Applied Energy 123 (2014) 273–280

Contents lists available at ScienceDirect

Applied Energy

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

Assessing the passive cooling effect of the ventilated pond protected with a reflecting layer

Artemisia Spanaki [a,*], Dionysia Kolokotsa [b], Theocharis Tsoutsos [b], Ilias Zacharopoulos [a]

[a] National Technical University of Athens, School of Architecture, Department of Architectural Technology, 42 Patission Street, 10682 Athens, Greece
[b] Technical University of Crete, Environmental Engineering Department, 73100 Chania, Crete, Greece

HIGHLIGHTS

- The 24-h cooling effect of the new pond has been experimentally established.
- Heat flow analysis of pond is based on simulations.
- Daily water temperature fluctuation reaches the 1/3 of the respective ambient temp.
- The proposed passive roof cooling technique does not demand daily operation.
- The investigated technique is has not been suggested by previous investigations.

ARTICLE INFO

Article history:
Received 25 April 2013
Received in revised form 22 January 2014
Accepted 11 February 2014
Available online 22 March 2014

Keywords:
Evaporative cooling
Radiative cooling
Passive technique
Roof pond

ABSTRACT

The present research investigates a new evaporative cooling technique, which is placed on the roof of a small building in the climate of Crete – Greece. A pond is filled with water up to 0.10–0.12 m deep while an aluminium layer is kept 0.15 above free water surface, allowing ventilation between water level and the aluminium shield. The temperature of water and indoor air is recorded for a 35 days summer period. The water temperature is analyzed, in regard to climatic conditions. According to the experimental records, the daily minimum temperature of water is practically equal to the corresponding air temperature while maximum daily temperature of water is about 8–13 °C lower compared to the corresponding value of air.

Furthermore, a heat flow analysis based on pond simulation indicates that the cooling effect occurs mainly due to evaporative losses. The effect of the proposed system to the indoor air temperature reduction is also assessed building simulation. According to the results of both experiments and simulation, the maximum indoor air temperature is reduced by 30%, compared to the corresponding temperature of a building without any roof cooling technique.

1. Introduction

The building sector worldwide accounts the 40% of global energy consumption, and a considerable carbon footprint [1]. Moreover the improvement of life standards during the last decades, the affordability of air conditioning, the globalization of modern architecture and also the temperature increase in the urban environment, have led to a considerable increase of the energy needs for cooling [1,2]. On the other hand, the research done during the last 30 years in passive cooling techniques is very promising [3–5] proposing technologies varying from evaporative cooling, to cool materials, ventilative cooling [6,7], etc.

Roof ponds have been proposed as a passive cooling technology that contributes to the reduction of both heating and cooling demands. A variety of roof ponds having different functional and constructional characteristics (e.g. water circulation, movable insulation, spraying system) and a variety of protective materials (e.g. louvers, insulation, etc.) has been proposed by various researchers [2].

Roof pond with wet gunny bags proposed by Tang et al. [8] and is consisted on an open pond, while a white cloth is kept afloat in its free water surface, encouraging evaporative cooling. The main advantage of this specific configuration lays on the lack of operation control on a daily basis. Moreover, according to simulation results [9], roof pond with wet gunny bags proved to perform

* Corresponding author. Address: W.B.18, Vrahokipos, Kokkini Hani, GR71500, Heraklion, Crete, Greece. Tel./fax: +30 2810326779.
E-mail address: Spanakiart@hotmail.com (A. Spanaki).

http://dx.doi.org/10.1016/j.apenergy.2014.02.040
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better compared to roof pond with movable insulation. Apart from the passive cooling effectiveness and the lack of control needs on daily basis, the system is easy to be constructed using common, low cost materials [2].

A research by Spanaki et al. [10] investigated analytically the parameters affecting water temperature of a roof pond with gunny bags. According to the parametric study, the optical properties of the protecting cloth are strongly affect water temperature. The experimental part of the study [10] investigates ways to protect pond with a metallic layer while encouraging evaporative cooling. According to small scale experiments, placing a reflective layer above or below water level results to increased bottom pond temperature reduction, compared to roof pond with wet gunny bags.

To this end, the aim of the present paper is to investigate the potential of a roof pond protected with a reflective sheet above water level, placed on a building based on both experiments and simulations. The thermal analysis of the proposed system analyzes the record bottom pond temperatures, the heat dissipation mechanism and the effect of the system to the indoor air temperature. The methodology followed is separated to the following steps:

- Description of the system.
- Analysis of water temperature in regard to climate, according to the experiments.
- Heat flow analysis, based on the results of pond simulation.
- The effect of pond to the indoor air temperature, based on both experimental records and building simulation results.

