Beyond Green: Growing Algae Facade

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ABSTRACT: As the popularity of glass façades in buildings continue to rise, the environmental impact of using glass façade systems is of increasing concern. Due to their high energy consumption through heat loss and unwanted heat gain, there needs to be a growing effort to promote an environmentally sustainable façade system. As a sustainable facade alternative, an innovative algae façade system was explored in this paper. The primary goal of this research is to demonstrate the design and development of the algae façade system and describe its preliminary structural and thermal performance using a FEA (finite element analysis) software and experimentation. The system details were explored throughout the prototyping of an algae façade panel. The research findings have demonstrated the viable application and improved performance characteristics of the algae façade system compared to a conventional glass façade system. The paper highlights areas of ongoing research activities and challenges associated with the algae façade system.

KEYWORDS: sustainable façade system, algae façade system, thermal performance, structural performance

INTRODUCTION

The construction and operation of a building significantly contributes to resource depletion and greenhouse gas emissions. A challenge for the building design, construction industries and building owners is to provide healthy indoor environments without depleting non-renewable energy resources and contributing to air pollution and global warming. According to DOE/EIA Annual Energy Outlook, buildings in the residential and commercial sectors in the US consume 40% of total energy, 72% of total electricity, and 40% of raw materials while generating 39% of the country's CO_2 emissions. For the transportation sector, transportation consumes 210 billion gallons per year and produces approximately 2.1 billion tons of CO_2 per year. Biofuels such as starch-based, biomass-based and cellulosic biofuels reduce our dependence on petroleum fuel and emerging technologies lead to the development of advanced biofuels using algae. A considerable amount of research on algae as a biofuel has been conducted and it has been reported that there are several advantages in using algae. First of all, due to their high growth rate, algae require less land and offer a high production rate for biomass and fuel. Further, they absorb CO_2 and do not require the use of fresh water. Figure 1 shows the algae production rate compared to other biofuels and its land use requirement. Corn, for example, requires twice the size of the USA to harvest biofuel of 210B gallons while algae need a state the size of North Carolina (around 50,000 sq. miles) to grow equivalent biofuel.

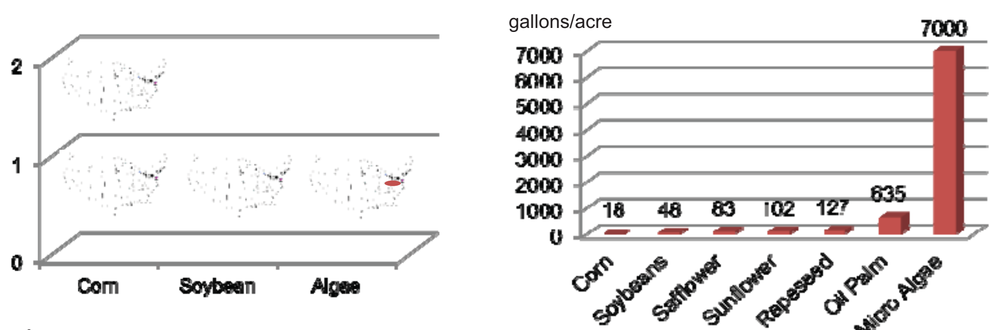


Figure 1: Algae production rate and required land compared to other biofuel alternatives. Image source: (Author 2013). Data source: (DOE, 2012)

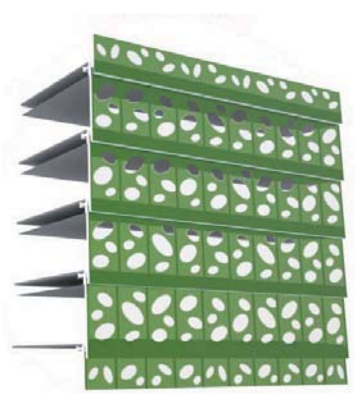
A variety of state-of-the-art transparent facade technologies are available: low-e coated IGU, inert gas integrated IGU, and shading device (such as stretched metal, frit, suspended film) integrated IGU. These technologies particularly reduce building energy consumption by improving the heat transmission (U-factor), SHGC (solar heat gain coefficient), and VLT (visible light transmittance). Managing heat flows through building facades alone, however, is not sufficient to give rise to a high performance façade system. Photovoltaic and solar thermal systems are examples of accomplishing both energy management and energy generation currently applied in buildings. As a high performance facade alternative, an innovative algae facade system has been investigated.

