International Journal of Research in Engineering, Science and Management
Volume-2, Issue-11, November-2019
www.ijresm.com | ISSN (Online): 2581-5792

Utilizing Active Materials in Building Façade for Building Efficiency

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***Abstract*: Since the early 2000s, active materials have attracted a wide range of research-based projects. These materials offer a broad scope of exceptional potential outcomes to the construction industry through their ability to detect and react to natural exterior upgrades such as shape-memory alloys, light-emitting diodes (LED), film-encased photovoltaic cells and thermochromic paints. Active materials allow the architect to integrate it into the architectural design process, helping to enhance buildings to be compatible with the environment. Micro-algae as an active material can be used in a photo-bioreactor façade as an example of active organic material. The effect of algae photo-bioreactor on temperature difference, illuminance, and clean energy analysis was examined in a room in a residential building. In this study, the algae photo-bioreactor showed that is a great difference in temperature between the indoor and outdoor temperatures. It managed to maintain the interior illuminance meeting comfort conditions. It reduces solar heat gained and produces energy from water temperature difference achieving energy saving.**

***Keywords*: Smart materials, active materials, active organic materials, building efficiency, biomass, bioreactor, building façade, clean energy, algae.**

1. Introduction

Historically, the development of materials has always been an essential source of inspiration for all design processes. The appearance of the industrial revolution started to have materials a great influence on the architectural design and the nature of the construction used [1]. Nowadays, the appearance of smart or active materials has proved to be promising in the building industry. Due to its ability to detect and react to the outer natural changes over time and changing its shape, density and color over time [2].

Recently, researches on active materials have focused on the possibility of using active materials in the design of building envelopes, as it can achieve a better response to climate changes, and to reduce energy consumption [3]. Researches inactive materials have been adopted by many countries worldwide to examine the possibility of its usage in the design process. Unfortunately, other countries lack the awareness of its potentials [4]. The present work's objective is to study the effectiveness of deploying a small-scale algae photo-bioreactor on a facade of a room in a residential building.

2. Active materials

We used the word ' smart materials ' liberally without specifying what we mean correctly. Nevertheless, it is challenging to create a precise definition [2]. It can define as intelligent, active and responsive materials, materials are designed to have one or more properties, and that can be changed significantly through external stimulation, such as stress, humidity, electric and magnet fields, light, temperature, or chemical compounds in a controlled manner [5]. Whether organic or inorganic There are two main classifications of smart materials are known as active and passive smart materials [6].

A. *Active (smart) materials*

A material, which can change their geometric or material property by applying electrical, thermal or magnetic fields, thus possessing an inherent capacity for energy transmission. An excellent example of active smart material is thermochromic paint, where the pigment is transparent under an external heat stimulus, exposing the layer(s) underneath. The picture of the coffee mug shows how the black pigment turns transparent when a heat source is applied, so the message underneath can be seen in figure 1 [7].

Fig. 1. The black pigment turns transparent when a heat source is applied

B. *Passive smart materials*

A material that can only sense the external stimulus but don't adapted to it. For example, sensors which integrated into baby clothing to monitor breathing and clothing that gives potential changes about the weather [7].

3. Types and characteristics of active materials

A. *Types of active materials*

According to Addington and Schodek (2005), active

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materials can be classified according to their performance into two types as can be seen in figure 2, type 1 property changing material: a material that changes one of its properties (chemical, mechanical, optical, electrical, magnetic or thermal) as a response to the changes in the environmental conditions without need to an external control [2].

Type 2, energy exchanging material: a material that can transform energy from one to another. The energy input into material changes the energy status of the material composition but does not change the material.

