required illuminance levels for urban farming. Three simple atrium designs of equivalent area will be selected to facilitate a straightforward simulation process: a long horizontal opening, a square-shaped opening, and a centrally positioned circular opening. This choice ensures a seamless simulation procedure without intricate calculations or extensive observations.

Atrium Design for Artificial Intelligence-Integrated Urban Agriculture for Food Security

The inception of this study's objective is based on a comprehensive review of various literature and publications centred on atriums, tropical atrium design, and typical Malaysian atrium design typologies. Understanding tropical atrium design and the distinct typologies prevalent in Malaysian architecture helps clarify the research objective. Such thorough theoretical grounding acts as a guiding framework, seamlessly aligning with the core focus of the study on simulating daylight penetration within building atriums. The alignment holds significant importance in incorporating artificial intelligence into the agricultural sector.

The theoretical framework provides a basis for understanding the study's fundamental purpose and characteristics. The primary objective of this study is to utilise thorough simulations to determine the level of daylight penetration in building atriums, with a specific focus on implementing artificial intelligence-integrated farming techniques. Fundamentally, the research employs building simulation as a crucial component of its technique. This methodology encompasses collecting critical sensory data and is a foundational pillar for facilitating informed decision-making by artificial intelligence systems. This comprehensive decision-making process goes beyond simple data gathering, incorporating the forecast and optimisation of agricultural yields. This aspect is of utmost importance as it can bring about a transformative shift in farming practices (Lu, 2019).

Atrium design plays a crucial role in urban farming and agriculture by optimising indoor environments for crop cultivation (Omrany et al., 2020). Atriums are strategically designed to maximise natural daylight penetration, reducing reliance on artificial lighting and enhancing plant growth through optimal light exposure (Rice, 2023). They also integrate climate control systems that regulate temperature and humidity, creating stable conditions for plant health and productivity (Ragaveena et al., 2021). This design versatility allows for vertical farming setups within urban spaces, maximising land use efficiency and increasing crop yield per square meter (Zhang et al., 2021).

Moreover, modern atriums often incorporate advanced technologies (Hi et al., 2023; Mohamed et al., 2022), such as AI-driven sensors and automation (Santos et al., 2024). These technologies monitor and adjust environmental factors in real-time, optimising resource use like water and nutrients (Maraveas et al., 2022). Beyond their functional benefits, atriums can serve as community hubs and educational platforms, fostering public engagement in sustainable agriculture practices and promoting local food production (Fahim, 2021). Overall, atrium design in urban farming represents a sustainable solution to urban food security challenges, leveraging architectural innovation to create resilient and efficient agricultural ecosystems within cities. The theoretical foundations of the study are consistent with current research trends and technological progress from a broader perspective. The interdependent association between artificial intelligence and building simulation highlights a progressive paradigm shift that leverages cutting-edge technologies to address real-world challenges. By meticulously delineating its purpose through theoretical exploration, this study establishes itself as a significant input to the current discourse surrounding sustainable agricultural practices and the seamless incorporation of technology within the contemporary farming landscape.

Correlation of Artificial Intelligence, Natural Daylighting, and Atrium Design as Tools of Urban Farming

The integration of artificial intelligence (AI), natural daylight, and atrium design represents a pivotal advancement (Habash, 2022) in urban farming practices (Shon et al., 2022). AI is a sophisticated tool that optimises various facets of indoor agriculture within atriums (Shon et al., 2022). It can analyse and regulate environmental conditions such as temperature, humidity, and nutrient levels, ensuring optimal growth conditions for crops (Ragaveena et al., 2021).

Natural daylight is crucial in this synergy by providing a sustainable illumination source (Münch et al., 2020). Atrium designs are pivotal as they determine the extent and efficiency of daylight penetration into indoor farming spaces (Omrany et al., 2020). Circular-shaped atriums, for instance, have been identified as particularly effective in tropical climates, maximising daylight ingress compared to rectangular or square designs (Yunus et al., 2010). These elements create a harmonious ecosystem where AI-driven technologies leverage natural daylight to enhance crop productivity and quality. By harnessing the benefits of both AI and natural daylight through well-designed atrium structures, urban farming can achieve sustainable and efficient food production, contributing positively to food security and environmental sustainability in urban areas.

Methodology

This study employs two methodologies. The first step is to conduct a literature review to determine the criteria for atrium design and which design simulates the best daylight penetration. Quantitative research primary data collection is chosen as the second method to analyse daylight penetration better and determine if the atrium design criteria selected for simulation are effective for daylight penetration.