The primary objective of this research is therefore to carry out a feasibility study of an algae façade system by exploring its performance attributes, façade system details and fabrication challenges. This paper discusses the preliminary performance assessment in the areas of structural and thermal performance. This effort includes FEA computer simulation and experimentation. More comprehensive study on optimal design configurations for the algae façade system is under development.

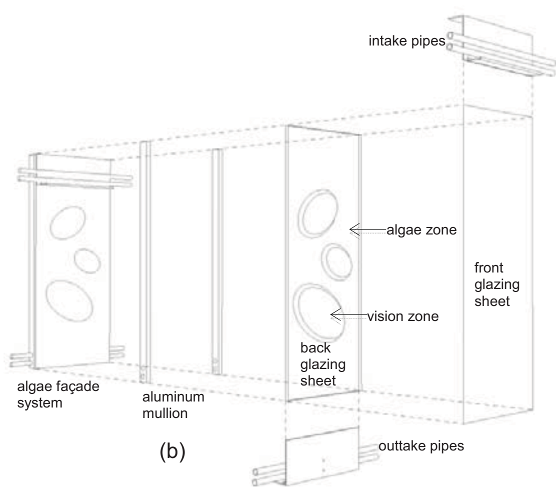
1.0 ALGAE FAÇADE SYSTEM

Environmental concerns and resource depletion are issues that we currently face. Algae integrated building envelopes are not a new concept in the architecture field. Several architects and designers have used algae in their conceptual buildings or art installations. The HOK's first place winning scheme for the 2011 IDEAS competition showed an algae photobioreactor tube attached to the top surface of the opaque building envelopes of the GSA federal building in LA. In addition to this project, their recent concept design of the net energy zero Battery Park project in San Francisco incorporated algae photobioreactor panels to grow algae and reduce CO_2. The world's first algae façade integrated building, the BIQ house in Hamburg, Germany is enclosed with an algae panel as a shading device. The algae façade system explored in this paper acts as a building facade system that fulfils various functional requirements such as airtight, watertight, structure, energy, daylighting, occupant's comfort and aesthetic. Further, it creates an optimum environment that maximizes algae growth, thus reducing the amount of atmospheric CO_2 and, as an added benefit, produces O_2.

The algae façade system consists of an algae panel, aluminum framing and algae growing apparatus. The algae facade system is insulated and thermally broken and is designed to be spanning between slab edges. The algae façade system is sized to be 5ft wide by 12ft tall or taller depending on building conditions and consists of vision zone and algae zone. Unobstructed vision zone in the algae façade system has been introduced for viewing, daylighting and ventilation where necessary. The remaining area called algae zone is assigned for growing algae. The algae façade system is simply supported on four sides of aluminum framings and is mechanically restrained with sufficient clearances for thermal expansion and contraction. A demountable single-piece metal cover is a part of the system to conceal algae growing apparatus. The algae growing apparatus is comprised of intake systems for supplying CO_2, and growing algae (e.g. algae, nutrients, medium etc) and discharging systems for emitting O2 and collecting grown algae. Figure 2 illustrates a schematic detail of the algae facade system and its generic application into a building facade.



(a)



(b)

Figure 2: Algae façade application in office building (a) and exploded system details (b). Source: (Author 2013)

The short-term research goal is to identify the feasibility of the algae façade system through schematic design and prototyping. The development work of the algae façade system is currently being carried out at the School of Architecture, University of North Carolina Charlotte working with faculties and students across a range of disciplines, under an EPA/NSF funded grant P3 (People, Prosperity and the Planet) project. A visual mock-up was fabricated to facilitate decisions on fabricability, aesthetics and performance (Figure 3). Acrylic was considered for the algae façade material due to its higher impact resistance, lightweight, optical clarity and ease of fabrication compared to glass. Given that it is important to consider scratch and UV resistance of the acrylic surface, there are coating or surface treatment technologies available that offer good UV and scratch protection.

