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Growblock: An Alternative Solution for Indoor Thermal and Visual Comfort Improvement

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Abstract: The vertical garden offers an alternative to meet the needs of green space in a limited urban area with the upwards planting method. Its function, among others, includes improving air quality, insulating sound and heat, and thus, reducing energy consumption. Growblock, a result of previous research in 2018, combines the function of an interlocking wall block with a vertical garden planter in several design alternatives that can be used indoors or outdoors. This follow-up research will examine the potential of Growblock as an alternative strategy to support the practice of passive designs in buildings. Simulation using the Revit Insight Plugin was carried out to measure the amount of solar radiation received by the Growblock wall. The initial design will then be explored and evaluated by incorporating two other parameters that have not been developed before, i.e., openings for natural ventilation and daylights. The former will be calculated manually, while the latter will be simulated with the Velux Daylight Visualizer. The qualitative comparative methods from various similar literature were used in formulating modification alternatives design. The results were then be compared with the current standards for each parameter. Growblock was proven to reduce solar radiation by 53.03%, compared to conventional walls. This is due to the shade of the planters in Growblock which can protect the walls from direct exposure. Several design alternatives with various stack arrangements were also able to meet the requirements of openings for daylight of 1-5%, and for natural ventilation of more than 5% to the floor area.

Keywords: Vertical garden, solar analysis, daylighting, ventilation, design exploration, passive design

1. Introduction

Global warming is one of the complex environmental problems that has become the center of public attention in recent decades. It occurs when carbon dioxide (CO_2) and other air pollutants and greenhouse gases collect in the atmosphere and absorb sunlight and solar radiation that have bounced off the earth's surface [1]. Most of the greenhouse gases generated from human activities are the result of burning fossil fuels for electricity, transportation, agriculture, commercial and residential, and other industrial activities. The buildings and construction sector itself accounted for 36% of final energy use and 39% of energy and process-related carbon dioxide (CO_2) emissions in 2018, 11% of which resulted from manufacturing building materials and products such as steel, cement, and glass [2]. To address this matter, Indonesia has voluntarily pledged to reduce Greenhouse Gases (GHG) emissions by 26% on its efforts, and up to 41% with international support by 2030 [3].

The concept of green building was introduced to help reduce the problems due to global warming caused by the construction industry. It is defined as creating structures and using environmentally responsible and resource-

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efficient processes throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation, and deconstruction [4]. Despite its higher initial investment, green building has been shown to save energy and water consumption, reduce operating and maintenance costs, produce lower greenhouse gas emissions, and increase occupant satisfaction than conventional buildings. Green buildings achieving the Green Star certification in Australia have been shown to produce 62% fewer greenhouse gas emissions than average Australian buildings and 51% less potable water than if they had been built to meet minimum industry requirements. In India, South Africa, and the United States of America, green buildings result in 25-50% energy savings and water savings of 11-50% [5]. Currently, its application has been regulated in the legislation in several countries, including Indonesia. According to Greenship [6], the six aspects are considered in performing a green building, i.e. appropriate site development, energy efficiency and conservation, water conservation, material resources and cycle, indoor air health and comfort, and building and environmental management.

Vertical gardens or the so-called green walls are surging in popularity these days. Other than being able to maximize the open space area as required in several green building standards, it offers other proven benefits such as improving air quality, insulating sound and heat, reducing energy consumption, reducing heat island effects, providing rainwater harvesting, adding aesthetic value, supporting biodiversity, increasing building selling prices, and making a positive contribution to human health [7]-[11]. A vertical garden is an excellent alternative to planting surfaces, especially in urban areas where land is increasingly scarce nowadays. Plants are generally allowed to grow vines on the surface area of the building façade, either directly or indirectly. The development of science, technology, and innovation continues to give birth to various types of vertical gardens to improve their performance towards sustainable development goals.

Based on the above background, research on Growblock was conducted for the first time in 2018. Considering the various advantages of the interlocking block wall system, Growblock was designed in such a way by adding a planter to each of its modular blocks. This initial research has resulted in a couple of design alternatives considering several parameters: irrigation and drainage systems, vegetation coverage and continuity, vegetation species mix, modular and construction systems. The system forms a straight wall without any openings. Those designs also allow the inclusion of steel reinforcement in the attached space in each modular block. As a follow-up, this current research will examine the potential of Growblock as a strategy for passive design practices in a building to meet the needs of energy efficiency and conservation while still paying attention to the health and comfort factors for building users. The thermal performance of Growblock will be determined by measuring the wall surface temperature due to solar radiation exposure. The research will be continued with design exploration to meet the needs of openings for natural ventilation and daylighting, for which the initial design alternatives have not been offered.