A simulation is carried out to assess the criteria of an effective atrium design. An analytical model serves as a tool for generating precise responses or decisions. In the context of atrium design, a diverse array of analytical models is employed to address different system components, encompassing elements like the dimensions of the opening and the overall design of the atrium. This investigation involved the simulation of each analytical model to obtain the data. Drawing from the variables explored in the literature review, each analytical model systematically evaluates a range of criteria, including:

1. Size of the opening of the atrium
2. Type of design of the opening
3. The constant tropical environment of daylight

The selected variables were derived from the literature review. At the same time, the rationale behind choosing these three designs stems from their categorisation as the most straightforward among the previously defined five atrium types.

The simulation method begins with the first stage, which involves modelling a prototype based on the typology of the atrium design. The prototypes are then modelled in Sketchup 2022 software using multiple analytical models to represent the typical atrium design identified in the literature review: long horizontal opening, square opening, centralised opening, and circular opening.

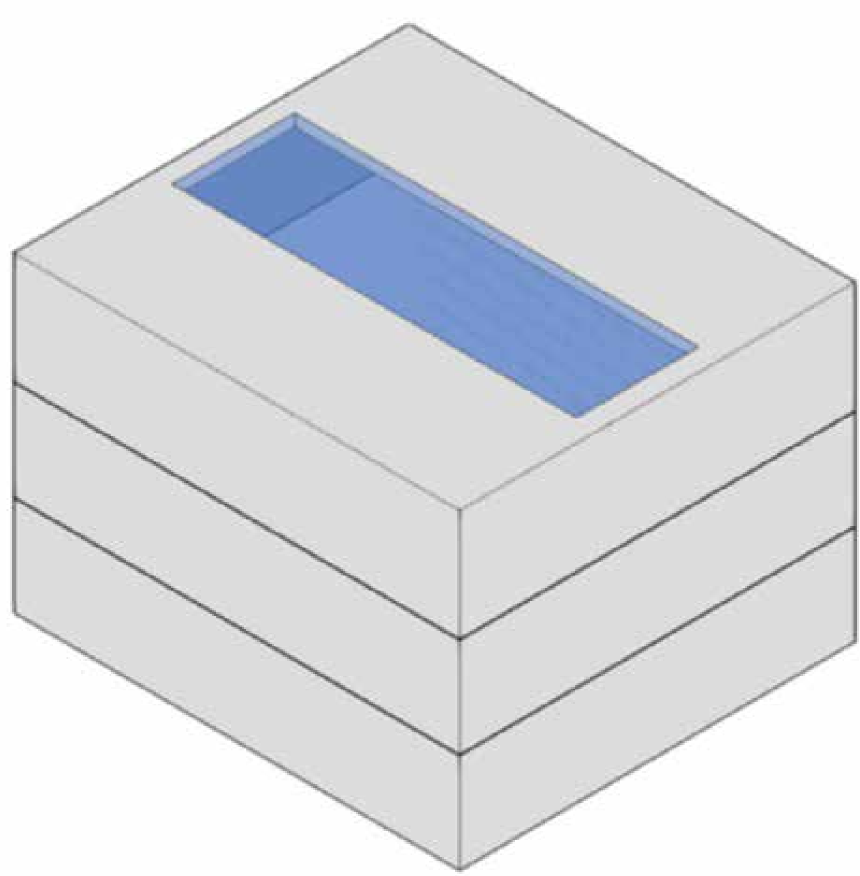


Figure 1: Long horizontal opening atrium prototype (Source: Author).