(a) (b) (c)

Figure 3: Algae façade panels[1] with different surface treatment; transparent (a), 50% sandblast (b) and 100% sand blast (c) at the algae zone. Source: (Author 2013)

The current research being carried out by the author includes geometrical variations of the vision zone and different surface conditions of the algae zone. One of the performance issues to consider was to block or minimize the green light transmission from the algae zone. As a result, the interior surface of the algae zone was sandblasted or covered with different colors. Figure 3 shows an algae panel with different levels of translucency at the algae zone. These prototyping algae façade panels revealed fabrication challenges associated with making a watertight assembly, especially at the interface between vision and algae zone. The kinds of adhesives and connection method are currently being researched.

2.0 PRELIMINARY PERFORMANCE ASSESSMENT

2.1. Preliminary Structural Analysis

One of the primary goals of this research was to understand the general structural behaviors of the algae façade under various loadings. Prior to the lab testing, the stress and stiffness levels of the algae panel were investigated using a FEA software tool, Strand7. The size of the algae panel is 5ft x 12ft x 2in, and the acrylic is 5/16in thick. The algae panel was modeled with plate elements in Strand7, and the mesh was sized to approximately 4in x 4in. The edge supporting conditions were a pin support and a roller support, simulating a typical curtainwall attachment condition and accommodating thermal expansion and contraction. The material properties (E-modulus, density, Poisson's ratio) of the acrylic were obtained from the product data of Acrylite FF provided by Cyro Industries. The shear modulus was calculated using the equation: $G = E/2(1+ v)$. The loading condition applied in this study included self-weight of the algae panel, wind load and water pressure. The weight of the panel is approximately 230lbs without water in the cavity and 650lbs with water. The design wind load for the algae panel is assumed to be 20 psf. It is assumed that the wind load is transferred by the finite volumes of water in the cavity without loss. The water pressure from the water in the cavity is assumed to be a distributed load that is increasing uniformly to the bottom of the algae panel. Additionally the internal temperature of the water in the cavity is assumed to be in the range of 68°F ~ 86°F and any internal cavity pressure from the external isobaric pressure is assumed to be zero. Deflection of a façade system controls the façade design of a curtainwall system.

The FEA simulation results showed that the current design deflects 0.62” under wind and 1.5” under water pressure. Deflection of L/90 or 1” is generally regarded as an upper bound on acceptable glass deflection. The current deflection exceeds maximum allowable deflection, which requires design alteration. Deflection can be reduced by increasing the thickness of the acrylic or adding vision zone where the greatest deflection occurs. The maximum principal stress occurs mostly at the panel edges and perimeter of the vision zone. The maximum stress is around 5ksi under combined loading condition. Special attention is required at the adhesion between vision and algae zone. Figure 4 shows the output of Strand7 simulation, indicating deflection and stress levels under self-weight, wind load, and water pressure, respectively. Long-term performance such as creep deformation under water pressure needs to be investigated. The results of a more comprehensive study on both analytical and experimental assessment of the structural performance are expected to be presented at the conference.