2. Vertical Garden

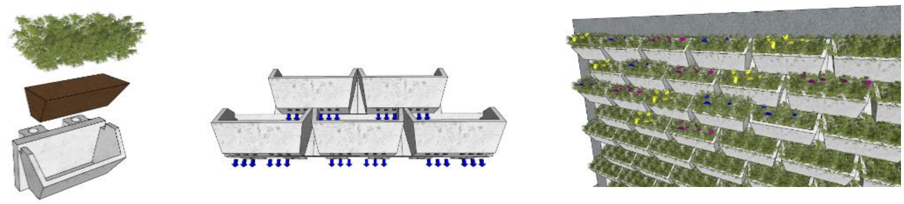
A vertical garden, also known as a green wall or vegetated garden, is a façade system consisting of partially or entirely covered plants that can be installed indoors or outdoors [12]. It is an alternative solution to address the need for green space in buildings, especially in high-density urban areas[13]. In general, vertical gardens can be classified into green façades and living walls [8], [14]. Green façades are made by rooting the plants directly on the façade or the supporting structure into the soil or at grade, using a natural or artificial substrate. Commonly used support structures include trellises, rigid panels, and cable systems [15]. This technique is cheaper and more straightforward since it does not require any equipment, or complicated irrigation and drainage systems [8], [14]. However, there are some drawbacks of green facades, among others, are limited plant species, longer time to cover all surfaces, and the potential for damage to wall structures and other building elements due to vine roots [8].

On the other hand, living walls, also called bio-walls or vertical gardens are composed of vertical modules, planted blankets, or pre-vegetated panels made of plastics, expanded polystyrene, synthetic fabric, clay, metal, and concrete [16]. Compared to green facades, living walls provide broader coverage of planted wall surfaces in less time, with greater plant species diversity, and higher density. The irrigation system is usually built inside the wall, equipped with a reservoir underneath, where the plants are watered from the top of the wall. Therefore, this technique generally costs more to install and maintain. Some of the criteria to be considered in choosing between the two vertical garden approaches are initial cost, plant types and density, the substrate (growing media), construction system and method, effects on building elements, irrigation, and drainage system, and maintenance. The maintenance criteria are cost, standards of appearance, the function of a vertical garden itself, and safety in operational activities.

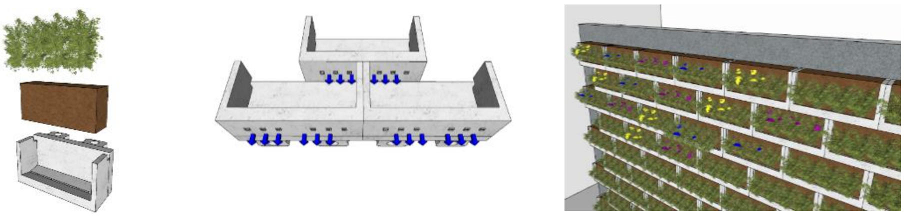
3. Growblock

Interlocking blocks as wall materials are commonly used in Indonesia. Its main feature, which is the interlocking system, allows the walls to stand independently without any binding mortar [17], [18]. This wall system can cut back the construction costs, deliver faster construction time, and use fewer skilled labor [8], [17]- [19]. Growblock is a design prototype of a modular planter-brick unit. It has a combined function of a common concrete wall block and planter box in a single module. It was initially designed in 2018 using coir-fiber reinforced concrete (CFRC) as the form-giving material, molded in reusable formworks. The CFRC was served as a tensile reinforcement to enable the required thin concrete of the planter. Growblock adopts an ARMO Block system designed by Juan Manuel Reyes and Jorge Capistran

[20], an innovative, low-cost construction system that uses single module interlocking blocks that do not require a mortar or any other binder. It is believed to save up to 50% faster and more efficient construction time, 70% labor costs, and 70% water consumption than conventional brick systems [21]. The adapted ARMO interlocking nodes enable the possibility to have a back-to-back wall planter configuration on both sides of single-wall construction. The planter can be placed on either one or both sides of each Growblock to accommodate the spatial design goal, growing media, and the desired plants. Although the irrigation system has not been integrated to date, the drainage system has been considered since the beginning. Water is supplied from the upper to the lower blocks using the force of gravity. This drainage system is expected to reduce water consumption at the operational stage. The details of two alternative designs of Growblock resulting from previous research are shown in Fig. 1.



