Passive cooling of cement-based roofs in tropical climates

Jorge L. Alvarado a,*, Edgard Martínez b

a Department of Engineering Technology and Industrial Distribution, Texas A&M University, MS 3367, College Station, TX 77843-3367, United States
b Department of Mechanical Engineering, University of Puerto Rico at Mayaguez, P.O. Box 9045, Mayaguez 00681, Puerto Rico

Received 22 January 2007; received in revised form 7 March 2007; accepted 7 March 2007

Abstract

In tropical climates, dwellings are made of cement-based materials like concrete to be able to withstand tropical storms and severe weather conditions. However, cement-based materials exhibit undesirable thermal properties including low thermal conductivity and thermal diffusivity which make living conditions almost unbearable. The purpose of this research project was to investigate the impact of a newly designed passive cooling system which can minimize heat transfer through concrete roofs. The passive cooling system consists of a corrugated aluminum sheet with a unique orientation to promote heat dissipation. A layer polyurethane is also used to minimize heat transfer. Experimental results based on lab-scale prototypes show that the well-designed roof insulation system can reduce the typical thermal load by over 70%. The passive cooling system also shows a desirable slow response time to irradiation, which is a desirable characteristic necessary to effectively control thermal fluctuations and reduce thermal loads simultaneously. The results also indicate that the cement-based roof midpoint temperature can be modeled accurately using an appropriate empirical model.

#2007 Elsevier B.V. All rights reserved.

Keywords: Passive cooling; Polyurethane aluminum insulation; Concrete roof; Tropical climate; Cement-based material; Mortar; Thermal diffusivity

1. Introduction

Typical high temperatures in the tropics can range from 30 °C (85 °F) in the winter to 35 °C (95 °F) in mid-summer. In the case of tropical islands like Puerto Rico, humidity and other factors contribute to a “heat index factor” which is generally 5–10 degrees higher than the actual temperature, Fig. 1. The ultra-violet radiation is also high due to the intense tropical sun. In Puerto Rico, the Island has two clearly identifiable seasons throughout the year: a dry season from December to April and the rainy season from April through October. The latter includes a hurricane season which peaks during the month of September.

Most of the structures in Puerto Rico are made of concrete. Concrete is an excellent construction material because it is able to provide protection against tropical storms including hurricanes. However, houses made of concrete can retain undesirable thermal energy for long periods of time. When the sunlight shines on concrete roofs, a large portion of the incoming radiation is converted to thermal energy. The thermal energy present in concrete roofs represents a large portion of the typical air conditioning load in tropical dwellings. Excessive thermal loads need to be managed properly to maintain comfortable indoor conditions. Typical concrete houses located in tropical places without proper ventilation can experience high temperatures which are usually greater than the outside dry bulb temperature. As a result, mechanical air conditioning systems are used which are costly to operate and own.

2. Background

Several passive cooling studies have been conducted recently in an effort to reduce heat transfer through residential roofs. Tiwari et al. [2] compared several passive cooling techniques for use in non-air conditioned apartments and concluded that evaporative cooling is the best alternative, if water is readily available. Meng and Hu [3] studied the impact of using a humid porous medium on a roof to take advantage of evaporative cooling. Their results indicate that the roof outer temperature can be reduced significantly. Niachou et al. [4] made use of green roofs as a passive cooling technique which