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PHOTOBIOREACTORS FOR SUSTAINABLE BUILDINGS

(FOTOBİYOREAKTÖRLER VE SÜRDÜRÜLEBİLİR BİNA UYGULAMALARI)

Suphi S.ÖNCEL[1], Ayşe KÖSE[2]

ABSTRACT

With the accelerated increase in World population, human activities leave bigger traces on environment and ecology, which are not always signs for good. Especially places where more concentrated populations live in, like metropolitans or bigger cities, these traces are more significant. Today, World population is more than 7 billions of people, and the individual or industrial activities of this population endanger the nature and many living systems. It is recognized that nature cannot handle this massive amount of negative accumulation and humans started to react to minimize the effects of the circumstances that harm nature. Renewable energy technologies are introduced for a better, green and sustainable energy consumption. With the idea of integrating microalgal biotechnology with renewable energy systems, a novel solution to energy problem has been introduced and a futuristic research area has been developed.

Keywords: Microalgae, Façade, Green wall, Photobioreactors, Algaetecture

ÖZ

Dünya nüfusunda meydana gelen hızlı artış ile beraber, insan aktiviteleri çevre ve ekoloji üzerinde daha büyük etkiler bırakmaya başlamıştır, ki bu etkiler her zaman iyi olmamaktadır. Özellikle popülasyonun yoğun olduğu büyük şehirlerde bu etkiler daha fazla hissedilmektedir. Günümüzde dünya nüfusu 7 milyarın üzerindedir ve bu nüfusun bireysel ya da endüstriyel aktiviteleri doğrultusunda doğa ve diğer yaşayan sistemler zarar görmekte ve tehlike altına girmektedir. Büyük resme bakıldığında, doğanın artık bu negatif etkilerle başa çıkamadığı fark edilmiş ve bu sefer insanlık bu etkileri minimize edebilmek adına çalışmalar yapmaya başlamıştır. Bu bağlamda yenilenebilir enerji teknolojilerinin günlük yaşama entegrasyonu ile daha temiz ve yeşil bir enerji tüketim anlayışı benimsenmeye çalışılmıştır. Bu bağlamda mikroalgal biyoteknolojinin de bina sistemlerine entegrasyonu fikri ile enerji çözümlerine yeni bir yaklaşım getirilmiş ye fütüristik bir çalışma alanı oluşturulmuştur.

Anahtar Kelimeler: *Mikroalg, Yeşil Bina, Fotobiyoreaktörler, Algaetecture*

[1]Ege University, Faculty of Engineering, Department of Bioengineering, 35100 Bornova/Izmir/Türkiye, suphi.oncel@ege.edu.tr (Corresponding Author)
[2]Ege University, Faculty of Engineering, Department of Bioengineering, 35100 Bornova/Izmir/Türkiye, ayse.kose@ege.edu.tr

1. INTRODUCTION

As rushed societies that we live in, we are not focused on the efficient use of energy; especially in places like houses, public areas and offices where the most of the population spends their daily-life [1]. However every single part of the wasted energy returns as a damage to nature and ecological balance [2]. Education on energy saving may be beneficial to construct energy efficient lifestyles however more than education like social cognition/realization is usually required [3].

One of the biggest thread for future societies is consumption of fossil fuel sources [2] which are utilized for transportation, housekeeping and for daily consumables. That's why It seems to be impossible to switch to renewable energy sources once at all but step by step new energy technologies can be introduced for utilization. Today renewable energy sources like wind, sun, geothermal, wave and biomass are trending and these sources seems to be more efficient at the future [4, 5]. But rather than creating an industry based approach, what will happen what if we surround our living and working areas with this technology? The answer is quite simple and creative. Renewable energy technologies can be introduced to the building systems using the force of biotechnology and core understanding of microalgal physiology.

Green wall applications are emerging area in modern cities where high storey buildings are continuously rising [6]. Green wall concept that can also be integrated with renewable energy technologies to construct self-sustaining eco-friendly buildings with positive physiological impacts started to get more attention with the 20th century [7].