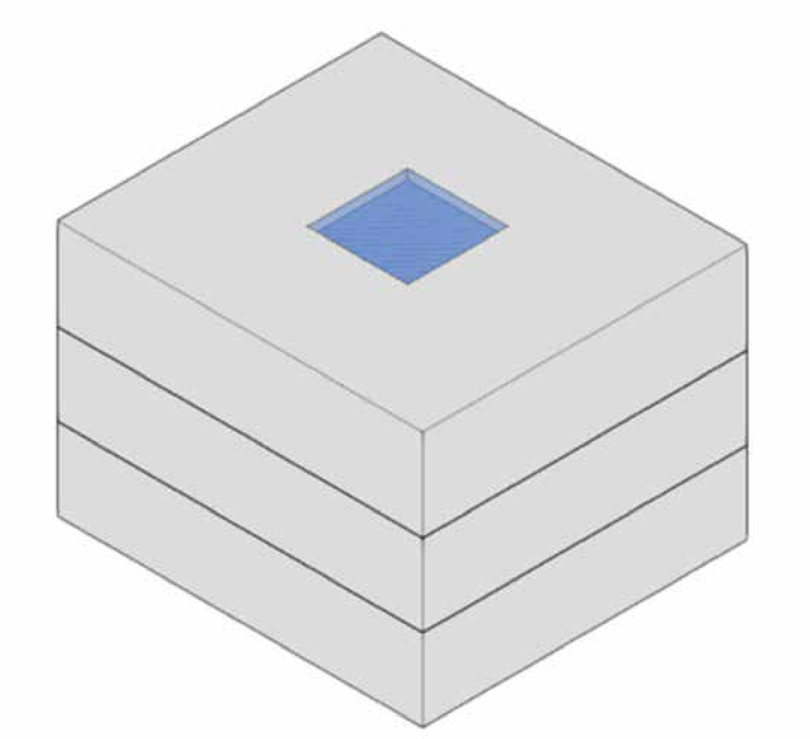


Figure 2: Square opening atrium prototype (Source: Author).

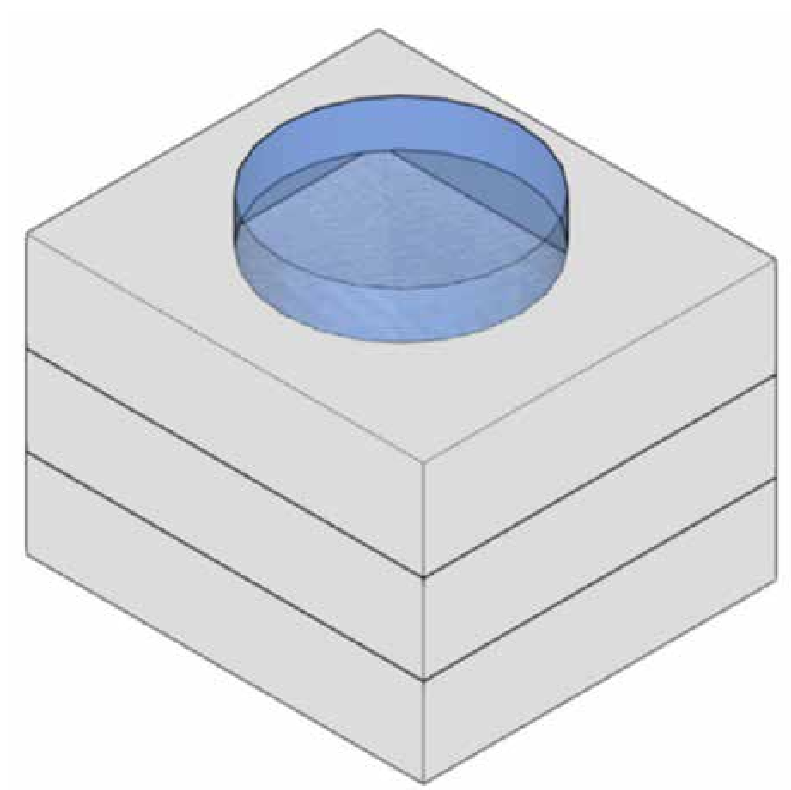


Figure 3: Centralised and circular opening atrium prototype (Source: Author).

The model's area is set at 10 metres by 10 metres for all prototypes, while the height of each floor's simulated area is kept constant at 4 metres (Figure 4). The minimum number of floors for a functioning atrium is two; thus, three floors are the workable number of storeys for the prototype's daylight penetration area simulation (Yunus et al., 2019).

