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A novel photo-bioreactor application for microalgae production as a shading system in buildings

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Abstract

The optical performances of plastic bag photo-bioreactors for microalgae production as shading systems for windows were assessed. The micro-algal growth rate and the light transmittance of prototypes were monitored in a photo-incubator and in a real room. Daylight in the room with algae and the energy demand for lighting ED_l were then simulated using Daysim and compared to the case of a traditional venetian blind, for two different Italian sites (Turin, Palermo) and 3 orientations (south, west, north). It was found that the algae-system resulted in increased daylight level and glare and in decreased ED_l.

Keywords: *photo-bioreactor; static shading system;microalgae growth rate; light transmittance; daylight availability; discomfort glare; energy demand for lighting; energy savings.*

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1. Introduction

This paper presents a feasibility study on photo-bio reactors (PBRs) used as vertical static photo-bio screens (PBSs) in buildings. PBSs integrate the ability of green microalgae culture to shield direct sunlight, i.e. to selectively absorb the red radiation (wavelength = 0.6-0.7 μm), with the capability to both bio-sequestrate CO_2 from the ambient air and to generate biomass contzaining bioactive compounds. The PBSs tested in this work are thin, modular, disposable, plastic bags and they consist of small transparent cubicles, of different shape, containing the culture of microalgae and the nutrient supply. Cubicles are embedded in a flexible polymeric matrix permeable to CO_2. Several

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factors provide the PBSs with a special appeal from the sustainability point of view: the carbon dioxide bio-sequestration, the production of biomass in indoor cultivation, the enhancement of indoor environmental quality IAQ and their recyclability. IAQ increases since the indoor air quality improves (due to the sequestration of CO_2 from the indoor environment), the direct sunlight is screened and scattered and the visual appeal of the green surface improves the psychological well-being of the occupants. In this study, five different PBS prototypes were built, measured in laboratory and installed in a real sample test room (3.9 m x 2.4 m; 3.5 m high): they were different for layout, size, shape and surface area/volume ratio of the cubicles, as well as for the presence/absence of mixing by bubbling air. In detail, the following parameters were determined: growth rate of micro-algal cultures, through optical density (OD) measurements; light transmittance LT through bioreactors, by measurements in-the-field on the prototypes as well as through Radiance simulations following a procedure developed in a previous work [1]; amount of daylight in the room and the related energy demand for lighting ED_l, through Daysim simulations.

The impact of electric light or of daylight on algae-systems was addressed in many studies [2-9]. These were mainly focused on aspects such as the biomass productivity, cell growth, CO_2 fixation efficiency or the efficiency of the production rate for different light sources, latitudes, orientation, shading effects, in both indoor and outdoor cultivating systems and by designing special PBRs to increase the microalgae growth rate and the biomass productivity. Very few studies analyzed the LT of algae-based systems, and through a qualitative approach only. For instance Kim et al. [10] described a system which was applied to a real office building in Seoul: they paid attention to aesthetical issues, to the possibility to guarantee a view to the outside for the occupants and to offer good energy and structure performance as well. The optical properties of the system, though, were not measured. In this context, the determination of LT of PBSs, visual comfort and the ED_l is one of the novelty issues addressed in this paper, as well as the rigorous comparison between different prototypes of PBSs so as to come up with the layout effectively arranged, able to assure a suitable solution in terms of microalgae growth rate at different ambient conditions.

2. Experimental procedure

2.1. Reactor design and preparation

The following parameters were considered for PBSs design: cost, volume, surface area/volume ratio, and thickness of reactor. Different types of PBS were selected to be tested, with and without mixing (Table 1); more precisely microalgae were cultivated in SCC and SCCO in static conditions or with air injection. SCC was the first one used for microalgae culture due to its low cost and easy availability. The bag consists of two LDPE sheets (0.05 mm thick) thermally welded so as to create circular cubicles with square packing (fig. 1a).

In order to compare the performances of PBSs, different layout were selected (see Fig. 1 and Table 1 for codes and description). SCR (fig. 1b), SCCO and ASCCO (fig. 1c) prototypes were prepared by thermally welding two LDPE sheets along a defined drawing: rectangular cubicles (SCR) or circular cubicles with high-density hexagonal packing (SCCO and ASCCO). LDPE was chosen because of its good permeability to CO_2 (permeability coefficient = 106 cm^3 mm/m^2 day atm [11]), thermal weldability, recyclability and absence of wall growth and fouling.

To avoid settling of the microalgae, relatively inexpensive mixing inside ASCC and ASCCO (fig. 1c) was promoted through air bubbling which caused agitation and distribution of the cells inside cubicles. Cubicles were interconnected each other and crossed by three vertical PTFE tubes (Φ_{int} = 4 mm) connected to a membrane pump aerator. Aeration rate was measured in liters of air per liters of cubicles per min (vvm). A video camera (set at 7000 frames per second) was used to capture the dynamics of the air bubbles and their mean size (1–5 mm). The maximum thickness, measured at the center of all cubicles filled with cultures was lower than 20 mm (table 1). Interconnection between cubicles allowed free circulation of fluid, microalgae and gas bubbles.

a) SCC b) SCR c) ASCCO d) SCC in the real room

Fig. 1. PBSs: a) SCC circular cubicles/square packing; b) SCR rectangular cubicles; c) ASCCO aerated circular cubicles/hexagonal packing.