Plants are traditional materials for green wall applications [8] however microalgae with photosynthesis ability that also contributes to carbon cycle and oxygen generation as plants do become an alternative and seems to be a newer volunteer for façade applications [9]. Some key features of microalgae can be mentioned with regards to its potential [10]. The rapid increase in the culture density resulting the shading effect prevents the loss of heat and provides thermal comfort [11]. On the other hand high biomass accumulation [12]of microalgae in photobioreactor systems can be used for further applications for food, feed, pharmaceutical and biofuel industries [13]. Production of potential biofuels as biohydrogen [14], biogas [15] with bio-refinery [16] concept can be integrated in the buildings also [9]. Besides energy efficiency[3], improved air quality [17] and visual appetite are also another positive reflection of green wall applications of microalgae [6].

Technology and know-how of microalgae bioprocessing upgrades hollow buildings into an alive structure to display the capability of algae in buildings. As a result microalgae are promising for future applications making the sketches of aesthetic buildings a reality.

2. A CRITICAL EXPERIENCE: GREEN WALLS AND FACADE SYSTEMS INCORPORATING PLANTS FOR ECO-FRIENDLY BUILDINGS

Relaxing scenery of a typical Mediterranean house is the grape vines hanging on the garden trellises with a simple wooden chair and a table under its shadow on a very hot summer noon. Or a country house with its smoking chimney covered from top to bottom with green leafs in a cold and moist English day. These two scenes can be a part of our life or a frankly tribute to Robert Norman "Bob" Ross who told stories while painting a sea shore or a mountain with beautiful small house in his famous television series "The Joy of Painting" in

90's.These two examples can be seen irrelevant but they are part of the human’s history which construct the green road to modern life, using plants as an envelope for energy efficient buildings.

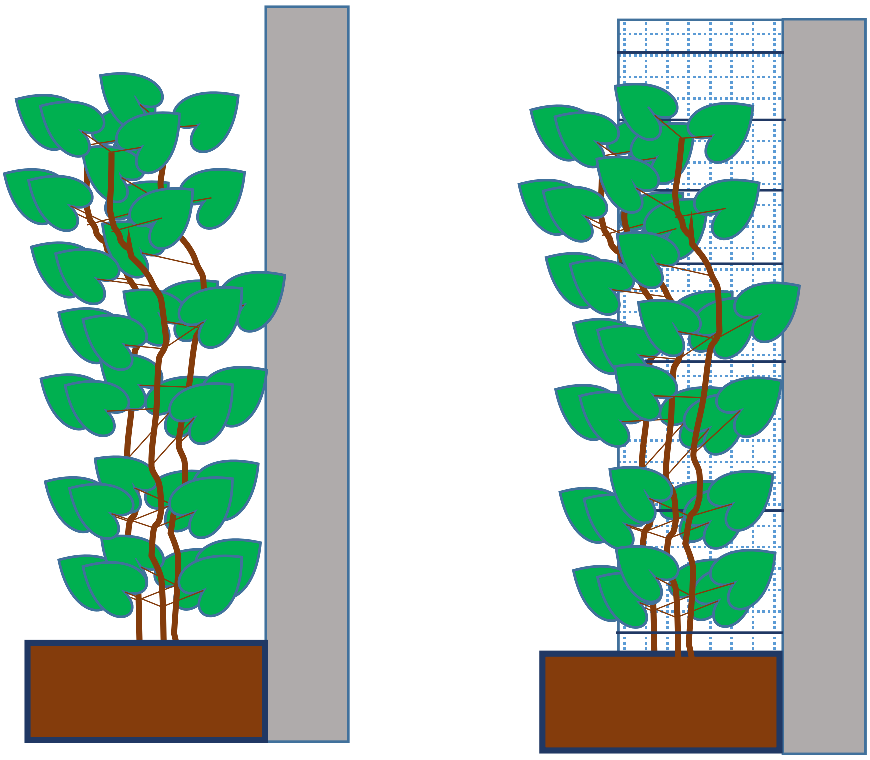
The idea of using green walls is the merging of foliage with a vertical structure/surface directly based on the plant's ability of climbing and attachment or indirectly by using special carriers like trellises, meshes or strings [18–20]. Keeping in mind the different terminology used in this area like vertical greenery, green facades, living walls or bio-walls mentioned in literature [6, 8, 19, 20]; the primary aim of these systems is to gain extra space for green in concentrated concrete habitat.

