Energy and Buildings 158 (2018) 964–970

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Innovative thermo-solar air heater

M. Cuzminschi [a,d], R. Gherasim [a,b], V. Girleanu [a], A. Zubarev [a,c,*], I. Stamatin [a,*]

[a] University of Bucharest, Faculty of Physics, 3Nano-SAE Research Center, Atomistilor 405, P.O. 38, Bucharest-Magurele 077125, Romania
[b] Center of Technology and Engineering for Nuclear Projects, 409, Atomistilor Street, Magurele, Judet Ilfov, Romania
[c] National Institute for Laser, Plasma and Radiation Physics, P.O. Box MG-36, Magurele, Bucharest, Romania
[d] Horia Hulubei National Institute for Physics and Nuclear Engineering, P.O. Box MG-6, 077126 Măgurele, Ilfov, Romania

ARTICLE INFO

Article history:
Received 12 December 2016
Received in revised form 22 October 2017
Accepted 23 October 2017

Keywords:
Air heating
Solar energy
Passive houses
Thermal comfort

ABSTRACT

In the present work we elaborate the innovative design of the solar air heater and justify it by a Computational Fluid Dynamics (CFD) simulation, implementing and experimentally testing a sample. We propose to use this device for maintenance of constant ambient conditions for thermal comfort and low energy consumption for indoor environments, inside greenhouses, passive houses, and to protect buildings against temperature fluctuations. We tested the functionality of our sample of the solar air heater for 50 weeks and obtained an agreement between the results of the numerical simulation, implemented using OpenFOAM (an open source numerical CFD software) and the experimental results.

1. Introduction

Heating, ventilation and air-conditioning (HVAC) systems are mainly designed for the building sector aiming to ensure the comfort living standards for various climatic zones. The building sector accounts for more than 39% of the primary energy requirements [1] and is a main contributor to carbon emission. The Solar-HVAC has been considered as an alternative to reduce contribution of the primary energy and in this respect, are developed solutions based on the direct transformation of the solar energy in internal energy of the transport medium [2–5].

This basic principle is successfully applied to the solar air heaters in passive houses keeping a minimal comfortable temperature of 15 °C [6] during cold seasons.

One niche where the solar-air heaters can bring an input of additional heat during cold season is the greenhouse growers. The cost of fuel is an increasingly significant production expense for greenhouse growers in temperate climates. High heating costs motivate growers to improve the efficiency of crop production to minimize energy inputs. The two parameters influencing plant development are: mean daily/night temperature (MDNT) and photosynthetic daily light integral (DLI) [7].

MDNT usually must stay in a close range of 15–20 °C for optimal conditions in the greenhouse environment. During warm season the growers are faced with high energy consumption for seeds and fruits drying, the intermediate stage in preservation. Several experimental demonstrations and reviews show that the electricity from primary energy sources can be replaced with solar energy (thermal and photovoltaic [8–10] conversion followed by storage in heat and electricity) [11–13].

To date, the key technologies applied to greenhouses are focused mainly on transforming diurnal solar energy into heat storage complemented with a smart insulation. The proposed solutions of solar energy utilization and the reduction of heating power via various combined systems (external thermosolar systems coupled with a storage tank, heating pumps and photovoltaics) [11] show promising solutions but the initial investment with return of investment are visible in the price of vegetables that can be higher than when using classical electricity heating.

Another key issue until now not taken into account is the solar energy conversion, during daylight, to internal energy of the air from greenhouse with free convective circulation. Given how it is not appropriate to use forced convection in a greenhouse because the airstreams have a negative effect on the plant growth [14], the only solution remains the free convection for thermal energy transfer.

A second requirement is to maximize the heat transfer from a blackened flat surface under sunlight irradiation to the backside cavity. In this respect, the solution proposed with this device is to increase the backside surface of the solar absorber [15] from A to nA

* Corresponding authors at: University of Bucharest, Faculty of Physics, 3Nano-SAE Research Center, Atomistilor 405, P.O. 38, Bucharest-Magurele 077125, Romania.
E-mail address: alxzubarev@gmail.com (A. Zubarev).

https://doi.org/10.1016/j.enbuild.2017.10.082
0378-7788/

Fig. 1. Experimental sample of the device.

