ISSN 2716-0890
Advances in Civil Engineering and Sustainable Architecture
ACESA

ACESA, Vol. 4, No. 1, Maret 2022, 26–36 publication.petra.ac.id/index.php/ACESA

Microalgae as a sustainable facade for occupants' health: A review

Livia Hariyanto[1*] , Lilianny Sigit Arifin[2], Rully Damayanti[3]

[1,2,3]Department of Architecture, Petra Christian University, Jl. Siwalankerto No. 121-131, Surabaya, Indonesia
[1]liviahariyanto97@gmail.com, [2]lili@petra.ac.id, [3]rully@petra.ac.id

Abstract. Microalgae facades as a proven sustainable strategy can provide energy-efficient solutions. However, no one has reviewed the impact of the microalgae facade on the health of residents. The purpose of this study is to examine the microalgae façade with the parameters of Strategies for Sustainable Architecture: Health by Paola Sassi through an analysis of the space comfort and the materials used. The research method is qualitative with a descriptive type of research from previous research articles and journals that discuss the microalgae facade. According to the findings, microalgae facades have a shading coefficient: 67% to reduce overexposure to 1,161 Lux and allow natural ventilation to meet comfort standards. The sound reduction index achieved by the facade microalgae is about 50dB. In dealing with urban pollution, a microalgae facade integrated with buildings can produce 60 to 75% of the oxygen needed by humans through CO_2 absorption.

Keywords: Microalgae Facade; Sustainable Facade; Occupants Health

1. Introduction

Most high-rise buildings are equipped with air conditioning systems with high energy consumption to achieve occupant thermal comfort. Long term exposure to an uncomfortable environment can have a significant impact on occupant health. The building envelope is one of the architectural elements that can provide solutions to the building's energy consumption and affect the health of the occupants [1]. Building designs with intellectual and ecological elements are increasing because designers follow the design paradigm, namely sustainable architecture. Some architects have not fully understood the concept of sustainable architecture. Several technological applications in buildings improve the building performance without considering the effect on the future [2]. This case shows the need for sensitivity as a designer in selecting building facade elements wisely for human health while considering energy efficiency.

Green technology in building envelopes, such as the microalgae facade, can be a sustainable alternative solution. Studies on the application of microalgae facades as sustainable facades are increasing. One example of its application is The BIQ House building, the world's first pilot project. With the integration of a $200m^2$ photo-bioreactor, this passive building apartment produces biomass and heat as a renewable energy source. As a multifunctional bio-facade, this system produces an algae population as a movable shading device used as thermal and sound insulation [3]. Previous review journals focused on the performance of facade microalgae on building thermal and energy [4]. As development of prior journals, this journal relates the performance of microalgae facades to human health and the environment as a sustainable strategy.

The parameters used in this study are Strategies for Sustainable Architecture by Paola Sassi, focusing on building occupants' health. The selection of parameters to create a healthy building by analyzing the factors of comfort and material components factors through the building envelope. The purpose of this study is to examine the microalgae facade with occupant health parameters as a sustainable strategy, namely through analysis of space comfort and materials used. Comfort analysis consists of natural lighting, temperature, humidity, and acoustics, which affect the occupants' health. The material analysis aims to determine the effect of material on pollution, which also affects the health of residents. As a result, the green technology facade concept is for building performance and occupants' health.

2. Methodology

Observation of the research background was obtained through online literature data collection. This study collected qualitative literature review data as a sustainable strategy parameter [1]. Data collection from the results and discussion is qualitative, with descriptive research from previous articles and journals discussing the microalgae. The analysis of the microalgae facade focuses on its effect on occupant health by looking back at healthy buildings as research parameters.