The historical background is rooted on ancient civilizations that used climbing plants for the aesthetic reasons or for more beneficial reasons like using their fruits or shade and sometimes for both, shaped the concept of modern green wall systems. Even though the green walls got a limited attention until the 20^{th} century [21], the rise of the public concern about climate change, global warming and rapid loss of green lands triggered the focus on these systems. Today, with the projection from the ancient approach that can still be seen in traditional applications, green walls evolved and adapted for the needs of modern societies

In today’s world where money plays the key role, it is not surprising that the idea of an esthetically fancy green wall building first attracted the real estate sector with its economic return. But this relatively shallow benefit later opened the new doors and catalyzed the progress for more technical advantages especially with the development of different standardization tools for sustainable eco-friendly buildings like Leadership in Energy and Environmental Design (LEED, United States), BRE Environmental Assessment Method (BREEAM, United Kingdom), Green Building Council of Australia Green Star (GBCA, Australia), Green Mark Scheme (Singapore), DGNB (Germany), Comprehensive Assessment System for Built Environment Efficiency (CASBEE, Japan), Pearl Rating System for Estidama (Abu Dhabi Urban Planning Council), Hong Kong Building Environmental Assessment Method (HK BEAM), and Green Building Index (Malaysia) [22, 23].

Developments necessitated the classification of these systems based on different specifications for example; climber (mechanical dependent) and herb-shrub (mechanical independent) systems according to the plants used[20, 21], or green façades and living walls according to the design requirements to identify the borders of technical expectations more clearly. It is more convenient to focus on the design requirement classification, keeping the plant types as a part of the design.

Green façades are the systems where specific plants with climbing or hanging capability used as the complementary component. It has a stronger connection with the traditional application in which the plant grown in the ground routed vertically on the surface of the building wall naturally by its claw-like extensions or by the help of special supports like steel cables or meshes [18, 21]. These systems can be further identified according to the contact with the building wall as direct or indirect [6, 20]. Direct green façades are the traditional way of vertical greening where plant contact the wall and creep on the surface when growing while indirect systems has the support materials acting as a barrier between the vegetation and the building wall (Figure 1). Indirect façades having special frames aim to prevent the collapsing of the growing vegetation under its weight and supply a guided route for the plants so a controlled covering of the whole building wall can be introduced [21]. On the other hand weight of the vegetation is taken over the building prevent the problems of building statics is an important point especially for modern construction norms [20]. From another point of view; the space between the wall and the vegetation on the support frame also help the circulation of air preventing unwanted heat zones and humidity. Besides this air space acts in the prevention of wall wear and unwanted growth of bacteria containing biofilms due to creeping plants and lower the maintenance costs [6, 21]. Also to overcome the difficulty of elevation in modern buildings planter boxes are used in different storeys to complete the flow of the uniform vegetation over the wall surface and they are both applicable to direct or indirect systems [18, 24, 25].



Direct green facade: Greenery will directly contact the building wall and rise up by its climbing nature

Indirect green facade: Greenery will contact the building wall over special meshes it will not need any climbing nature

Figure 1. Conventional direct and indirect green façades using plant systems. (The left one is dedicated to the direct plant growth and the right one displays support-assisted plant growth on cell wall surface)

Compared to the green façade, living wall system (Figure 2) idea is quite recent with the ability of adaptation to modern buildings with diverse plant species [20, 21, 26]. The key difference with the green façade is the cultivation approach. In living walls the plants are grown on a support frame which acts as a continuous surface like a vertical garden over the wall. Various support frames similar to the green façades can be incorporated in these systems, other than the living wall specific units like trays, flexible bags, geotextile felts and planter boxes. Living walls even if attached to the wall, separate the building surface from the vegetation with the frame interface. They can be continuous over the surface with plants cultivated in these frames which supply a large cultivation surface on the building wall or modular with the ability of growing plants in jigsaw like planter units that can be replaced or changed easily [6, 21, 23]. From a different aspect the jigsaw like planter designs can be used as a concept which can be named as "*painting with plants*" for also an aesthetic vision.