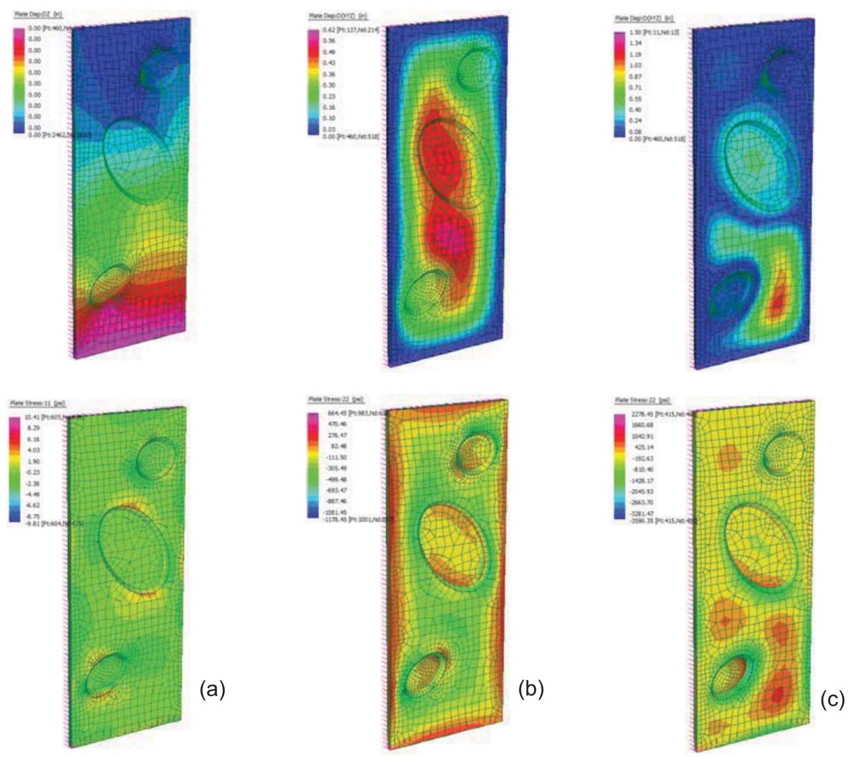


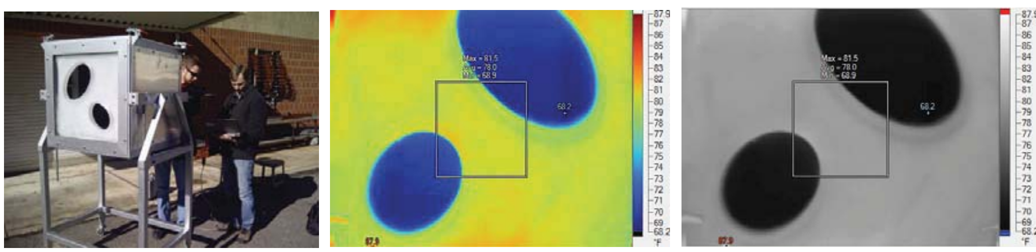
Figure 4: Preliminary structural analysis results of algae façade; stress (top) and deflection (bottom) output under self-weight (a), wind load (b) and water pressure (c). Source: (Author 2013)

2.2. Preliminary Thermal Performance Analysis

In the building industry, thermography technique is often used to detect air infiltrations, cold bridges, moisture creation, and heat loss through windows. An understanding of the surface temperature distribution over a building envelope is important, as the thermal variations affect cooling and heating loads of a building, as well as the occupant’s thermal comfort. Ambient temperature and solar radiation are the primary factors affecting the thermal distribution on the exterior building envelope. Infrared cameras convert the thermal energy (i.e. the infrared band of the electromagnetic spectrum) radiated from an object into a visible image where each thermal energy level is represented by a color or grey scale. The thermal energy is dependent on the emissivity of a material surface and a fraction of the thermal energy can be added or absorbed by the atmosphere between the surface and the camera.

In practice, the thermal performance of a facade system is determined in accordance with various standards such as ASTM (American Society of Testing and Materials), NFRC (National Fenestration Rating Council) and AAMA (American Architectural Manufacturing Association). These standards require a specific apparatus and testing procedure and evaluate a final assembly of a building façade system. Since the algae facade system in this paper continues to evolve and develop, the thermography technique proved to be an efficient tool to assess the preliminary thermal performance. The thermography technique is an image based analysis tool that offers a user friendly and time efficient assessment. It allows evaluating preliminary energy performance of a façade system and facilitates design evolutions from the fast performance feedback.

