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An investigation into the use of a wind shield to reduce the convective heat flux to a nocturnal radiative cooling surface

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Abstract

The effect of a wind shield on the convective heat flux from an ambient air stream blowing over a horizontal surface intended for nocturnal radiative cooling has been studied by computational fluid dynamical calculations and by wind tunnel experiments under conditions appropriate for the climate of Thailand. The test unit was a rectangular plate 312 mm × 250 mm, with vertical metal strips for the wind shield having heights up to 100 mm along the edges of the plate. It was found that a wind shield of height 25 mm slightly increased the convective heat transfer due to increased turbulence over the surface, but wind shields of height 50 mm and 100 mm reduced the convection due to a separation of the main airflow from the surface. Radiative cooling was reduced by the wind shields. The net cooling of the surface was best with no wind shield at wind velocities less than about 1 m s^{-1}, and with the wind shield of height 100 mm at wind velocities greater than about 2 m s^{-1}.

Keywords: Nocturnal cooling; Nocturnal sky radiator; Computational fluid dynamics; Convective heat transfer coefficient; Separated airflow

1. Introduction

The present paper reports the results of theoretical and experimental investigations on the application of a novel wind shield to reduce the convective heat flux to the surface of a

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study unit. The results of the studies will be employed in designing and fabricating a novel nocturnal sky radiator for cooling in the tropical climate of Thailand.

The nocturnal sky radiator emits long-wave radiation into the sky at night. At the radiative surface, radiative cooling is achieved if the emitted radiation exceeds the absorbed radiation. This occurs especially under clear sky conditions. The radiative surface principally consists of thin metallic panels exposed to the sky. Commonly, the panels are coated with spectrally selective radiating materials emitting mainly in the spectrum of the atmospheric window (8–13 μm) as explained in previous research by Catalanotti et al. [1], Bartoli et al. [2], Granqvist et al. [3], Berdahl [4], Matsuta et al. [5], Martin [6], and Tazawa et al. [7].

Alternatively, the panels may be coated with white high-emissivity paint (TiO_2) for restricting the absorption of solar radiation and enhancing the emitted radiation from the radiator to the sky at night. Research focused on the high-emissivity paints for nocturnal radiative surfaces includes that of Harrison and Walton [8], Harrison [9], and Michell and Biggs [10]. Experimental investigations on radiative surfaces with white paint in the climate of Thailand have been made by Boon-Long et al. [11] and Khedari et al. [12].

The net cooling power of a radiative panel can also be enhanced by reducing the convective heat gain from the ambient air provided that the method used does not interfere too much with the emission of long-wave radiation. The aim is to reduce the wind speed over the radiative surface and prevent cool air resting on the surface from flowing away.

Often a transparent material, such as polyethylene film, which transmits approximately 60–80% of the infrared long-wave radiation, was used to cover the radiative surface to stop the convective heat flux from warm air reaching the surface. The performance of nocturnal radiative surfaces with the convective heat gain inhibited by a polyethylene film covering the radiative surface has been studied by Mostrel and Givoni [13], Berdahl et al. [14], Saitoh and Ono [15], Al-Nimr et al. [16], and Hamza et al. [17]. Investigations on uncovered nocturnal sky radiators have been carried out by Ito and Miura [18], Mihalakakou et al. [19], and Meir et al. [20].

However, in the case of the tropical climate in Thailand, strong solar radiation during the day may degrade the polyethylene film and shorten its lifetime. Furthermore, the thin polyethylene film can be destroyed by hail, which often occurs in the summer season in northern Thailand.

Another method of reducing the convective heat flux between a surface and the air is to use a wind barrier to separate the airflow from the surface. Loveday et al. [21] have investigated the effect of obstacles to reduce the convective heat loss from building facades. They used the computational fluid dynamical (CFD) technique to visualize the airflow for comparison with the results of wind tunnel experiments. Their research suggests that a reduction in the convective heat transfer coefficient h_c occurs for certain obstacle heights, wind speeds, and obstacle spacings. This is caused by airflow separation, giving rise to stagnant recirculation zones between the obstacles. A wind barrier was also used by Gomes et al. [22] to minimize heat losses from a flat plate solar collector. The wind barrier created a region of recirculating separated flow over the collector which reduced the convection heat transfer coefficient h_c.

Many researchers have investigated h_c over flat, smooth, or uncovered radiative cooling surfaces with the temperature of the radiative surface lower than the temperature of the ambient air (eg. Clark and Berdahl [23] and Givoni [24]). But, to the authors' knowledge, studies of the airflow over *a radiative cooling surface with a wind barrier* have not been published so far.

The aim of the research reported in this paper is to investigate the effect of obstacles that hinder the airflow and minimize the convective heat flux to a nocturnal radiative cooling