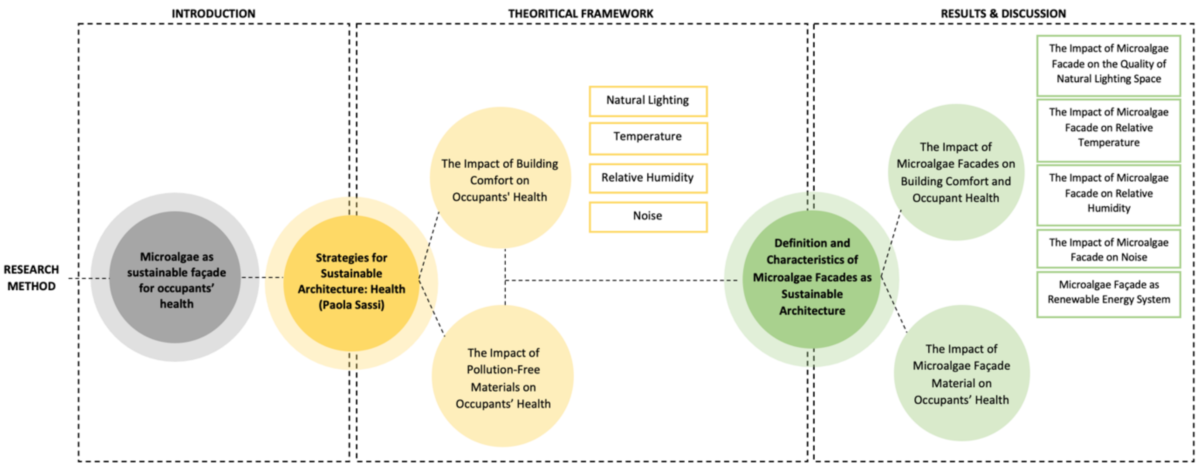


Figure 1. Research method diagram (Source: Author)

3. Theoretical framework

3.1 Creating Healthy Buildings as a Sustainable Strategy

In designing buildings, it is necessary to have a sustainable strategy to solve global problems that occur. Research [5] refers to Paola Sassi's Strategies for Sustainable Architecture, showing that sustainable strategy creates a better, socially responsible, and economically viable living environment. A healthy building is an essential part of a sustainable strategy. Health is the presence of disease and a state of complete physical, mental, and social well-being. Environmental characters can influence and determine lifestyle choices, human proximity to pollution, potential contact with viruses, social interactions, and much more [1]. Buildings can have a direct and indirect impact on health. Directly felt impacts, such as a cool room temperature or low illumination. In the impact that is difficult to identify, health will be visible in the years after exposure to the disease. Not only from negative impacts, but some positive impacts also take time to be identified.

3.2 The Impact of Building Comfort on Occupants' Health

Building comfort in terms of quantity and quality can affect the physical and psychological health of occupants. Some of the parameters used to create building comfort are natural lighting, temperature, humidity, noise, and the individual's ability to control the environment. The thermal comfort approach has changed to a more comprehensive yet flexible [1]. This chapter focuses on comfort parameters in buildings to provide a healthy environment for occupants.

The first parameter is natural lighting. In terms of quantity, good natural lighting values are obtained in the following table of standard illuminance and daylight factor values:

Table 1. Lighting Levels (Sassi, 2006, p. 102)

Room Type	Standard Service Illuminance [Lux]	Daylight Factor Minimum Values
Rarely used area	50	
Storage area	150	
Church hall	150	1
Entrance, living room, kitchen	200	2
Library, teaching area, sports center, visual workspace	300	2
Office, shops, commercial kitchen, painting area	500	2
Meat inspection, drawing office, ceramic decoration	750	2
Cabinet making, supermarket, assembly industry	1000	5
Reproduction chart inspection, precision industry	1500	5

Illuminance and daylight factor values can affect the quality of room comfort. Good quality natural lighting can increase feelings of energy and positivity. On the other hand, poor or dark natural lighting can lead to feelings of sluggishness to depression. Excess sunlight can also harm health. Exposure to large amounts of UV rays can cause skin, eye, and skin cancer. If the standard illuminance and daylight factor values cannot be met through natural lighting, a hybrid lighting system by adding artificial lighting can be an alternative solution. However, there needs to be a wise arrangement in using artificial lighting to consider the value of energy consumption produced [1] .