Initial Design 1



Initial Design 2

Fig. 1 - Two initial designs of Growblock [22]

4. Thermal and Visual Comfort

Passive design is an approach that is becoming increasingly popular in building construction these days, as the need for sustainable buildings increases. The integration of passive design is key to energy-conscious buildings [23]. The design was created to minimize energy consumption and improve thermal and visual comfort for building users by taking direct advantage of nature, particularly from the sun and wind [24]- [26]. Thus, it potentially can reduce the need for mechanical systems for cooling especially in tropical countries [27], [28]. Some of the passive design strategies that are most widely used in tropical countries, such as Indonesia, include responses to building and site orientation, applying shading or second skins, utilizing natural ventilation and natural light [29], [30]. This is due to more straightforward execution and relatively cheaper costs.

Natural ventilation allows natural exchange between outdoor and indoor air to lower the room temperature, as well as control the humidity and unwanted compounds for the well-being of building users [27], [31]-[35]. Moreover, it also supports energy savings at the operational stage. The ventilation openings in typical buildings must be not less than 5% of the floor area. However, this requirement is increased to a minimum of 10% for green buildings in Indonesia, coupled with the requirement that above 50% of the total space area must be designed with cross ventilation [6]. Apart from wind, the sun is the most important energy source that can be used to form a sustainable building. Solar energy received by an object is influenced by three factors: the intensity of the sun, the duration of radiation, and the sun's position to the earth. In Indonesia, solar insolation can reach 4 kWh/m^2 [36], with an average of 12 sun hours per day [37]. Due to the orbit's elliptical shape, the position of the sun to the earth will be marked following the date and month of illumination. Solar radiation with high energy and long exposure will increase the building surface temperature.

Daylighting is one of the parameters used for visual comfort assessment. One of the earliest, easy, dan common metrics used for calculating daylight is Daylight Factor (DF) [38]. DF is the illumination ratio inside and outside the building under an overcast sky. Rooms with an average DF of 2% or more can be considered daylit, but electric lighting may still be needed to perform visual tasks. A room will appear strongly daylit when the average DF is 5% or more, in which case electric lighting will most likely not be used during daytime[39], [40].

5. Research Methodology

This follow-up research aims to measure the Growblock walls' performance in supporting passive design to reduce building energy consumption, in this case, the reduction of solar radiation, and the optimization of natural lighting and ventilation. Simulation using the Revit Plugin Insight was carried out to determine the solar radiation received by the building's outer walls. The results between Growblock walls and conventional concrete block walls (as a control-model) were compared on the four sides of the building. The control model was assumed to have a density of 2,407 kg/m^3, and compressive strength of 24.1 MPa. The simulation considered several thermal parameters, i.e., sun exposure, depending on geographic location set-up, as well as Growblock shape and size. The solar radiation exposure received by a-6 m x 9 m x 3 m model was measured in four directions: east, west, south, and north. The geographic location was set in Bandung, Indonesia, where this research was conducted, by considering a-full-year exposure in 2019 with the hourly time interval. The output was produced as cumulative energy per unit area over an entire year and displayed in a different color spectrum (kWh/m^2).

Furthermore, the Growblock design was explored to meet the need for ventilation and daylight openings due to the lack of both features in the initial designs. The modified designs were then tested to measure its performance in providing the daylighting through a simulation using the Velux Daylight Visualizer 3.0. The measured DF value expresses as a percentage the amount of daylight available inside a room (on a work plane) compared to the amount of unobstructed daylight available outside under overcast sky conditions [41]. Meanwhile, the openings to the floor area percentage were then quantified to determine the Growblock's performance in meeting natural ventilation requirements. These results were compared with four existing standards. The first one is SNI 03-6572-2001 regarding Procedures for Designing Ventilation and Air Conditioning Systems in Buildings. The second one is the Greenship for ventilation openings. The other two are the Building Research Establishment Environmental Assessment Method (BREEAM) [40] and Lechner [21] for typical minimum daylight factors as no standard is available in Indonesia.