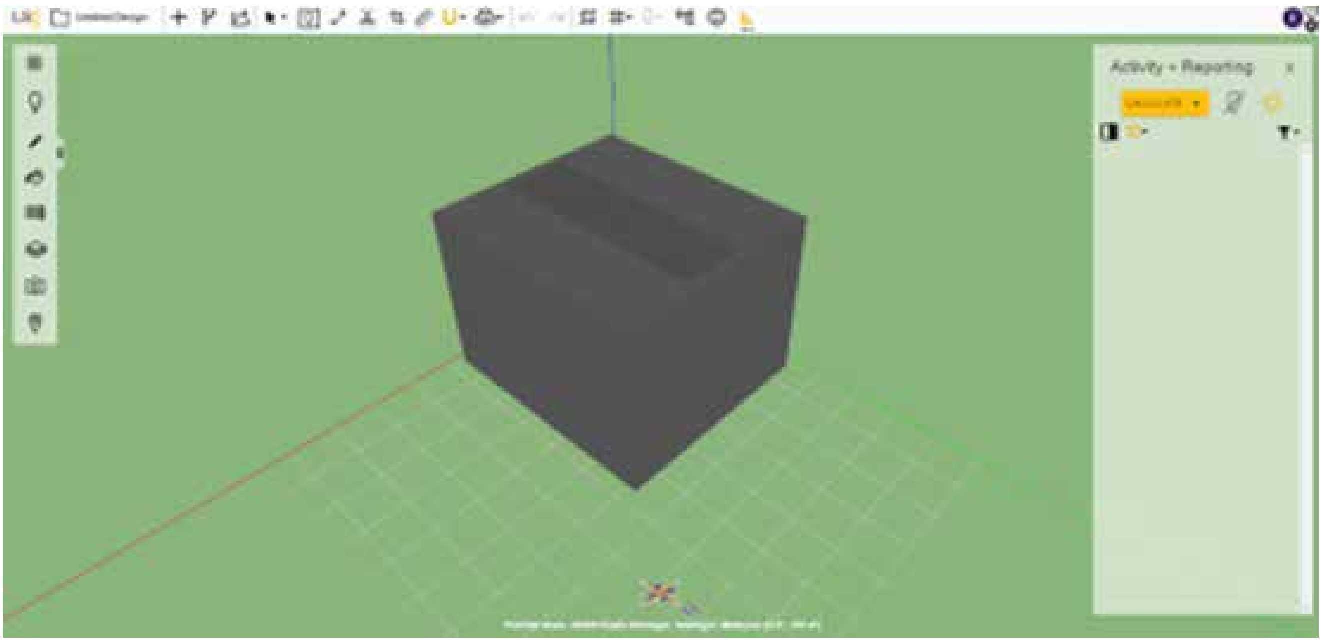


Figure 4: Example of the imported model in Lightstanza (Source: Author).

Next, the prototypes are transferred into Lightstanza software for daylighting simulation as shown in Figure 5. The daylighting simulation is set with a 10-hour daylight cycle of 8.00 am to 5.00 pm and quarterly intervals of 21 March, 21 June, 21 September, and 21 December. The final step is the analysis based on the results obtained from the Lightstanza simulation.

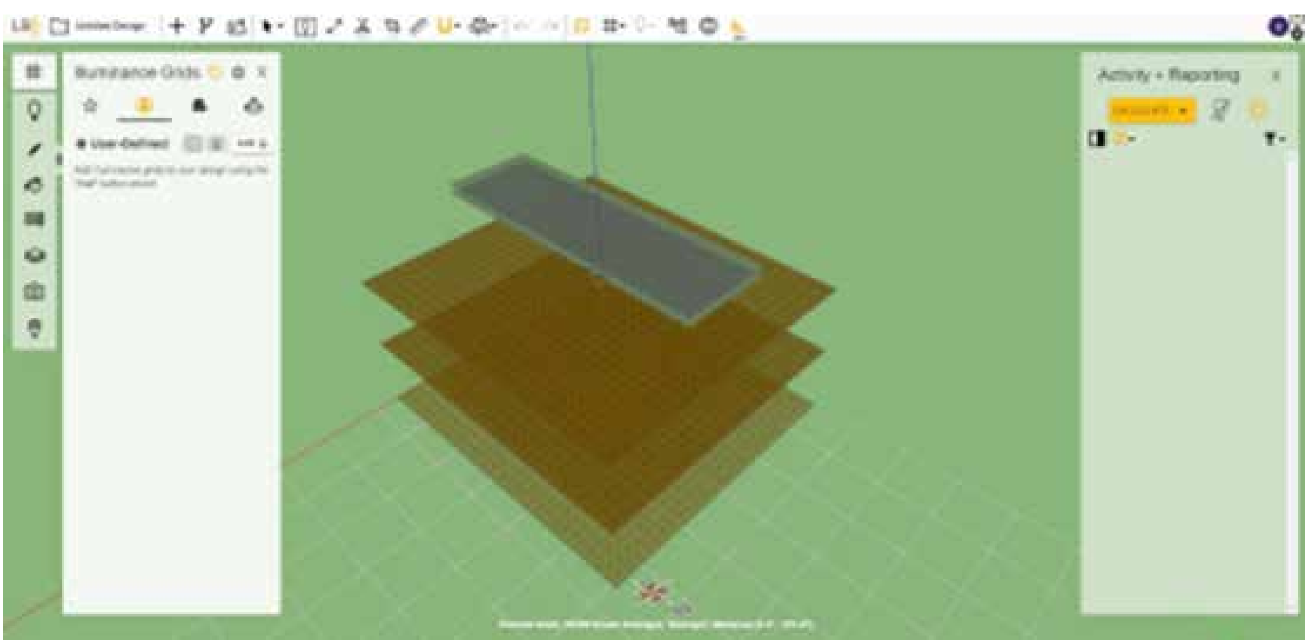


Figure 5: Example of illuminance grid placement inside a model (Source: Author).