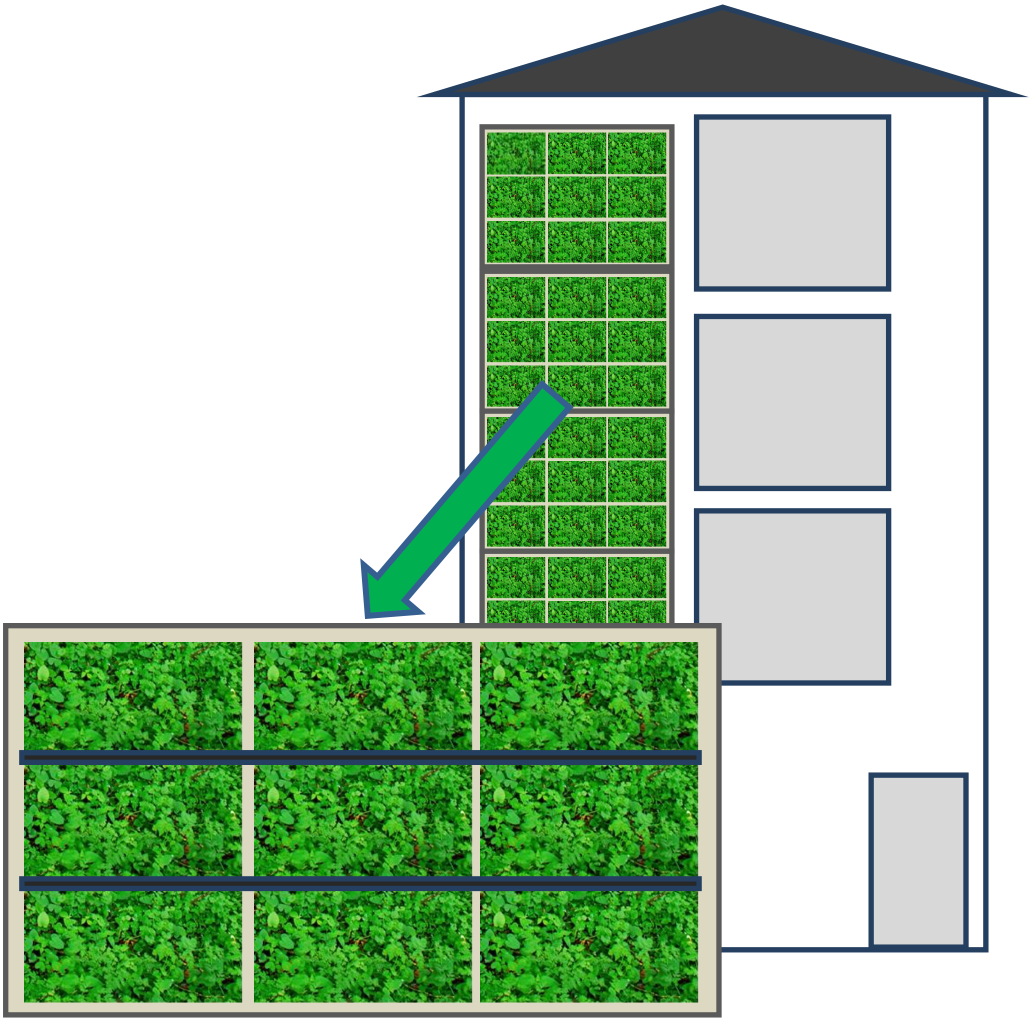


Figure 2. Living walls; Greenery are planted in special cover materials that are embedded on the building walls

Support elements used in the green wall systems can be made from stainless steel, aluminum, polyethylene, polypropylene and some other plastics which are selected due to their easy handling, light weight, market availability, cost, compatibility and durability because of the direct contact with plant, water and environment [18, 19]. The design should also focus on the needs of the selected plants such as nutrients, water, temperature, light and system components like cultivation units (planters, support frames or polymer tiles), irrigation systems, drainage systems and recycle systems [6]. Also depending on the soil or soil-less cultivation methods where special porous polymers, coconut granules, perlite, peat etc. can be used as the cultivation surface, should be considered in these systems. Soil used systems are the traditional approach where directly ground or planter planted vegetation was grown. Depending on the soil quality, especially in the case of ground planted vegetation, the yield may vary and it is not easy to control the nutrient feed. On the other hand soil-less approach like hydroponics is a recent application that gave a more controlled nutrient supply by the nutrients mixed water irrigation and giving a chance for diverse plant species [18]–[20].