6. The Performance of Growblock

The Growblock wall performance test against solar radiation exposure was carried out from sunrise to sunset, from 06.52 to 18.39 local time [43]. In the simulation, each building model is oriented in two different directions, where the 9-m long side will be directed east-west and south-north. Fig. 2 shows the simulation results delivered with a diverse spectrum of colors describing their intensity on both types of walls. The yellow color represents the highest energy at 1,637 kWh/m^2, while purple shows the lowest energy at 0 kWh/m^2.

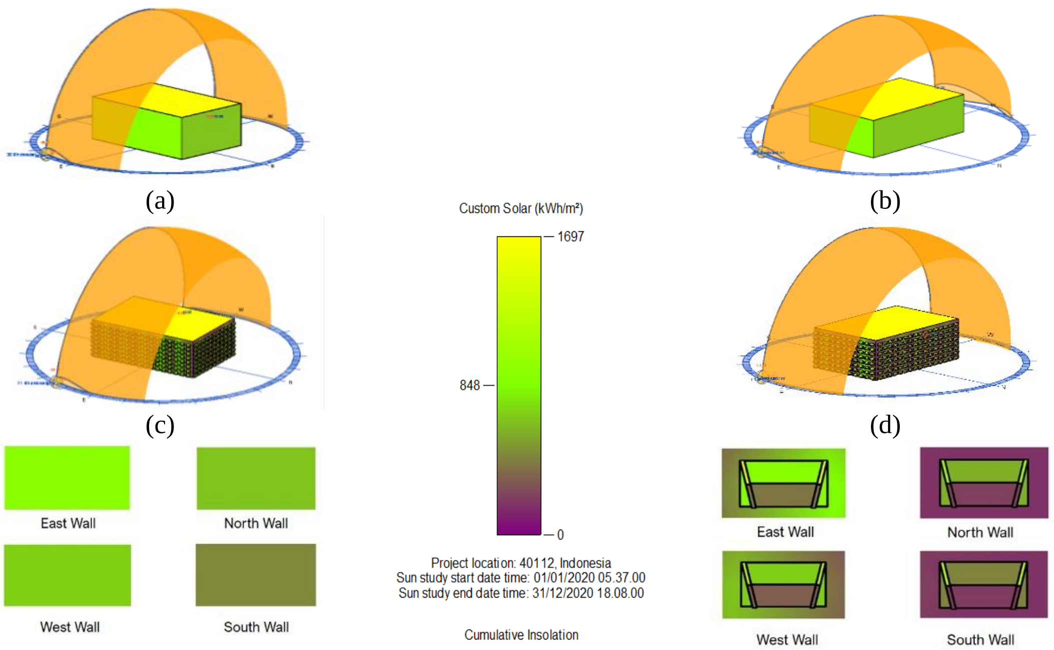


Fig. 2 - Simulation results of solar radiation received by the two types of walls: (a) conventional (east-west), (b) conventional (south-north), (c) Growblock (east-west), dan (d) Growblock (south-north)

Both types of walls produce a relatively similar color spectrum, although the long and short sides are rotated in different directions since the Revit Plugin Insight produces average insolation per unit area in kWh/m^2 instead of the cumulative energy in kWh in the solar analysis. However, the most significant amount of solar radiation per unit area is received by the conventional wall on the east side with values ranging from 848-1272 kWh/m^2. The west wall received 424-848 kWh/m^2, while the north wall has a similar value to the west wall. The south wall is marked with dark green, darker than the north and west walls, ranging from 0-424 kWh/m^2.