An algae panel was set up to test the thermal distribution of the interior surface temperature. Tests were conducted in a sunny winter noon in outdoor environment using the FLUKE thermography system with its software package. The testing algae panel was 2ft by 2ft and the interior surface of the algae zone was sandblasted with 100% translucency. In order to minimize energy flow between the material and the atmosphere, the interior surface of the testing chamber was covered with black painted plywood. The preliminary thermography data showed that the temperature difference between the vision and algae zone during winter time is approximately 13°F (the vision zone is 69°F while the algae zone is 82°F), indicating that the vision zone is subject to higher heat transmission (U-factor) compared to the algae zone (Figure 5). A simple mouse click of the thermal image shows a surface temperature of the algae panel where dark blue (black in grey scale) represents the minimum temperature and red (light grey in grey scale) represents the maximum temperature.



(a) (b)

Figure 5: Preliminary thermal performance of algae façade; test set-up (a) and temperature distribution (b). Source: (Author 2013)

In the next step, it is intended to conduct the same experimentation of an insulated glass unit (IGU) in order to understand how much the algae façade outperforms in U-factor relative to an IGU. The temperature data obtained from the thermography testing will be used in a CFD analysis tool to verify interior temperatures of a building enclosed with algae panels. The interior temperature will be used in DesignBuilder to run a whole building energy simulation. By carrying out the whole building energy simulation, energy saving from algae façades can be determined. Since this is an ongoing process, the results of energy performance of algae facades will be presented at the conference.

CONCLUSION

This paper shows the development of the algae façade system and its preliminary structural and thermal performance. The research demonstrated that the algae façade system has the future potential for sustainable façade alternatives and energy generation possibilities. The computer simulation on structural behaviors provided alternative design solutions to meet stress and stiffness criteria under various loadings. The IR experiments involved determining the thermal characteristics of the vision and algae zone of the algae façade. The prototyping of an algae façade panel reveals fabrication challenges associated with watertight interfaces between the vision zone and the algae zone. Additional façade system details need to be explored, incorporating algae growing apparatus and artificial lighting to grow algae at night time. The future direction of this research is to investigate long-term performances such as weatherability under outdoor use, durability from periodical maintenance of the algae zone, and creep deformation behaviors under water pressure.

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REFERENC ES

"Algae Powers Process Zero Concept Building" accessed Jan 20, 2013, http://www.hok.com/thought-leadership/algae-powers-process-zero-concept-building/

DBS. 2011. DesignBuilder (Version 2.3) [Computer software]. Gloucestershire: DBS.

Department of Energy. 2012. Replacing the Whole Barrel To Reduce U.S. Dependence on Oil. Washington: US DOE, downloaded from http://www1.eere.energy.gov/biomass/pdfs/replacing_barrel_overview.pdf

Energy Information Administration. 2009. *Annual Energy Review*. Washington: US Energy Information Administration.

"First Algae-Powered Building in Germany Nearing Completion For Next Year's Hamburg Exhibition", last modified Dec 14, 2012, http://www.greenvitals.net/designdecoratingnet/2012/12/14/first-algae-powered-building-in-germany-nearing-completion-f.html

Hausladen, G., Saldanha, M., & Liedl, P. 2010. *Modern Construction Envelopes*. Vienna: Springer

Fluke. 2006. SmartView (Version 3.2) [Computer software]. MN: Fluke

"HOK's Net Zero "Battery Park" for San Francisco Has an Algae Façade", last modified Feb 3, 2012, http://inhabitat.com/hoks-net-zero-battery-park-for-san-francisco-has-an-algae-facade/

National Fenestration Rating Council, Inc. NFRC 100-2004: Procedure for determining fenestration product U-factors. MD: National Fenestration Rating Council. http: nfrc.org, 2004

Strand7. 2012. Strand7 (Version 2.4.4) [Computer software]. Sydney: Strand7

ENDNOTES

[1] Algae façade system© is fully copyrighted and patent pending by Kyoung-Hee Kim in its entirety.