2. Description of ventilated pond with reflective layer

The tested pond is filled with water up to 0.10 m. An aluminium sheet is placed about 0.15 m above water level. The system is placed on the roof of a small building.

The aluminium sheet is chosen due to its long term durability and strength [10] in order to be able to be exposed in ambient conditions. The total emissivity of the protective sheet is 0.04 was according to the record using the D&S Emission meter, Model AE1. The thickness of the aluminium sheet is 0.0004 m and it was measured by a Vernier calliper. The aluminium Roll's Width was 2 m. The reflectivity of aluminium sheet varies from 0.85 to 0.92 [11].

The heat loss mechanism combines convection, radiation and evaporation losses. Direct solar radiation is reflected during the summer day, as shown in Fig. 1a. During the summer night, the metal surface acts as a radiator, apart from evaporative and convective heat losses as shown in Fig. 1b.

During the winter, the water can be removed and replaced by insulation panels in order to meet the building energy regulations for the heating period. As a result, the proposed system needs a seasonal operation twice a year, in turn from cooling to heating season and vice versa.

Water is totally shaded by the aluminium sheet, which reflects direct solar radiation. Part of the heat reaching water may be absorbed and transmitted depending on the upper and lower surface conditions, and the water depth. There is not net effect of the reflection process on the water, while absorption has the effect of increasing the internal energy of water, acting as a heating storage due to its high thermal capacity [12]. Water absorbs heat from the surrounding air and the upper surface of roof, and evaporates. The energy required to sustain the evaporation comes from internal energy of water, which experiences a reduction in temperature (cooling effect).

The proposed system has a constructional similarity with the ventilated pond protected by a secondary roof that has been proposed by Givoni [13–15]. The difference lies on the properties of the protecting material, resulting different heat dissipation mechanism since aluminium sheet acts as a reflector during summer day, and a radiator during summer night.

3. Bottom pond temperatures according to the experiments

3.1. Experimental set-up

The experiments were conducted from June to August 2011, on the Campus of Technical University of Crete in Chania – Greece. The climatic data was obtained from meteorological station of the Institute of Environmental Research, of the National Observatory of Athens, placed on the site of the experiments. The altitude of the site is 137 m, while the exact coordinates are: latitude 24°04′09″E and longitude and 35°32′00″N.

The ventilated pond with aluminium layer is placed on a flat roof of a 6 m^2 stand alone building, shown in Fig. 2. The plan of the building is depicted in Fig. 3. Roof and wall section is shown in Fig. 4(a) and (b) respectively. Building's roof is partly insulated, as shown in Fig. 4(a). Insulation panels inhibit heat transfer from the indoor air to water. The infrared pictures listed in Fig. 5(a)–(d), show the different temperature patterns of the insulated and non-insulated parts. According to the experimental records, the temperature deviation between insulated and non-insulated parts varies from 1 to 3 °C, while the average temperature difference is 2 °C.

The roof is externally smeared with waterproof cementations. The pond's perimeter is consisted of a wooden frame. A polyethylene sheet (nylon) is placed inside the pond for waterproofing. Small beams attached to the perimeter supporting the aluminium layer, as shown in Fig. 6. A floater keeps the water level at 0.10–0.12 m. A photo of the upper view of the pond is shown in Fig. 7.

The metering equipment consists of 8 temperature recorders T-Logg 100 placed on the internal surface of the roof and in the bottom of the pond. The internal air temperature and humidity are recorded by 2 loggers temperature – humidity T-Logg 100E brand Greisinger electronic. The loggers have a resolution of 0.1 °C and accuracy of measured values ± 0.5 °C. Minisoft and GSOFT 40 K software is used for data transferring. The water consumption is recorded by a water meter.

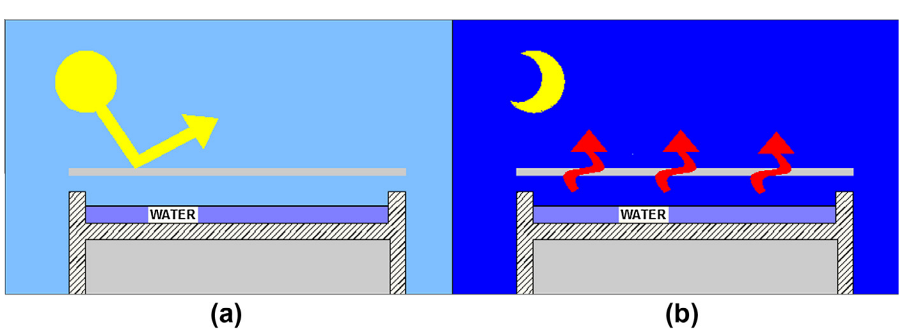

Fig. 1. Ventilated pond with aluminium layer during summer day (a) and night (b).