Applied Energy 160 (2015) 336–357

Contents lists available at ScienceDirect

Applied Energy

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

Review

Roof ponds as passive heating and cooling systems: A systematic review

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HIGHLIGHTS

- Literature on roof pond cooling and heating systems has been reviewed.
- Nineteen roof pond cooling systems and 4 roof pond heating systems are identified.
- Some roof pond variants can provide year-round thermal comfort.
- Climatic conditions, pond depth, and roof material affect performance of roof ponds.
- Major research gaps are identified.

ARTICLE INFO

Article history:
Received 16 June 2015
Received in revised form 29 August 2015
Accepted 12 September 2015

Keywords:
Roof pond
Passive heating and cooling
Passive design
Energy saving
Carbon-neutral design

ABSTRACT

This paper systematically reviews literature on passive heating and cooling of buildings using roof ponds. The main aims were to gain a detailed understanding of different roof pond configurations and their performance, compare effectiveness of different roof pond variants, evaluate performance of different roof pond variants relative to other passive design techniques, explore effects of climatic conditions and various design configurations on the performance of roof ponds, and identify gaps in knowledge and data. Overall, 19 roof pond cooling and 4 roof pond heating systems were identified. This review suggests that, in some cases, roof ponds can provide year-round thermal comfort while reducing demand for active heating and cooling systems. Therefore, they can be utilized in efforts towards the goal of carbon–neutral design. Roof ponds with wet gunny bags, shaded roof ponds, ventilated roof ponds, and roof ponds with movable insulation proved to be more effective relative to other variants of roof pond cooling systems. Comparing performance relative to other passive strategies showed that, in many cases, roof pond cooling systems are about equally effective in maintaining indoor thermal comfort. Meteorological conditions, water depth, roof deck material, and thickness of the insulating panel are the main factors affecting performance of roof ponds. Several areas of weakness in the literature are identified. Future research should, among other things, provide more detailed knowledge on performance of all roof pond variants, further explore suitability of roof ponds relative to other passive design measures, examine effectiveness of roof ponds when combined with other passive design measures, analyze life-cycle costs of roof ponds, and provide more knowledge on their real-world application.

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http://dx.doi.org/10.1016/j.apenergy.2015.09.061
0306-2619/

1. Introduction

Buildings account for about 35–40% of final global energy consumption [1], and about 35% of world's total GHG emissions [2,3]. This significant share indicates that substantial reduction in building energy consumption is required for climate stabilization below a global average of 2 °C above pre-industrial conditions. Over 90% of people's lifetime is spent inside buildings and, not surprisingly, the largest share of energy consumed in buildings can be attributed to space heating, cooling, and ventilation provided by active and energy-intensive mechanisms such as air conditioning [4–6]. Shift to passive and less energy-intensive techniques is, therefore, necessary for achieving the target of near-zero GHG emission buildings. Passive techniques, once implemented, can provide indoor thermal comfort without, or with minimal, use of electrical or mechanical means [7,8]. It should be noted that some of the techniques explained in this paper require using equipment such as fans, pumps, and mechanical control for their enhanced operation. However, evidence shows that the amount of energy required for these purposes is very small and, therefore, these systems can be regarded as passive [9].

Among different elements of building envelope, roof is believed to be the most important when it comes to developing passive measures [10]. This is because it is the most exposed part of a building to direct solar radiation and there is enough evidence indicating that roof alone can be responsible for up to about 50% of heat load in single or two story buildings during summer [11–15]. Shading the roof, increasing roof thickness, enhancing albedo of roof, insulating the roof and providing false ceiling, vegetating the roof, spraying and flowing water over the roof, and provision of roof ponds are several passive measures for regulating heat gain through the roof [10,16]. This study is focused on the latter type. Using water as an ideal thermal mass (due to its large volumetric heat capacity and the fact that it is cheap and nontoxic [17]) roof ponds are capable of providing passive heating and cooling. Since the invention of roof pond system by Harold Hay and his colleagues in late 1960s [18,19], a vast body of work has been published on design and performance of different types of roof ponds. The broad aim of this systematic review is to synthesize this scientific literature. Over the past 4 decades, three review papers have been published on this subject [18–20]. The review by Tiwari, Kumar [20] was published in 1982 when literature on roof ponds was still scarce. Two more recent reviews have been conducted by Givoni [18], and Spanaki, Tsoutsos [19]. The first paper reported on studies investigating potential of various passive cooling systems, including radiant cooling, and indirect evaporative cooling by roof ponds for reducing indoor temperature. Findings from several studies focused on different variants of roof ponds (i.e. open, with movable insulation, ventilated, Cool-roof, and shaded) have been presented in this work. The review by Spanaki, Tsoutsos [19] provides a relatively comprehensive account of roof ponds designed for the purpose of passive cooling of buildings. After categorizing different variants of roof ponds, they have compared performance of several roof pond variants and finally made some recommendations on choosing the desired roof pond system. This review builds on previous research by providing statistical data on the reviewed literature, presenting a more comprehensive account of different roof pond configurations and their performances, investigating both cooling and heating performances of roof ponds, providing more information on comparative performance of different roof pond variants, comparing performance of roof ponds with that of other passive measures, exploring effects of climatic conditions and various design configurations, and identifying gaps in knowledge and data.

2. Methods and materials

This is a desktop research that included content analysis of literature related to roof ponds. Literature review was conducted using the method outlined in Pullin and Stewart [21]. The specific review questions to be addressed were: "what are the major roof pond variants studied in the literature?", "what are the basic statistics related to roof ponds examined in the reviewed studies? (Typology, configuration, geographic distribution, etc.)", "how effective are different roof pond variants in providing passive heating and cooling?", "how do roof ponds perform relative to other passive measures?", and "what are the major research gaps that need to be addressed?". Overall, over 80 studies were reviewed for the purpose of this study (see the Online Supplementary