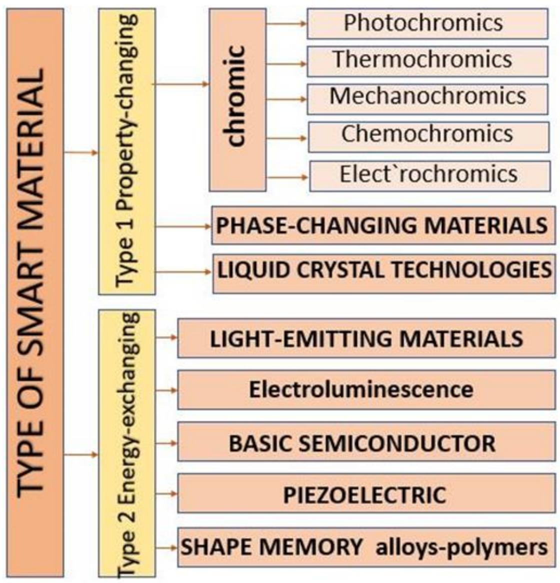

Fig. 2. Active material types

B. Characteristics of active materials

According to different stimulus-responses, active materials are able to change their properties reversibly. The five fundamental characteristics distinguishing an active material from traditional materials used in architecture are defined as follows [2]:

- Immediacy – they respond in real-time.
- Transiency – they respond to more than one environmental state.
- Self-actuation – intelligence is internal to rather than external to the 'material'.
- Selectivity – their response is discrete and predictable.
- Directness – the response is local to the 'activating' event.

4. Active materials in architectural applications

The application of advanced technologies based on active materials can significantly improve the sustainability of buildings by focusing on the phenomena rather than the material artifact. The potential of active materials in energy efficiency are numerous. Active materials can be retrofitted to buildings. They can also produce diverse designs [8].

Either molecular structure or microstructure determines material properties. So, architects have to understand all material behavior concerning the phenomena and the environments they create, some examples of active materials capabilities are as follow:

A. Type 1

Photochromic: could be used as coatings, heat-regulating, light conductive, useable as lighting and display surfaces.

Thermochromics: paints can change color with temperature, white when hot (solar reflective) and black when cold (solar absorptive), could provide home heating or cooling adjustments, Photochromic pigments darken in proportion to exposure to UV light when the metal is heated by the sun, and the panels start to change color.

Chemochromics: filled solar panels with active materials which is used to produce heat by absorbing solar energy, the materials can produce biomass for biogas production which is used to provide electrical energy and heat.

B. Type 2

Light-emitting materials: Polymer light-emitting and fluorescent pigments and paints.

Memory alloy form: Nickel–titanium alloys (NITI) are often used in shape memory.

Fig. 3. The 'heat' chair that uses thermochromic paint

Fig. 4. Effect of using fluorescent pigments and paints

5. Case Study

The benefits of applying active organic materials in the building industry are numerous. Egypt as an agricultural country contains a large stock of algae, which could be used as an active organic material [9]. Figure 3 displays a map of the availability of material algae worldwide. It can be exploited to start applying active materials through The Solar leaf façade, which uses algal biomass in combination with solar thermal heat to create a dynamic system.

Fig. 5. Non-European countries that contain alage

A. Tools

1) Organic active material

For this experiment, microalgae are used. Microalgae is single-celled organisms, about 5 micrometers wide. Microalgae grow on sunlight with CO2 and nutrients, where it builds up biomass. This process photosynthesis occurs in nature in the same way as all other plants. Biomass production from microalgae is higher than other plants because of two essential reasons. First, microalgae have a single-cell where each cell performs photosynthesis [10]. So, the conversion of light energy into biomass is much more efficient in the case of microalgae than multicellular plants. Second, microalgae can double their biomass, which is an energy carrier, as it can divide up to once a day.

2) Photo-bioreactor model

A room model of a residential building (350 cm wide, 400 cm length and 300 high) with three windows (50 cm wide and 160 cm high) in the southeast façade where the bioreactor (350 cm wide, 300 cm high and 15 cm thick) is used for the experiment adapted from standard of residential room in Egyptian code.

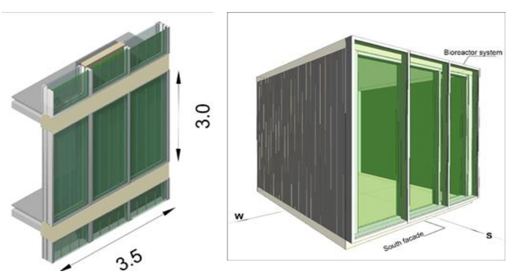

Fig. 6. Simplified model

3) Bioreactor Façade

A photo-bioreactors (PBRs) consist of a disc-shaped hollow body with laminated safety glass (LSG) on both sides used for the experiment. The Photo-bioreactor filled with a solution of drinking water and plant nutrients (nitrogen, phosphorus, trace elements). That is necessary for algae growth. CO2 is one of the most significant parameters that affect microalgae growth. So, CO2 continuously added to the aqueous solution which comes from micro-CHP (combined heat and power unit fueled with biogas) [11].