The following parameter is the thermal comfort of the building through temperature. Humans can quickly adapt to temperatures of 16ºC to 25ºC with the opportunity to keep adjusting the environment as needed. The design of the building can affect the process of heat exchange between the body and the environment through convection, radiation, evaporation. Therefore, the building elements that make up the thermal comfort should be adjusted and operated by the occupants. These are the two main characteristics that make up a comfortable environment. The indoor air temperature affects the convection process, while the building envelope temperature affects the radiation process. The radiation process that makes up 45% of the body's heat exchange with the environment can be reduced if the internal temperature of the building envelope is the same as the internal room temperature [1].

The third parameter is air humidity. Relative humidity (RH) is one of the parameters that are less aware of its influence. Humidity is an essential factor because it significantly affects thermal comfort and indirectly impacts air quality and occupant health. Humidity levels affect the human body's ability to cool down through evaporation. A hot and humid environment will feel hotter than a less humid environment at the same temperature. In some buildings, the use of HVAC is applied to reduce RH levels rather than reducing temperatures. Quantitatively, the standard RH level is 40% to 50%. Levels below 35% can cause dryness of the eyes, nose, throat, and sensitization of mucous membranes, which can lead to increased viral and allergic reactions. Levels above 70% can result in condensation and biological contaminants such as fungi and mites. Indoor RH is a condition resulting from the integration of building insulation, indoor materials used, sources of humidity, quality of ventilation, and heating [1].

The fourth parameter is noise. Noise is unwanted sound, from high to low volume, which can cause physiological and psychological disturbances. The following is the effect of noise level on physiological comfort:

Table 2. Noise Levels (Source: Sassi, 2006, p. 100)

Noise Levels [dBA]	Physiological Impact
65	Body and mental fatigue
80	Increased blood pressure
90	Heart pressure
90-120	Hearing disorders
145	Damage eardrum

The psychological effects are hypertension, sleep problems, headaches, nausea, irritability, anxiety, and worsening memory [1]. These parameters indicate that comfort is a condition for creating a healthy environment.

3.3 The Impact of Pollution-Free Materials on Occupants' Health

As technology develops, materials with maintenance systems are integrated into each other in a building. After the installation of the material, the impact of the material on health risks is not considered. The use of untested materials with minimal ventilation can increase indoor air pollution tenfold. Building materials, equipment used, and external air can form indoor pollution. The impact of indoor pollution on health can worsen due to the influence of the lifestyle of building occupants. Most people spend 90% of their time at home, at work, and in cars, so their exposure to indoor pollutants increases. Contact with chemicals and biologics that carry disease is thought to increase allergies in residents. Adequate air ventilation can be a solution to avoid the accumulation of pollution in the space. The standard internal air velocity is 10m/min for winter and higher for summer. Speeds less than 6m/min are considered ineffective [1]. Therefore, it is necessary to pay attention to the selection of wise materials for the future for the health of residents.

4. Results and Discussion

4.1 Definition and Characteristics of Microalgae Facades as Sustainable Architecture

The microalgae facade system is an exterior building envelope with a living creature as part of it. This system is a climate-responsive building facade innovation and for renewable energy solutions [6]. The bioreactor panel on the microalgae facade system generates renewable energy by utilizing the photosynthesis process and the carbon cycle. The algae bioreactor system is integrated between two glazing systems (glass/acrylic) on which algae grow in a nutritious liquid. Algae are grown in two different systems. The first is an open pool system, and the second is a closed system that will be studied in this research. This closed system is called a photo-bioreactor (PBR) (see Fig. 2).

Figure 2. Microalgae facade photo-bioreactor system (Source: https://www.archdaily.com/339451/worlds-first-algae-bioreactor-facade-nears-completion)

This system encloses the algae in the tube to avoid cross-contamination. Controlled algae have better yields in unit growth rates. In the last decade, there have been many studies on photo-bioreactor systems that are efficient as fuels. A photo-bioreactor can be described as a closed, illuminated culture vessel designed for controlled biomass production that is closed to an environment that has no direct gas exchange and contaminants with the environment [7].