Meanwhile, assuming the same size, shape, material properties, and sunlight conditions as the base-model, the Growblock wall produces a dominance of purple, with the same side order in receiving the highest energy. The four sides of the walls produce two color spectrums due to the planter's shading on each Growblock module. Compared to the other two sides, the east and west walls were hit by the most significant average energy due to solar radiation received perpendicularly to the direction of sunrise and sunset. Moreover, the simulation location, which was set in Bandung, is located between 107° east longitude and 6° 55 'south latitude, causing the sun movement to shine more on the north side of the building. In other words, the southern wall has the lowest radiation reception. Naturally, walls with a larger surface area will receive more solar energy. Therefore, the typical practice is to orient building mass away from the direction with the most significant insolation, such as east and west. Setting out the direction of the building walls is one of the passive cooling practices known as heat avoidance. Fig. 3 summarizes the average insolation's comparison results per unit area for the two types of wall models. The graph shows that the conventional wall model receives solar radiation per unit area more intense than the Growblock wall model. It is found that the Growblock wall on the north side can reduce the energy reception by 337,273 kWh/m^2 or 53.03%.

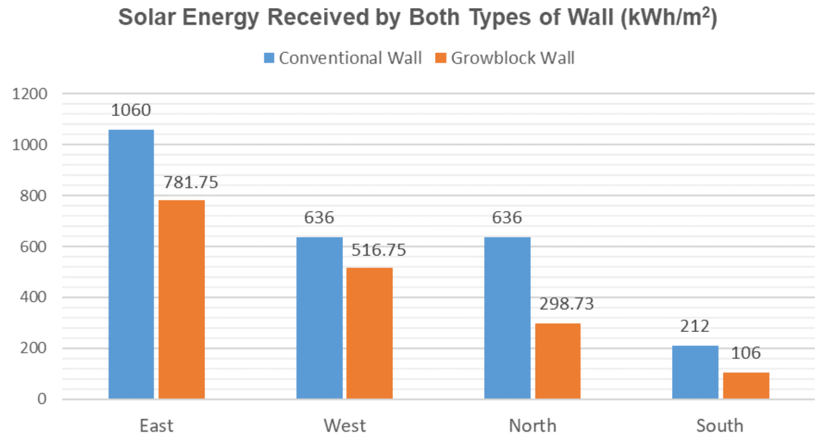
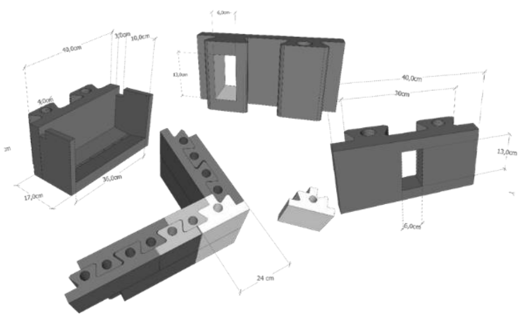


Fig. 3 - Comparison of the average insolation per unit area between the two types of walls

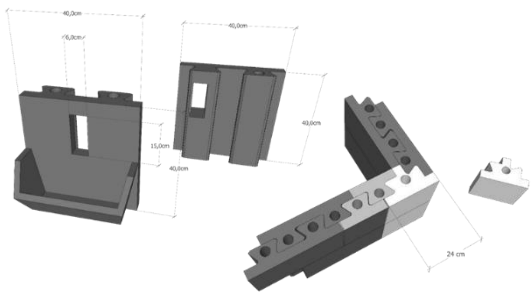
7. Design Exploration

The design exploration began by integrating either the ARMO Block or the conventional interlocking block bonding system with the initial Growblock designs. In the previous research, the ARMO Block was used for the structural strength reason and that was the reason why the modified designs were developed before this bonding system. However, this system limits the modification of the opening, and thus, the openings can only be attempted by perforating the Growblock itself. This approach, unfortunately, will weaken the joint. Also, the Growblock stacking cannot be done inclined using this system. Therefore, the conventional interlocking block bonding system was also considered as an alternative in the exploration. By using this conventional system, the stacking, either straight or inclined can be applied in the Growblock wall. The exploration resulted in four new designs, where the ARMO Block system was applied in designs no. 1 and 2 as in the initial designs. In contrast, a conventional interlocking block system was integrated into designs no. 3 and 4. Fig. 4 exhibits the four modified designs.