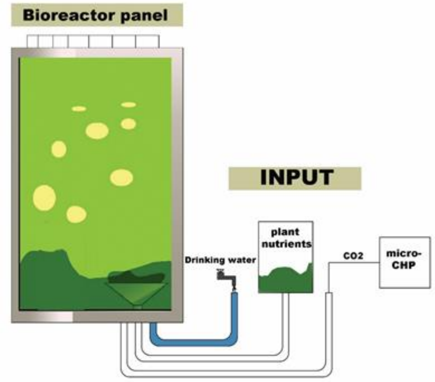

Fig. 7. Bioreactor facade input

4) Measuring Instruments

In this study, LX-102 light meter used in illuminance measurement because of its accuracy and efficiency. Where Quick temp 850-1 used for temperature measurement because of its accurate readings.

B. Method

1) Small scale photo bioreactor model

Based on the concept of application of the photo-bioreactor system, a small-scale model was applied in the south façade because it has the most solar irradiation throughout the day. The measurement was carried out on 24 and 25 August 2019 and lasted for 24 hours, because it is the hottest day of the year. Temperature and illuminance difference between indoor and outdoor calculated after experimental observation. Water temperature measured before and after exposure to the sun for energy production.

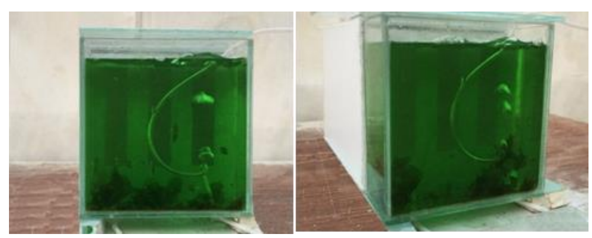

Fig. 8. Photo bioreactor model

2) Small scale photo bioreactor model

Photo bioreactor plays a vital role as a solar thermal absorber from sunlight. It can increase the water temperature up to 35 °C. Extraction heat operation is done through a heat exchanger. Geothermal boreholes used for storing excess energy, where heat pumps are used for energy drawn as required. Biomass obtained from the energy center is collected and converted into biogas in an external biogas plant. Also, biogas is used in combined heat and power units for producing flue gas as a nutrient for microalgae growth. Waste heat resulting from micro-CHP is also used to heat water or storing surpluses in the district heating system of the energy network where, if necessary, it is retaken.

Compressed air is used for inhabiting microalgae from

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sinking and stirring the culture medium continuously. Bio pollution has a negative effect on microalgae growth. However, high flow velocities and scrapers enclosed within the Photo-bioreactor prevent microalgae from deposition and bio pollution problems [11].

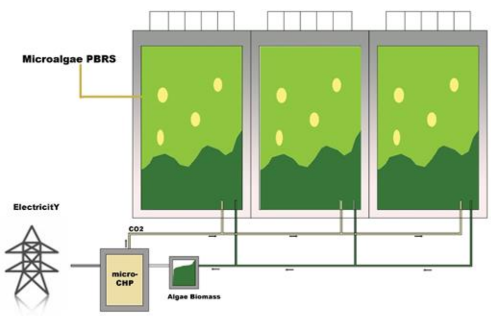

Fig. 9. Functioning of a bioreactor façade

C. Results & discussion

1) Temperature difference (ΔT)

The graph shown in figure (9) illustrates that the difference between the maximum indoor and outdoor temperature at 1:21 pm was 5 °C, While the difference between the minimum temperature at 4:21 am was 1.5 °C as shown in figure 9. The chart indicates that in certain times between 5:42 pm until 4:42 am the indoor temperature was higher than the outdoor temperature. However, after 5:50 am the outside temperature was higher from the interior.