The plant species used in green wall systems are mostly conventional herb-shrub or climber types like *Hereda helix*, *Parthenocissus tricuspidata*, *Ophiopogon japanuicus*, *Tradescantia spathacae*, *Nephrolepis exaltat*,*Lumicera japonica*, *Juniperus chinensis*, *Juniperus conferta*, *Euonymus fortunei*, *Cotoneaster horizontalis*, *Vitis labsurca*, *Wisteria macrostachya*, *Polygonum aubertii*, *Rubus idaeus*, *Actinida arguta* or *Vitex rotundifolia* [6, 20, 25, 27]. Even if most of these species have a traditional background and prove their success through the years of experience in gardening and agriculture, their application in green wall systems is limited with the moderate climate zones [20, 21, 28–31]. For an extensive application around the world, studies should focus on more species aiming the integration with the building type considering diurnal and annual environmental changes.

A well-integrated building and green wall couple will be beneficial for energy saving with a special regards to the thermal efficiency. Acting as a shade provider, the green walls will help to reduce the temperature of the building, supporting the air conditioning systems especially during high temperature days like in summer. Also the evapotranspiration from the system will help to sweep the heat load of the building results a cooling effect. Considering the colder days, the green wall will act as a wind barrier which may slow down the heat loss from the building by forced convection as well as acting like a natural insulator layer to protect building temperature [32, 33, 34]. According to real life applications and simulations presented in scientific literature the thermal effect of green walls is up to 50% difference compared to outside temperature depending on the building insulation, building orientation, building location, environmental parameters, climate, plant type, plant foliage thickness, plant density and green wall type (green facade or living wall) [18, 32, 35]. These interacting parameters as compromised by the researchers make the standardization of the efficiency very difficult [25], nevertheless the positive effect is worth investigating.

3. PHOTOBIOREACTORS

Photobioreactors (PBRs) are closed cultivation chambers specially designed for cultivation of microalgae to conduct photosynthesis. PBRs have been utilized more than 60 years after the Acceleration of microalgae biotechnology at late 1950s. Recognition of microalgae as a sustainable source for several industries form pharmaceuticals to biofuel also opened new gate to research on cultivation systems. Thus considering the disadvantages of open production designs PBRs are accepted as a promising system for bulk microalgae cultivation in a more controlled way.

In order to understand the PBRs understanding the microalgae is crucial. Microalge utilize light energy for reproduction, growth and cell maintenance. During the reproduction; microalgae converts' inorganic carbon sources CO2 as primary, to oxygen. The produced oxygen is released to the outer environment of cell. Meanwhile with photosynthesis microalgae also accumulated organic substances which are important for biotechnology. However to keep microalgae cells active and alive, design of the PBR is vital.

There are several PBR designs which are conventionally used. These PBRs are named as Panel type and tubular type and with the integration of conventional fermentors; stirred type PBRs. Using these key designs, currently there has been introduced novel PBRs with sophisticated equipment or approaches. Considering façade applications; panel PBRs are more efficient. Thus only panel type PBR will be discussed in here.

3.1. Panel Type PBRs

Panel type PBRs are also named as flat-plate PBRs due to flat surfaces resembling solar collectors [36]. The plates can be scaled up vertically keeping the design limiting parameters such as dissolved oxygen, light penetration, aeration in mind [37–39]. These parameters with combination of microalgal metabolism give ideas to design and run an optimal panel type PBRs. The mixing in individual panels can be done via aeration however with the increase in the volume; additional mixers can be equipped in order to increase heat and mass transfer ratios.