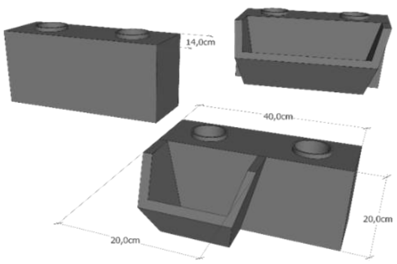
The Growblock's performance in producing ventilation openings and daylighting was assessed by arranging the four modified designs into a four-sided room with dimensions of 3 m x 4 m x 3 m. Table 1 describes the modification details. Each design produced two arrangements of openings that were located on one side (A), and two sides (B) of the wall. The third design had a variation in its stacking system using rotating (inclined) blocks, while the other designs applied a straight stack system. Fig. 5 to Fig. 8 present the room models with different Growblock designs made using SketchUp and their daylight visualization using Velux Daylight Visualizer 3.0. These figures show visualizations of daylighting that can be produced using the four modified designs. Modified designs no. 1 and 2 show a darker room than designs no. 3 and 4 which are caused by the lack of daylight entering the room. In other words, a brighter room can be formed with the walls using modified designs 3 and 4. Between the two types of openings arrangement, the two-sided certainly produce more daylight entering the room. Furthermore, the resulting DF values are summarized in Fig. 9.



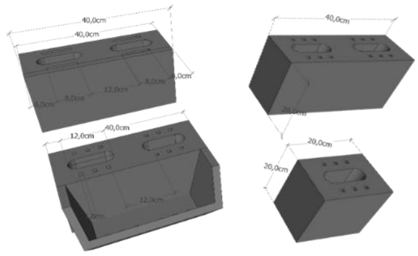
Modified design 1



Modified design 2



Modified design 3



Modified design 4

Fig. 4 - Results of design exploration

Table 1 - Details of Growblock modifications

Design Modification	**Interlocking System**	**Stacking System**	**Arrangement of Openings**	
			A	**B**
Modified Design 1	ARMO Block	Straight	One-Sided	Two-Sided
Modified Design 2	ARMO Block	Straight	One-Sided	Two-Sided
Modified Design 3	Conventional Interlocking Block	Rotated	One-Sided	Two-Sided
Modified Design 4	Conventional Interlocking Block	Straight	One-Sided	Two-Sided

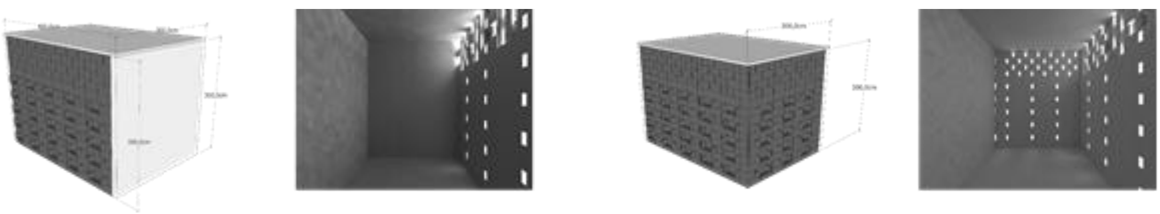


Fig. 5 - Room model, using modified design 1 with one-sided and two-sided opening walls

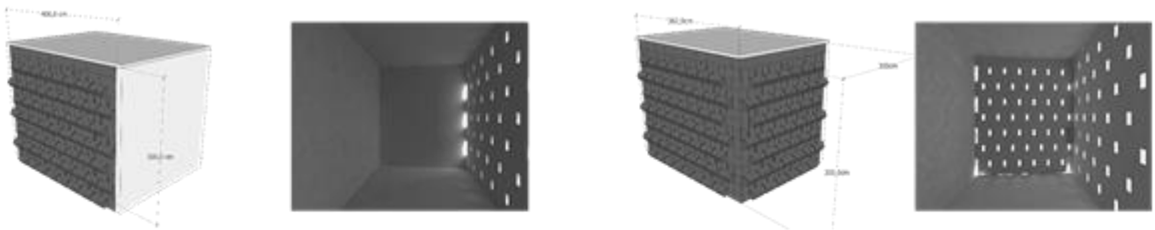


Fig. 6 - Room model, using modified design 2 with one-sided and two-sided opening walls