The result shows the active role of the algae phot-bioreactor in decreasing the indoor temperature when the outside temperature is higher from 5:21 am to 3:21 pm. On the contrary, the heat gained from algae photo bioreactor could make up the temperature difference when the outside temperature is low.

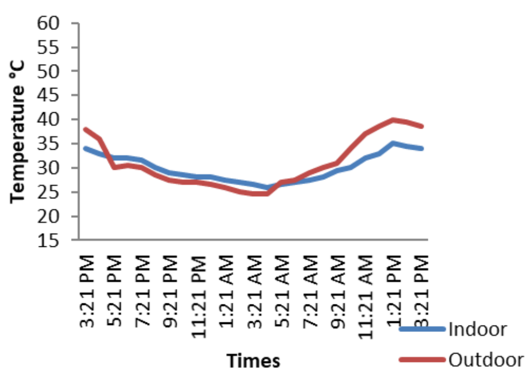

Fig. 10. Temperature measurement

2) Illuminance test

It can be seen from the graph shown in figure (10) that the highest illuminance for indoor was 936 lux at 1 am and for outdoor was 18500 lux at 4 pm as presented by figure 3. Average interior illuminance was evaluated and found to be 1105 lux.

The average of interior illuminance digitally recorded was 1105 lux, and the result meets the requirement of illuminance for a room in a residential building. The experimental results indicated that there is a difference between indoor and outdoor illuminance. The result indicated that there is no relationship between the indoor and outdoor illuminance, as it depends on the opening position of the building and the material of the building. The algae photo-bioreactor model could reduce more than 85% of the daylight, yet the illuminance in the interior still meets the standard of daylight for a room in a residential building. Microalgae photo-bioreactor plays a significant rule in reducing solar heat gain from solar radiation. The algae photo-bioreactor can absorb solar radiation. This reduction could also have a great effect on energy usage.

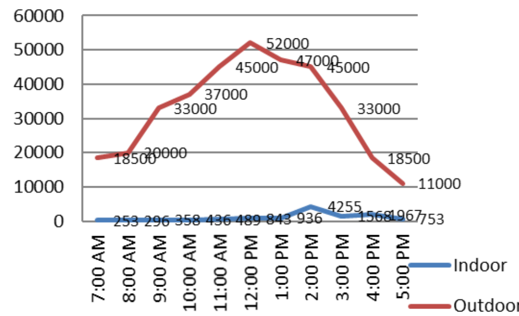

Fig. 11. Illuminance measurement

3) Clean energy analysis

Based on experimental observation during daylight, there was an increase in water temperature due to heat absorption from the sun. Water temperature was measured before and after exposure to the sun. The total temperature difference (ΔT) was about 1.5 °C. The energy produced was calculated based on water temperature difference, where the energy analysis equation is denoted by Eq.1.

$$Energy\ produced = mass\ of\ water\ (g)\ \times \Delta T\ (°C) \times ((4.18\, J)/(g.°C))$$

The energy produced from water temperature difference was about 6 KJ, which can be used for different applications.

6. Conclusion

Active materials have proved to have a high impact on providing buildings that are compatible with the environment. Algae is an active organic material has been founded to enhance the ability to reduce energy consumption and enhance building efficiency. This paper indicates that from the experimental model reads, it is possible to apply algae photo-bioreactor on a model of a room facade in a residential building. Photo-bioreactor has an impact on several sustainable variables as it decreases the indoor temperature and the heat gain from algae. It could make up the difference when the temperature is low. Also, the system can reduce more than 85% of the daylight while maintaining the comfort illuminance in the interior space. Photo-bioreactor has also been founded to be able to absorb solar radiation, which reduced solar heat gain and has a significant effect on energy consumption. In addition to energy efficiency, the study has also shown the possibility of producing energy from water temperature difference used in algae Photo-bioreactor.

7. Recommendation

Study the possibility of using other organic active materials and utilizing their behavior in architectural design processes to consolidate the idea of design work compatible with the environment and changing climatic conditions. Study the possibility of integrating active organic materials into advanced smart systems and applying it on facade to achieve adaptiveness and durability.

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