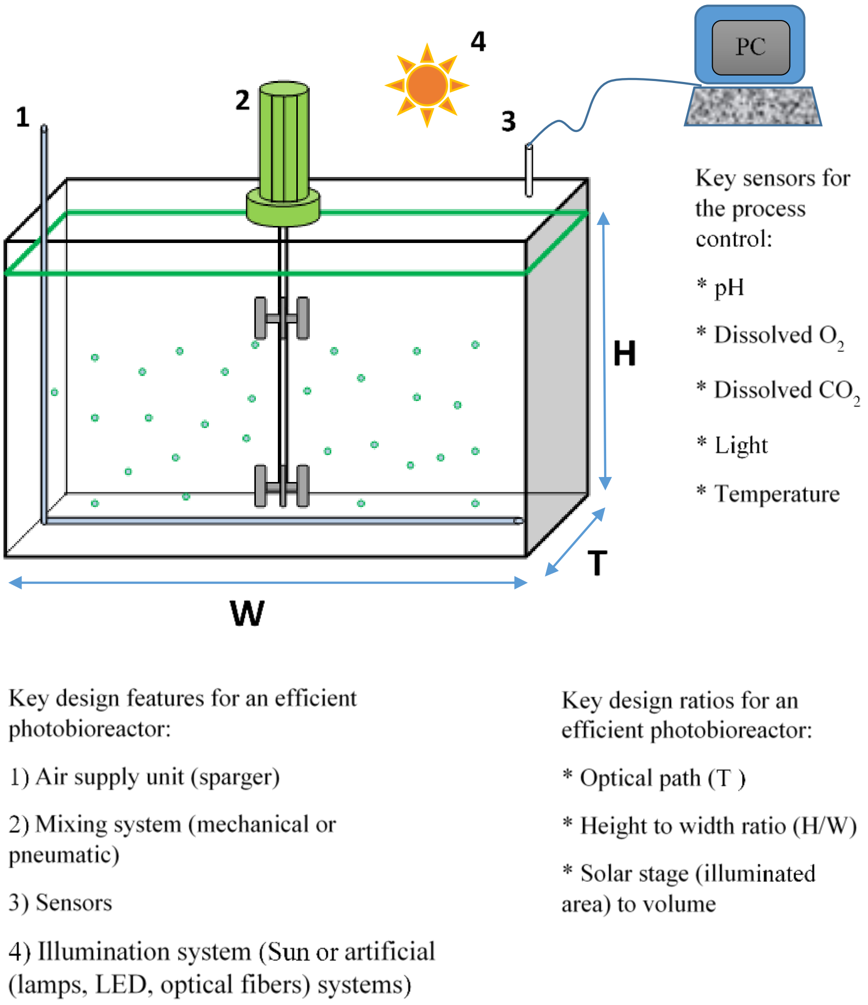
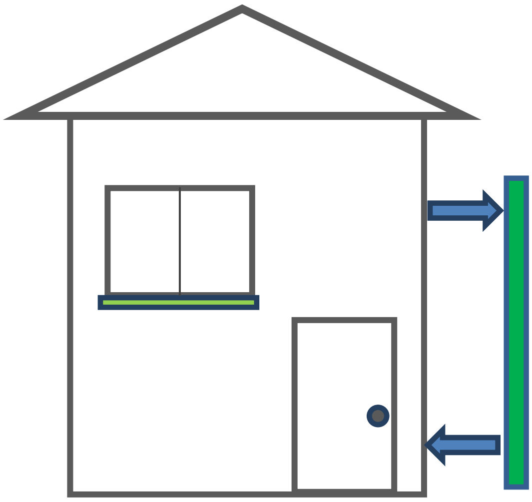


Figure 3. Schematic diagram of the panel PBR

The homogenous dispersion of cells, gasses and nutrients as well as metabolic wastes are highly important. When mixing is inefficient, microalgae cells due to their weight can settle through the bottom of the PBR and triggers mass cell deaths. Illumination in a panel PBR can be done via natural and artificial light sources. Considering artificial light sources as a cost effecting factor, outdoor cultivation units using sunlight is preferred however in natural illuminated systems, due to changing diurnal light intensities, may affect the cell growth and culture response to the light saturation. The panels can be tilted according to the angle of the sun. With this approach optimum culture growth is aimed (Figure 3).

4. COMBINING PBRS WITH BUILDINGS: APPLICATIONS FOR SUSTAINABLE BUILDINGS

Combination of green wall systems with buildings is not a new concept, however revisited and renewed according to the construction understanding of modern architecture [6]. In green wall systems, planting is the key design element [8], however using microalgae in buildings is done with the integration of PBRs to the outer wall surfaces of the building [9]. Rather than a surface growth of a plant system microalgae are produced within the PBRs under controlled environment. The role of microalgae in this kind of application is being a bio-scavenger for generated CO_2 within the building [40]and continuous pumping of the oxygen through exhaust channels of PBR to the inside the building. There are several important points to mention about microalgae and façade applications as primarily, PBRs can be an insulation material for temperature deviations and also filters noise from the noisy crowded environment especially in city centers (Figure 4).