4.2 The Impact of Microalgae Facades on Building Comfort and Occupant Health

In a sustainable strategy, climate-responsive architecture needs to be applied to respect building occupants' environment and physical comfort. The journal [6] describes the microalgae facade as a building facade element with the application of energy efficiency that is integrated with the application of passive design. Energy efficiency is applied by converting natural lighting into biomass and heat energy. To further discuss the effect of the microalgae facade on the comfort level of occupants, the parameters that will be used are natural lighting, temperature, relative humidity, and noise by Paola Sassi's theory.

4.2.1 The Impact of Microalgae Facade on the Quality of Natural Lighting Space

Natural illumination impacts the comfort of space, including building occupants' physiological and psychological health [1]. Microalgae facades can improve optimal daylighting quality in space by absorbing light based on microalgae culture density [4]. Journal [20] conducted a study on microalgae facades applied to tropical climates in Jakarta to create good quality natural lighting for residents

The study results (see Fig. 3) show that the light intensity on the front of the facade panel with 9 hours of sun exposure is above 2000 Lux. While on the back of the facade panel with 9 hours of sun exposure, the value is 416-839 Lux. The sunlight received at the front of the facade is more than the back of the facade. High light intensity is used for algae growth, which requires 2000-8000 Lux, while on the facade of the internal space, the light intensity is reduced. This study shows that microalgae facades can help reduce light intensity according to the needs and standards of predetermined light levels.

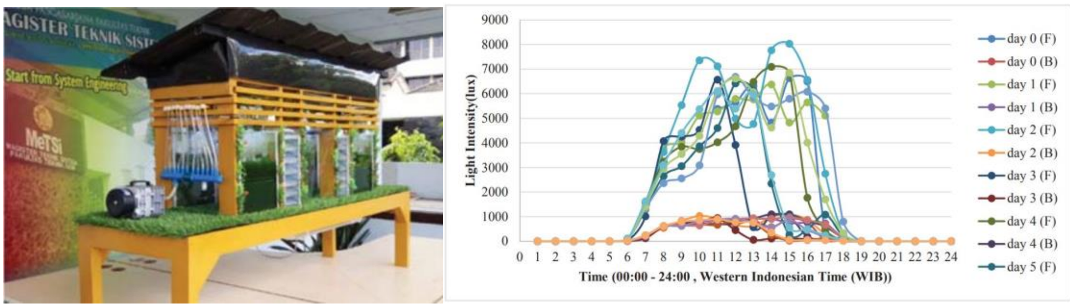


Figure 3. Microalgae facade prototype and Light intensity parameter (F) Front (B) Back (Source: (S et al., 2020, p. 5))

4.2.2 The Impact of Microalgae Facade on Relative Temperature

Room temperature affects occupant comfort and building energy load through an HVAC system [1]. Microalgae facades can prevent unwanted solar heat gain from entering the space through their role as a thermal insulator and as adaptive shading [8]. The role of the microalgae facade as a thermal insulator is to utilize absorbed sunlight for the growth of microalgae by photosynthesis and to prevent excess sunlight from entering the building. However, this process needs to be controlled for optimal algae growth [9]. The role of the microalgae facade as adaptive shading is a panel that can adjust the angle of incidence of the sun to maximize the photosynthetic process and perform well as a shading tool [10]. Several shading designs with microalgae facades have been developed, one of which is the Algae Tower located in Melbourne by UOOU Studio (see Fig. 4)[11].

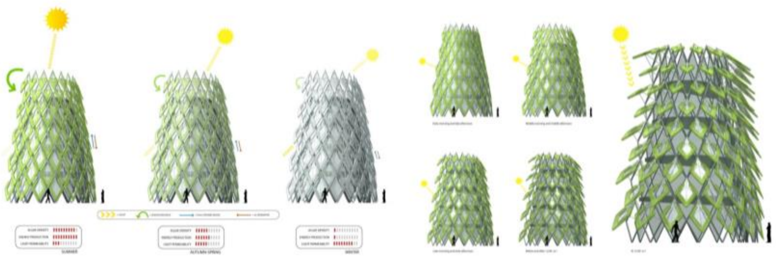


Figure 4. The shading device of Algae Tower (Source: https://uooustudio.com/algae-tower)

Research [12] compared the performance of PBR with venetian blinds as a shading device and light transmission. The results showed that the microalgae facade with a closed system has better quality as a shading device and light transmission than venetian blinds. Another study [13] tested tubular microalgae facades. The results showed that the microalgae facade has a shading coefficient value of 67% to control building daylighting. By controlling daylighting, the indoor temperature can be adjusted to meet comfort standards.