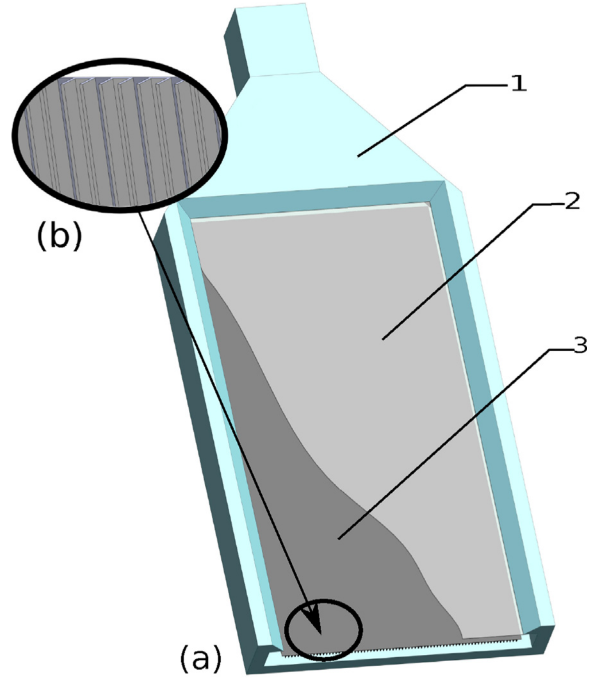

Fig. 2. Design of the sample of the device. (a) General preview. 1—insulated case of the device, 2—plexiglass front glazing, 3—radiator-like absorbent. (b) Inset shows the detailed U-shape form of profiles of the absorbent part.

by one set of 'decorative' elements uniformly distributed along the air stream direction. If in an air-heater with forced convection such elements can induce a transition from laminar to turbulent flow decreasing the efficiency of the thermal energy transfer [16,17] in the air-heater with free convection such elements have a minimum effect only in the hydrodynamic resistance [18,19]. The maximum heat transfer in the free convective air heaters is dependent only on the residence time with the hot surface [20].

Taking into account the above considerations we propose one cost-effective solution for one solar air-heater to supply thermal energy by free convection of the air into a greenhouse as well as for other farming application [21], as for a supplementary advantage of the air heaters which work upon the principle of natural convection is their independence from external energy sources.

By comparison with other types of solar air systems glazed [22,23], unglazed [24,25], and with double glazing and double pass air circulation [26] for a higher yield and relative simple production was chosen the simple glazing design with an effective back cavity. To ensure maximal conversion of solar radiation and efficient heat transfer to air flow the solar absorber was made from blackened aluminum. This decision was justified by the fact that, usually, most energy losses occur through the front cover [26], other parts being insulated.

One of the advantages of portable air heaters is the possibility to flexibly vary the power of the heating in respect to the consumer's preferences and weather. In this paper, we propose a new model of a portable, light-weighted and modular air heater based on solar air heating and natural convection inside of the device shown in Fig. 1, which is suitable to be integrated in greenhouses, passive houses and office buildings, and to dry fruits, seeds, and nuts [27,28] during warmer seasons.

2. Device description. OpenFOAM simulation

2.1. Solar air heater design

The most effective and flexible air heaters are made as self-contained devices, meaning that they can be attached to an exterior wall of a building [29,30]. A vertical installation is considered. The unit consists of an insulated frame (implemented out of extruded polystyrene foam), a solar absorbent (presented by a blackened aluminum metal board inside of the thermo-insulated case), a front plexiglass glazing, an inlet for the incoming air recirculation, and an outlet. At the outlet of the heater is placed a hood in order to collect hot out-coming air (Fig. 2a).

We propose an innovative way of leaving a cavity between the back insulating part and the solar absorbent in order to decrease dissipation of thermal energy. This can lead to an efficiency increase by 30% in comparison to the glazed single pass solar collector, especially in case of air recirculation. In other solar air heaters a part of the thermal energy losses occur due to the contact between hot air and cold front glazing, which we have successfully prevented in our device. For better efficiency, we designed the solar absorbent part to have a flat side that faces the glazing, and the radiator-like surface facing the insulating back part. At the back part of the blackened aluminum board with a thickness of 0.8 mm U-shape profiles are made with the dimensions of 7.5 mm to increase the contact surface between heated air and the metal (Fig. 2b).

Due to the fact that the heat transfer is three times larger at the back side of the metal board in comparison with the front side area [31,15], we have: $Q_{back}/Q_{front} = A_{back}/A_{front} \approx 3$.

2.2. Theoretical model

The functionality of the solar air heater is achieved by the buoyancy phenomena [32,33] and greenhouse effect [34]. Solar rays enter the plexiglass glazing and are captured by the solar absorbent. Due to that, the air inside of the installation is heated up. Because of the thermal transfer the air inside of the back cavity is heated