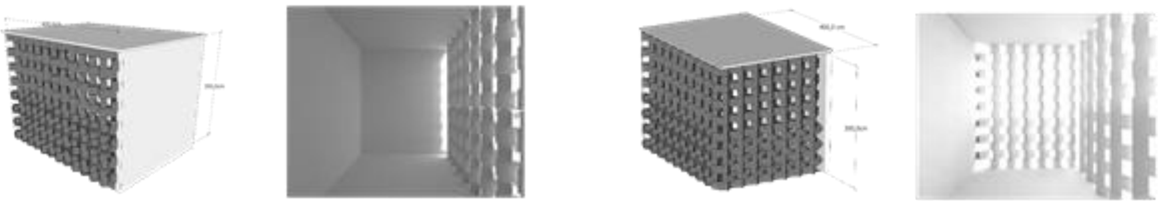


Fig. 7 - Room model, using modified design 3 with rotating blocks with one-sided and two-sided opening walls

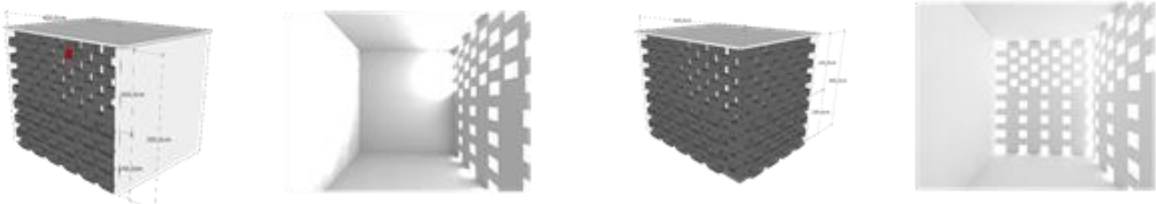


Fig. 8 - Room model, using modified design 4 with one-sided and two-sided opening walls

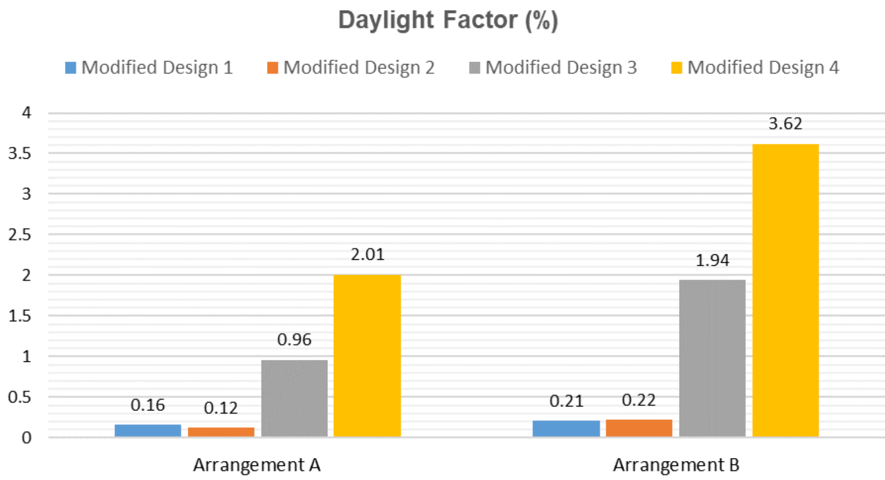


Fig. 9 - Daylight factors (DF) of each modified design with different openings arrangement

The results shown in Fig. 9 show that modified designs no. 1 and 2 were not able to generate appropriate DF values for any room function, or building, which is a minimum of 0.5% (based on Lechner), and 1.5% (based on BREEAM). Despite the larger openings caused by the taller size of Growblock, the modified design no.2 still produces DF values that are relatively the same as modified design 1. It is due to the position of the opening(s) around the planter's shadow area. The design results in DF values from 0.12 to 0.22% depending on the openings' different arrangements. Modified designs no. 3 and 4, with the integration of a conventional interlocking block system, gave higher DF values that meet the requirements. The joints allow more flexible modification and arrangement to create larger openings than the ARMO block joints. With a DF value between 0.96 to 3.62%, this Growblock design can be used to produce daylighting in typical room functions, such as lobbies, lounges, living rooms, churches (DF = 1%), offices, classrooms, gymnasium kitchens (DF = 2%), and factories, laboratories (DF = 3 to 5%) according to Lechner (2015). The Growblock design can also be used for various building functions specified at BREEAM, starting from residential buildings, schools, higher education (campus), healthcare buildings, retail buildings, courts, offices, to industrial spaces.