4.2.3 The Impact of Microalgae Facade on Relative Humidity

The humidity level of the room affects the occupants' comfort through the human body's ability to cool down [1]. Airflow through the ventilated facade has a significant influence on the room's humidity level [14]. Microalgae facades can be used as ventilated facades to control humidity levels and ensure space comfort. An algae bioreactor system is combined with two glazing systems to create the microalgae facade system. The development of the microalgae facade divides the facade into two zones, namely vision and algae-growing. Vision zone provides views, natural lighting, and ventilation for indoor airflow [7].

Several precedent studies have used the microalgae facade system as a sustainability strategy in conceptual design. The U.S. General Services Administration Building by HOK Architect applies a microalgae facade as an innovative passive cooling strategy through shading effect (see Fig. 5). Not only to provide natural lighting, but the ventilated microalgae facade design that is integrated with the louvers also allows for a more open lower floor for natural ventilation [7].

Figure 5. GSA Building concept with microalgae facade (Source: https://www.dexigner.com/news/23070)

4.2.4 The Impact of Microalgae Facade on Noise

Unwanted sounds can interfere with the physiological and psychological comfort of building users [1]. Some sources show that the microalgae facade framework can reduce noise in buildings. According to Build Up[15], the microalgae facade not only functions as thermal insulation of buildings but can also function as sound insulation. According to Cellparc [16], the sound reduction index achieved by the microalgae facade is around 50 dB, so it is classified as class 6 according to DIN 2719. However, no research has been carried out focusing on discussing the microalgae facade as sound isolation.

4.2.5 Microalgae Facade as Renewable Energy System

It is impossible to apply passive design to achieve thermal comfort in some areas inside the building. An alternative solution is to design using electrical energy. However, there needs to be a wise arrangement to consider the value of the energy consumption produced. Renewable energy systems (RES) such as wind turbines, biomass, and hydrogen are increasingly being developed and applied to building facades to minimize the use of conventional energy sources. RES can be an alternative energy source to avoid the greenhouse effect. Environmentally compatible RES can be easily applied to building [17]. Microalgae facades can provide renewable energy by using the carbon cycle and photosynthesis. By absorbing light, CO_2, and necessary nutrients, the microalgae facade can produce biomass. The resulting biomass can be a source of energy, namely heat and electricity [4].

4.3 The Impact of Microalgae Facade Materials on Occupants' Health

Air pollution and global warming are the main problems faced on earth that affects climate change and human health [18]. Microalgae facade as an alternative solution that can reduce air pollution by absorbing and reducing CO_2. Microalgae integration with building facades produces about 60 to 75% of the oxygen needed by humans through the absorption of CO_2 from the air or water during the photosynthesis process [19]. Several previous studies have proven that the microalgae facade is a type of facade suitable for application to urban contexts with air pollution problems.

Research [18] proves that the application of microalgae as living microorganisms integrated with building facades can utilize walls as surfaces for the photosynthesis process (see Fig. 6). Surfaces that respond to climate change transform buildings into living buildings with the ability to reduce air pollution. This study examines the application of the microalgae facade in buildings on Enghelab Street. The selected area is an area with low air quality due to pollution. After testing, the results show that the microalgae facade affects CO_2 absorption within a 6-day test time of 22.55%. A total of 5040 liters of air containing carbon dioxide and carbon monoxide enter the bioreactor, and as much as 1136 liters of clean air are removed.

This research shows that the microalgae facade is a practical step in improving air quality to preserve the environment.

Figure 6. Implementing microalgae facade on buildings in Enghelab Street area (Source: (Haghir et al., 2020, p. 44))

5. Summary

Based on the discussion's findings, this research is summarized in the schematic diagrams (see Fig. 7) and table below, see Table 3.