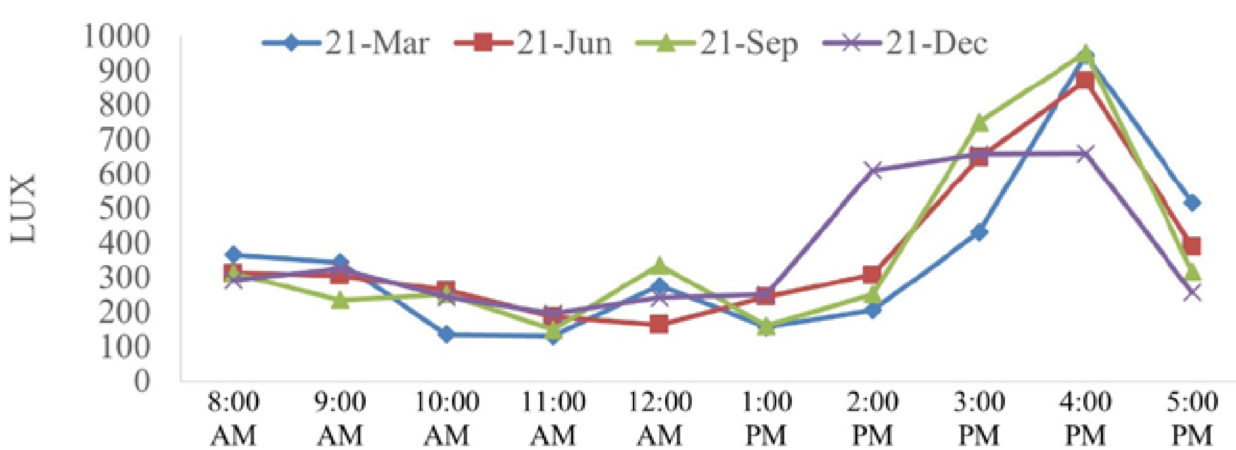
The data analysis process involves the analysis of atrium designs based on their daylight penetration levels, identifying the design with the highest and lowest penetration. This assessment is conducted at an optimal efficiency level. In urban agriculture, vertical farms necessitate an illuminance range between 400 lux and 700 lux (Song et al., 2019). The atrium design's standard could be compromised if the lux level is above 700, whilst a lux level below 400 would fail to fulfil the intended criteria for adequate daylight penetration. The daylight penetration observed in the three models must meet a sufficient threshold to comply with the set efficiency criterion. This consideration is necessary to select the ideal design that effectively promotes daylighting.

Results and Discussion

Atrium design features include the ability to offer sufficient indoor daylighting and circulation of areas and spaces for landscaping purposes. The design has the advantage of lowering the building's energy demands and providing a focal point. On the other hand, the constraints of atrium architecture include excessive lighting from poor construction, glare, and high temperatures in tropical climates.

According to secondary data, the six general typologies of atrium architecture recognised and found across the tropical environment are centralised, semi-enclosed, attached, linear, long horizontal opening, and centrally circular (Yunus et al., 2019). The data analysis for the simulation approach will examine the data to determine which atrium designs have the highest and lowest daylight penetration, where the data must be observed at an effective level. Vertical farms in urban agriculture require 400 lux to 700 lux of illumination (Song, Tan & Tan, 2018). Atrium design with excessive sunlight above 700 lux is inefficient, whereas little daylight penetration below 400 lux is insufficient. The daylight penetration performance of the three models must be efficient enough to meet the efficiency criteria to qualify for the best design that enables daylighting to flow through. This study can ascertain the most efficient atrium design by contrasting the heat dissipation and degree of daylight penetration among the three simulated atrium models with the lux requirement standards established by JKR and IES.

Table 1: Simulation data recorded from Lightstanza for a long horizontal opening atrium.