Modified design no. 3 allows the inclined or rotated arrangement by arranging the basic shapes and joints. Based on the simulation, the resulting average DF value was higher than the two previous designs, with 0.96% (one-sided opening wall) and 1.94% (two-sided opening walls). Meanwhile, modified design no. 4 produces the largest daylighting without any artificial lighting, with DF average values of 2.01% and 3.62% for the two types of arrangements. These designs generate average DF values greater than modified design no. 3 due to the frontal and straight openings that minimize obstructions by the Growblock itself, including its planter. The simulation also shows a better daylight distribution with the openings on the two sides of the wall. It can be concluded that several factors affecting the daylighting performance on Growblock are the opening area, opening position, the wall thickness, and the shade from the planter that could obstruct the entry of the daylight into the room.

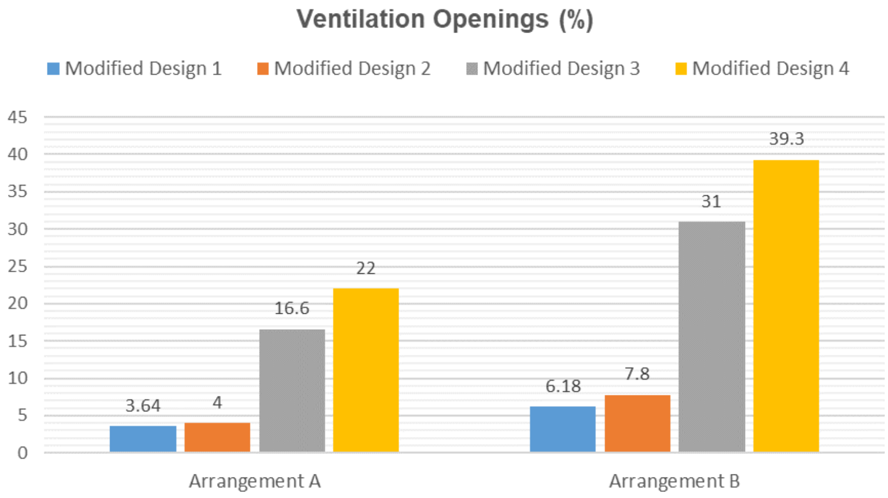


Fig. 10 - Ventilation openings to floor ratio percentage of each modified design

As seen in Fig. 10, most of the Growblock modifications are able to accommodate the need for ventilation openings. Only modified designs no. 1 and 2 with a one-sided opening wall that could not meet the applicable requirements, i.e. minimum 5% of the floor area. According to SNI 03-6572-2001 regarding Procedures for Designing Ventilation and Air Conditioning Systems in Buildings, the ventilation openings should face a properly sized walled courtyard, open area, open terraces, parking lots, or the like with a minimum of 5% of the floor area. For different building functions based on the same standard, i.e., office buildings, laboratory or industrial buildings, commercial buildings, and public buildings, as well as green buildings in Indonesia based on Greenship, the requirements raised to 10%. Modified designs no. 3 and no. 4 results in ventilation openings that are larger than 10%. Although both standards do not put any limitation, an opening larger than 10% could potentially allow excess heat from outside to enter the room and increase the temperature, especially in tropical countries such as Indonesia. Thus, it will increase the room temperature. Thus, it is suggested that the Growblock application could be integrated with the overall passive design efforts. These efforts include, but are not limited to, the various approach to provide shading, microclimate planning for site cooling, and application of heat-absorbent materials. Further research is needed to refine the Growblock innovation in support of sustainable design and construction in the future.

8. Conclusion

Based on the results, the Growblock, as an alternative to the wall material, is potentially proven to support the practice of passive designs by improving indoor thermal and visual comfort. The first finding represents a reduction of solar insolation by 53.03% compared to the conventional walls. It is due to the planter of each Growblock that creates a shading area that blocks direct insolation to the wall surface. The second finding, the design exploration adds to the Growblock's ability to meet the needs of ventilation openings and daylighting. Modified designs no. 3 and 4 that incorporates the conventional interlocking block bonding system can accomplish both parameters quite well. Future research can specifically address the issue of excess heat entering the room by revisiting the individual or integration Growblock designs into the holistic passive design endeavor. Thermal analysis can also be carried out as a complement to the present research findings. In the long term, this research is expected to benefit the key players in the construction industry to keep developing and using such material innovations that promote sustainable design practice.

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