What to expect from an efficient photobioreactor house integration

Air quality: exchanging the inner air (CO_2) through the photo bioreactor will act as a bio-filter (by photosynthesis CO_2 will be used to produce O_2 by the microalgae cells)

Thermal comfort: The photobioreactor will act as a bio-curtain by blocking or reflecting the light (especially the dense cultures will be a strong light blocker)

Aesthetic design: A green façade will give extra attraction to a building

Figure 4. The sketch of PBR integrated façade system

Rather than using plants, PBRs integrated façade system may have positive impact on building system. Seasonal changes do not affect the growth of microalgae like it is in plant systems thus selected microalgae specie can be grown in the PBR. Microalgae also benefits within a bio-refinery approach [41]; the biomass of the microalgae can be utilized further to process as food/feed or biofuel purposes [42]. The PBRs can be designed with a more aesthetic [43] way to provide a visual appetite for the environment . Thus the technology and design of a PBR should meet in a common idea; it should look fancy with eco-friendly approaches.

In theory; even using microalgae in buildings may seem to be promising there yet to be some disadvantages. The scale of the PBR utilized for façade is limited by a number of factors such as; light dispersion coefficient, kl_a, temperature, aeration and mixing [44–46]. These parameters are related with the operating conditions of the PBR. Another point is related with the construction of the overall system [45]. The selection of the mixing units, construction materials, piping systems for water/culture media, design of aeration units, pumping systems for CO_2 and O_2 transport, placing the PBR is fundamental design aspects for construction [37]. The other consideration is about cleaning the PBR surfaces. The outer surface of the system can be cleaned according to conventional ways of cleaning larger glass surfaces. However inside the PBR, cleaning is a challenging part. The maximum width of a PBR cannot be more than 10-15 cm. This narrow area will limit the cleaning procedures. Some microalgae species are tend to grow on the flat surfaces, causing another layer of microalgae on the PBR surface. This situation has two disadvantages; one is the limiting due to the shading affect and the other one is contamination risks because of inefficient cleaning. Thus an optimum procedure for inner PBR cleaning method should be introduced.

From a broader point of view; microalgae for façade applications seems to be a promising candidate for future modern architecture approaches. Using the nature itself for human population may be beneficial from several points of view which should be delicately evaluated.

5. CONCLUSION

Microalgae are a promising microorganism for community use and futuristic applications. These applications are limitless with the imagination and inspiration. One of the inspirations with this regard is uniting microalgae with building to provide inner air quality, temperature and heat control as well as aesthetic comfort with the utilization of biotechnological tools. Each building can be a headquarter for its own biorefinery understanding and rather than trying to build massive industries to supply the demand, microalgae-equipped buildings may be a good starting point with a social impact.

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CV/ÖZGEÇMİŞ

Suphi Ş. ÖNCEL; Doç. Dr. (Assoc. Prof.)
Suphi Ş. ÖNCEL is a chemical engineer with a MSc and a PhD in bioengineering. He is currently working in the Ege University Engineering Faculty Department of Bioengineering (Izmir, Turkey). His research areas include bioprocesses, bioreactor design, renewable energy, photobioreactors, microalgae cultivation, microalgal fuels, biohydrogen production and scale-up.

Lisans derecesini Ege Üniversitesi Kimya Mühendisliği Bölümü'nden; yüksek lisans ve doktora derecelerini ise Ege Üniversitesi Biyomühendislik Bölümü'nden almıştır. Şu anda Ege Üniversitesi Biyomühendislik Bölümünde çalışmalarına devam etmektedir. Çalışma alanları biyoproses, biyoreaktör tasarımı, yenilenebilir enerji, fotobiyoreaktörler, mikroalgal yakıtlar, biyohidrojen üretimi ve ölçek büyütmedir.

Ayşe KÖSE; MSc. (Research Assistant)
Ayşe KÖSE obtained her BS degree in 2011 from Ege University Engineering Faculty Department of Bioengineering (Izmir, Turkey) and continued MSc studies at the same department. She is currently working as a *research* assistant at Ege University Department of Bioengineering. The subjects she is interested in are bioprocess engineering, microalgae cultivation, biohydrogen and biodiesel production from microalgae, photobioreactor design and downstream processing in microalgal production systems.

2011 Yılında Ege Üniversitesi biyomühendislik Bölümü'nden mezun olmuş ve yüksek lisansını aynı bölümde tamamlamıştır. Şu anda Ege Üniversitesi Biyomühendislik Bölümü'nde araştırma görevlisi olarak çalışmaktadır. İlgilendiği çalışma alanları biyoproses mühendisliği, mikroalg kültivasyonu, mikroalglerden biyohidrojen ve biyodizel üretimi, fotobiyoreaktör tasarımı ve alt akım işlemleridir.