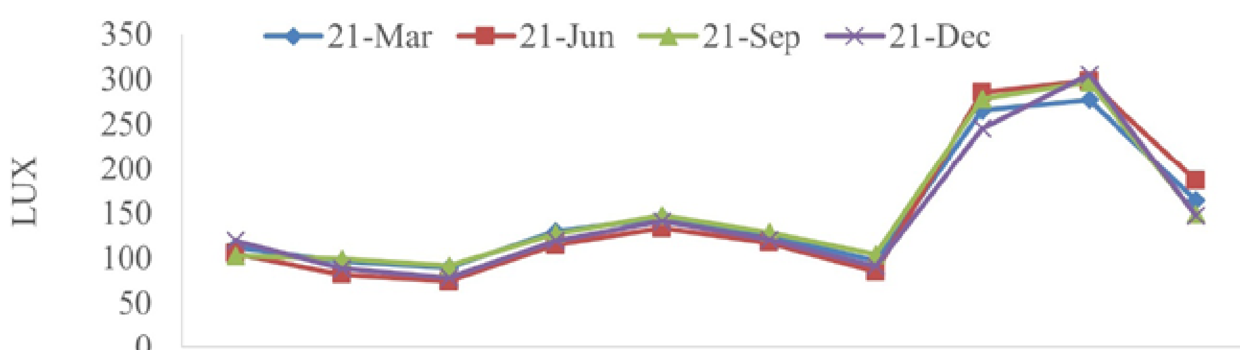


	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 AM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
21-Mar	366.4	344.4	135	129.8	275.7	156	204.6	431.2	944.7	515.7
21-Jun	313.6	304.3	262.9	185.3	162.2	243.5	308.2	647.9	870.3	389.9
21-Sep	312.4	234.1	250.2	148.3	336.2	159.6	250.8	749.3	951.5	316.5
21-Dec	292	325.1	242.3	194.4	240.2	249.9	610.8	657.9	659.1	256.4

AVERAGE LUX

Table 1 shows the data accumulated by the 10-hour long daylight exposure simulation for the first atrium sample, the long horizontal opening atrium. On 21 March, the lowest level of daylight penetration was observed at 10:00 am, recording an illumination of 135 lux. Conversely, the peak daylight penetration on 21 March was recorded at 4:00 pm, reaching 944.7 lux. This peak coincides with the sun's westward position relative to the building. When the sun is directly above the atrium, daylight penetration measured 275.7 lux at noon, aligning optimally with the atrium design to facilitate ideal daylighting. Moving to 21 June, the least daylight penetration occurred at noon, registering 162.2 lux. This phenomenon can be attributed to the sun's angle, which impacts the anticipated penetration. Conversely, the highest daylight penetration on this date was observed at 4:00 pm, reaching 870.3 lux. However, this illumination intensity introduces excessive heat and glare in the atrium. On 21 September, the pinnacle of daylight penetration was noted at 4:00 pm, recording a luminance of 951.5 lux. Similarly, the excess of light at this level presents challenges related to glare and temperature. The nadir of daylight penetration was observed at 11:00 am, measuring 148.3 lux, and noon recorded a moderate 336.2 lux, providing satisfactory daylighting. Lastly, on 21 December, the highest point of daylight penetration occurred at 4:00 pm, though at a relatively lower level compared to other months, reaching 659.1 lux. However, even this amount contributes to excessive heat and glare. The weakest daylight penetration on this day was observed at 11:00 am, registering 194.4 lux, which, while slightly below average, still presents an acceptable daylight level.

Table 2: Simulation data recorded from Lightstanza for the square opening atrium.



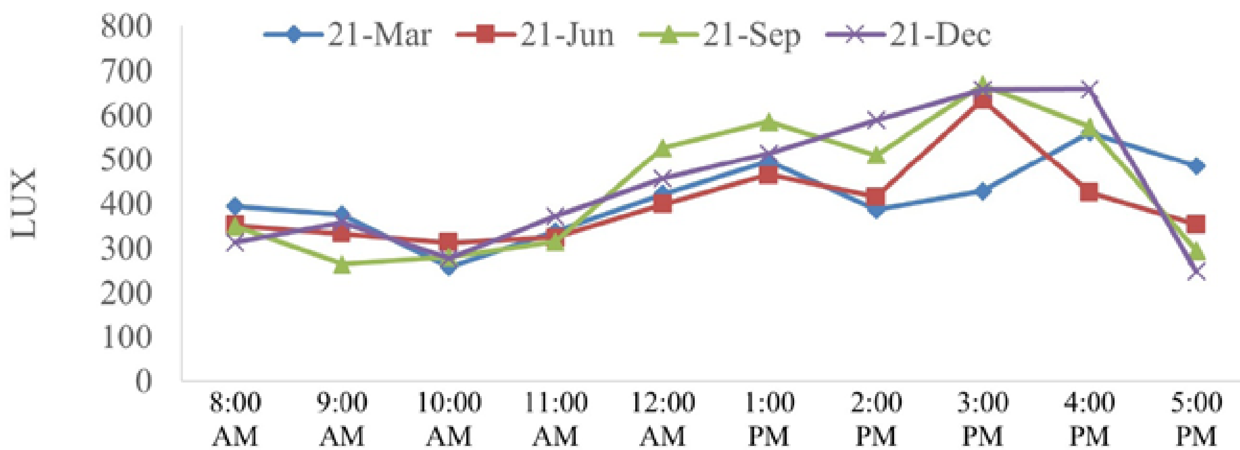
	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 AM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
21-Mar	112.4	96.4	89.5	129.8	145.1	124.6	97	265.4	277.2	164.5
21-Jun	105.2	81.6	74.2	114.9	133.2	117.2	85	285.2	298.2	186.5
21-Sep	102.6	99.1	91.5	127.2	147.3	128.6	104	278.2	296.8	148.5
21-Dec	119.4	88.5	78.1	119.3	141.2	120.4	91	245.3	305.2	147.3