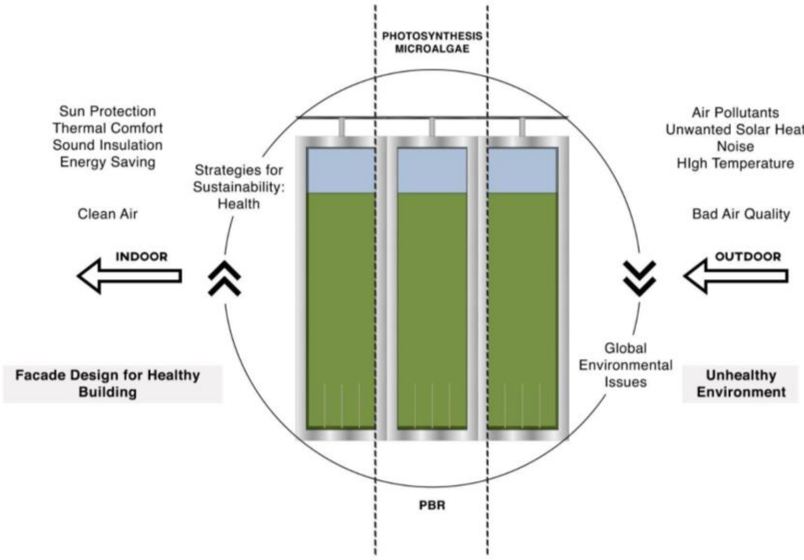
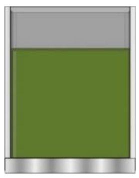
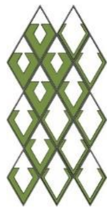
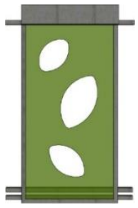
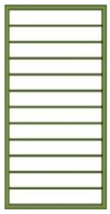
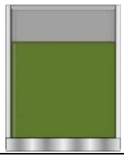


Figure 7. Schematic of Microalgae Facade for Healthy Building (Source: Author)

Table 3. A summary table of the results and discussion (Source: author)

Author	Strategies for Sustainable Architecture: Health	Microalgae Façade Type	Schematic Panel Design (Source: Author)
[20]	Improve the quality of natural lighting	Flat-panel bioreactor	
[13]	Reduce the temperature through a passive shading device	Tubular bioreactor	

[11]	Reduce the temperature through an adaptive shading device	Geometry bioreactor shape	
[7]	As a ventilated facade for humidity control	Flat-panel bioreactor	
[7]	As a ventilated facade for humidity control	Horizontal tubular bioreactor	
[15]	Reduce noise pollution	-	-
[18]	Reduce air pollution through the materials used	Flat-panel bioreactor	

6. Conclusion

This research proves that the microalgae facade is a sustainable strategy that pays attention to residents' health and saves energy. The theory used to evaluate the microalgae facade as a sustainable building envelope is Strategies for Sustainable Architecture: Health by Paola Sassi. Microalgae facades are proven to provide good quality natural lighting for spaces and reduce building heat to achieve a comfortable room temperature for occupants. A good level of room humidity can be met through the design of a ventilated microalgae facade. In the role of sound insulation, there has been no further research that focuses on the microalgae facade as sound insulation. However, several sources show that the microalgae facade can reduce noise up to 50 dB. Several studies have shown that the microalgae facade effectively improves air quality by reducing air pollution and producing clean air for the health of building occupants. With this research, it is hoped that sustainable facade innovations will develop not only for the benefit of building performance but also have a good impact on the health of residents and the environment.

Reference

1. Sassi, P., *Strategies for Sustainable Architecture*, first edition, Taylor & Francis, New York, 2006.
2. Bonenberg, W. and Kapliński, O., “The architect and the paradigms of sustainable development: A Review of dilemmas” *Sustainability*, MDPI, Vol. 10(1), 2018, pp. 1-15.