AVERAGE LUX

Next, Table 2 shows the data accumulated from the 10-hour-long daylight exposure simulation for the square

opening atrium. On 21 March, the minimum daylight penetration occurred at 2:00 pm, registering a mere 97 lux. Conversely, the pinnacle of daylight penetration on the same date was witnessed at 4:00 pm, reaching 277.2 lux, corresponding to the sun's westward position relative to the building. At noon, when the sun is directly overhead the atrium, daylight measurement was 145.1 lux, aligning optimally with the atrium design for optimal penetration. Turning to 21 June, the feeblest daylight penetration materialised at 10:00 am, recording a reading of 81.6 lux. This decrease can be attributed to the sun's angle, which limits the expected penetration level despite its direct overhead position. Conversely, the zenith of daylight penetration was observed at 4:00 pm, recording an intense 298.2 lux. However, this elevated level poses challenges due to excessive heat and glare within the atrium. On 21 September, the peak daylight penetration was noted again at 4:00 pm, marking a measurement of 296.8 lux. Similarly, the abundance of light at this magnitude contributes to glare and increased indoor heat via the atrium. The lowest point regarding daylight penetration occurred at 10:00 am, registering 91.5 lux. At noon, the sun emitted a daylight intensity of 147.3 lux, sufficient for effective daylighting. Lastly, on 21 December, the summit of daylight penetration emerged again at 4:00 pm, albeit at a significantly lower level than the other months, reaching 305.2 lux. Even this reduced amount contributes to glaring and excessive heat. The weakest daylight penetration on this date appeared at 10:00 am, with a measurement of 78.1 lux—a tad below average, yet still within an acceptable range of daylight levels.

Table 3: Simulation data recorded from Lightstanza for the centralised and circular opening atrium



	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 AM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
21-Mar	394.2	375.6	258.6	338.2	421.5	496.3	386.4	428.1	562.1	485.6
21-Jun	351.4	332.8	312.6	324.6	398.7	465.8	415.2	634.7	425.3	354
21-Sep	349.2	264.5	280.7	314.8	527.2	586.1	510.4	668.5	574.1	294.8
21-Dec	313.5	358.9	277.6	372.5	457.2	514.3	589.6	657.9	659.1	248.1

AVERAGE LUX

Finally, for the final atrium sample, which is a centralised and circular opening atrium, Table 3 shows the data accumulated from the 10-hour long daylight exposure simulation. On 21 March, the minimum level of daylight penetration transpired at 10:00 am, registering a value of 258.6 lux. Conversely, the summit of daylight penetration on the same date was reached at 4:00 pm, culminating at 562.1 lux. This peak corresponds with the sun's positioning on the west side of the building. At noon, when the sun is directly above the atrium, daylight levels measured 421.5 lux, harmonising ideally with the atrium design's intent for optimal penetration. Shifting to 21 June, the feeblest daylight penetration materialised again at 10:00 am, recording a reading of 312.6 lux. This decline is attributed to the sun's angle, which restrains anticipated penetration despite its direct overhead orientation.

In contrast, the zenith of daylight penetration was observed at 3:00 pm, registering an intense 634.7 lux. This elevated level, however, poses challenges due to heightened indoor heat and glare within the atrium. On 21 September, the zenith of daylight penetration resurfaces at 3:00 pm, attaining a measurement of 668.5

lux. Similarly, the abundance of light at this magnitude contributes to glaring and heightened indoor heat through the atrium. The nadir of daylight penetration was noted at 9:00 am, registering 264.5 lux, and noon marked a sunlit output of 527.2 lux, signifying adequate daylighting potential. Finally, on 21 December, the pinnacle of daylight penetration was reached again at 4:00 pm, albeit at a notably lower level compared to other months, measuring 659.1 lux. Even this reduced value contributes to excessive heat and glare within the building. The lowest point on this date was observed at 10:00 am, recording 277.6 lux—a tad below average, yet still within an acceptable range of daylight levels. By comparison, the first variant, the long horizontal opening atrium, has decent daylighting penetration at an average of 350.35 lux but can be excessive at times, reaching 944.7 lux and producing glaring. The acceptable heat dissipation exhibits satisfactory daylighting penetration with an average lux of approximately 350.35, but the temperature remains higher than usual, as simulation results show. The square opening atrium is the least efficient since it has the lowest average lux of 150.19 lux compared to the other models. It also has the lowest quantity of heat dissipation as compared to the previous result. Finally, the ideal simulation model would be the centralised and circular opening model. It has the most efficient amount of daylighting at 512.66 lux with a potential reduction of up to 48% in energy consumption for lighting compared to traditional infrared compared to the other models, and it also has the best heat dissipation amount compared to the previous result.