3. Miceli, M., “World's first microalgae facade goes live”, *Arup*, Retrieved October 2021, from https://www.arup.com/news-and-events/worlds-first-microalgae-facade-goes-live.
4. Talaei, M., Mahdavinejad, M., and Azari, R., “Thermal and energy performance of algae bioreactive façades: A review”. *Journal of Building Engineering*, Elsevier, Vol. 28, 2020, pp. 101011–101025.
5. Soltani, S., “The Contributions of Building Information Modelling to Sustainable Construction”, *World Journal of Engineering and Technology*, SciRes, Vol. 04(02), 2016, pp. 193–199
6. Zagi, N. Z., “Studi penerapan solarleaf – The bioreactor facade sebagai solusi alternatif arsitektur tanggap iklim dan energi”, *Jurnal Lingkungan Binaan Indonesia*, IPLBI, Vol. 6(1), 2017, pp. 65–69.
7. Kim, K.-H. “A feasibility study of an algae façade system”, *International Conference on Sustainable Building Asia*, Semantic Scholar, 2014, pp. 333–341.
8. Casini, M., *Energy-generating Glazing*, In Smart buildings: Advanced materials and nanotechnology to improve energy-efficiency and environmental performance, first edition, Woodhead Publishing, Duxford, 2016, pp. 327–353.
9. Richmond, A., “Principles for attaining maximal microalgal productivity in photobioreactors: An overview”, *Hydrobiologia*, Springer, Vol. 512, 2004, pp. 33–37.
10. Genin, S. N., Aitchison, J. S. and Allen, D. G., *Photobioreactor-Based Energy Sources*. In Nano and biotech based materials for energy building efficiency, Springer International Publishing, Switzerland, 2016, pp. 429–456.
11. Studio, U., “Algae Tower: Photo-bio-reactor façade”, *UOOU Studio*, Retrieved October 2021, from https://uooustudio.com/algae-tower.
12. Pagliolico, S. L., Verso, V. R. M. L., Bosco, F., Mollea, C., and La Forgia, C., “A novel photo-bioreactor application for microalgae production as a shading system in buildings”, *Energy Procedia*, Elsevier, Vol. 111, 2017, pp. 151–160.
13. Elnokaly, A. and Keeling, I., “An empirical study investigating the impact of micro-algal technologies and their application within intelligent building fabrics”, *Social and Behavioral Sciences*, Vol. 00, 2016, pp. 712-723.
14. Haase, M., Marques da Silva, F., and Amato, A., “Simulation of ventilated facades in hot and humid climates”, *Energy and Buildings*, Elsevier, Vol. 41(4), 2009, pp. 361–373.
15. Fytrou-Moschopoulou, A. “The BIQ House: First algae-powered building in the world”, *Build Up*, Retrieved October 2021, from https://www.buildup.eu/en/practices/cases/biq-house-first-algae-powered-building-world.
16. GmbH, C., “How a bioenergy facade works”, *Cellparc*, Retrieved October 2021, from https://cellparc.com/en/function/.
17. Chel, A. and Kaushik, G., “Renewable energy technologies for sustainable development of energy efficient building”, *Alexandria Engineering Journal*, Elsevier, Vol. *57*(2), 2018, pp. 655–669.
18. Haghir, S., Tashakori, L., Rezazadeh, H., and Ahmadi, F., “Algae facade for reducing CO2 emission and mitigating global warming (Case study: Tehran Enghelab Street) ”. *The Scientific Journal of NAZAR (Nrc) for Art, Architecture & Urbanism*, Bagh-E Nazar, Vol. 17(89), 2020, pp. 37–48.
19. Wolkers, H., Barbosa, M., Kleinegris, D., et al., *Microalgae: The green gold of the future*, In Large-scale sustainable cultivation of microalgae for the production of bulk commodities, Wageningen UR, Wageningen, 2011.

20. Arbye, S., Arianti, R. F., Pradana, Y. S., et al., "The design of microalgae (Chlorella sp.) photobioreactor as a façade bus shelter building in Indonesia", *AIP Conference Proceedings 2296*, Surakarta (Indonesia), November 2020, pp. 1–9.