Discussion

Ultimately, the most optimal simulation model emerges as the centrally positioned circular opening model. It attains the highest daylight efficiency level, averaging around 512.66 lux, surpassing other models. Furthermore, it demonstrates superior heat dissipation, as inferred from the preceding outcomes. Based on the simulation, the circular-shaped atrium has the highest daylight penetration efficiency, followed by the long horizontal and square opening atrium helping to determine which atrium design is more efficient by comparing the heat dissipation and amount of daylight penetration between the three simulation models and the standard necessary amount of lux established by JKR and IES.

Although this study focuses on indoor urban farming in Malaysia's tropical climate, the findings offer potential applications for different indoor farming systems. With its balanced daylight penetration and effective heat dissipation, the circular atrium design can accommodate a wide variety of crops with varying light intensity and duration requirements. Crops with higher light demands, such as tomatoes or peppers, would benefit from the circular atrium's optimal light levels. In contrast, shade-tolerant crops like leafy greens could be cultivated in areas where light intensity tapers off from the centre. Additionally, the efficient heat dissipation characteristics of the circular atrium help maintain stable temperature

conditions, making it adaptable to both temperate and controlled-environment farming systems. Thus, the results suggest that while the models were tested within a tropical context, the principles of atrium design and light management could be effectively tailored to support diverse indoor farming applications globally.

Conclusion

Amidst the COVID-19 pandemic, Malaysia is grappling with a food security crisis. Consequently, it is imperative to augment food production to address the inadequacies in the country's food supply. One of the strategies being embraced involves the establishment of indoor urban farms within buildings, serving the dual purpose of increasing production and raising awareness about food significance within the community. Ensuring an ample and efficient daylighting source is vital in pursuing productive food output. Typically situated within building atriums, urban farms rely on the infusion of daylight for optimal growth. The atrium design must be meticulously orchestrated to facilitate the optimal penetration of daylight into the structure. Distinct variations in atrium design have a discernible impact on the extent of daylight infiltration and possess attributes that encompass the provision of sufficient daylight, efficient space circulation and surfaces suitable for landscaping. The advantages of this design include reduced building electrical usage and the creation of a central hub. However, the drawbacks of atrium design include the risk of excessive daylight due to inefficiencies in design, glare, and elevated temperatures in tropical climates. The literature review conducted for secondary data analysis yields six prevalent typologies of atrium design commonly observed in tropical climates.

These categories comprise Centralised, Semi-enclosed, Attached, Linear, Long Horizontal Opening, and Centralised Circular designs.

In conclusion, the circular-shaped atrium is the best form of atrium design in tropical climates, with the most efficient amount of daylighting at 512.66 lux, more daylight penetration and distribution than the rectangular-shaped atrium and the square opening atrium besides adhering to the recommended standard necessary amount of lux established by JKR and IES. As a result, the circular-shaped atrium can be deduced as a recommended typology of atrium design for artificial intelligence-integrated urban farming that meets the purpose and objectives of the study. Overall, this paper is a compilation of a comprehensive study and forecast of daylighting penetration into the building atrium for AI-integrated farming, which is made viable by building simulation. The initial aim and objectives of the research were met by providing a complete overview of the topic through the literature review and supported by the simulation results. The food problem can be overcome with effective food production through urban farming, hinting at a positive contribution to addressing the food crisis.

This research provides novel perspectives into how suitable atrium design will provide adequate daylight penetration into buildings with urban farming with an integrated artificial intelligence system to optimise agricultural produce that can benefit the agricultural-based government bodies and private sector. This paper establishes the importance of atrium design and urban farming with artificial intelligence. The analysis presented in this study aims to provide valuable insights for future research on the intersection of urban farming and artificial intelligence. Specifically, it investigates the potential of atrium design in facilitating sufficient daylight penetration into buildings incorporating urban agriculture and an integrated artificial intelligence system. Future recommendations for this research would be an extension towards testing the findings from the simulation result of this study with a real case study, which involves real facilities for a comparative study between theoretical, simulation and real case study, thus providing validated results supported with detailed empirical studies on incorporation with artificial lighting in comparison with traditional lighting.

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