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Optimal spacing for double-skin roofs

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Abstract

Double-skin design is known as an effective way to reduce the building's solar heat gain. In this study, inclined parallel plates with upper plate heated by a lighting system are used to simulate double-skin roofs exposed to solar irradiation. Heat transfer experiments were carried out for different inter-plate spacing and different inclined angles. In some of our test runs, a radiant barrier is also installed on top of bottom plate to further cut down the building's heat gain. The Nusselt numbers reduced from our test data are consistently matched with Azevedo and Sparrow's correlation. The optimal inter-plate spacing, when the most heat gain is blocked out, can be directly obtained from our test data which is very close to the sum of both plate's thermal boundary layer thicknesses.

Keywords: Double skin; Solar heat gain; Roof; Radiant barrier

1. Introduction

Double-skin design for building exterior walls and roofs is considered as an effective method for energy-saving designs. Double-skin structure enables the mezzanine to form an air layer. In summer, the air layer with opened ends can reduce the heat entering into the room; in winter, the air layer with closed ends can reduce the heat loss from inner building to outer cold environment.

In Taiwan, with a hot and humid weather, electric wattage used in summer for air-conditioning systems may reach up to 28% of the total consumption, and the annually growth rate is as high as 7.5%. With the pressure of high energy cost and increasing concern of global warming potential (GWP), it is meaningful to adopt the double-skin concept and design a proper roof (call double-roofs here) to replace the low-cost metal sheets, which are still quite popular for warehouse and residential roofs in many rural areas of this country.

Many literatures have experimentally and analytically investigated the heat transfer characteristics and the inducing air movement behavior within parallel walls, such as that cited by Chen et al. [1]. In Chen et al.'s paper, experiments were carried out using a solar chimney model with uniform heat flux on one (lower) wall. The inducing air flow rates were obtained by changing the gap-to-height ratio between 1:15 and 2:5 at different heat fluxes and inclination angles. In this paper and some of its cited papers considered the optimal gap width or optimal gap-to-height ratio is the gap size or ratio when a maximum ventilation flow rate was achieved; see the cited papers [2–4]. However, the obtained optimal spacings from these studies were lack of consistency. From heat transfer point of view, the optimal spacing should be the gap size when the vented heat is maximum, or when heat blocked by roof structure is maximum.

In heat transfer community, considerable attention has been focused on free convection between heated vertical parallel plates. Some attentions have been made to optimize the spacing between parallel plates, such as Bodoia and Osterle [5], Bar-Cohen and Rohsenow [6], and Bejan [7]. The motivation of these papers might arise from the cooling of electronic packages, in which the optimal spacing between two adjacent fins is closely related to number of vertical fins (fin array) to attach to a surface of fixed dimensions. The correlations from literatures [6,7]

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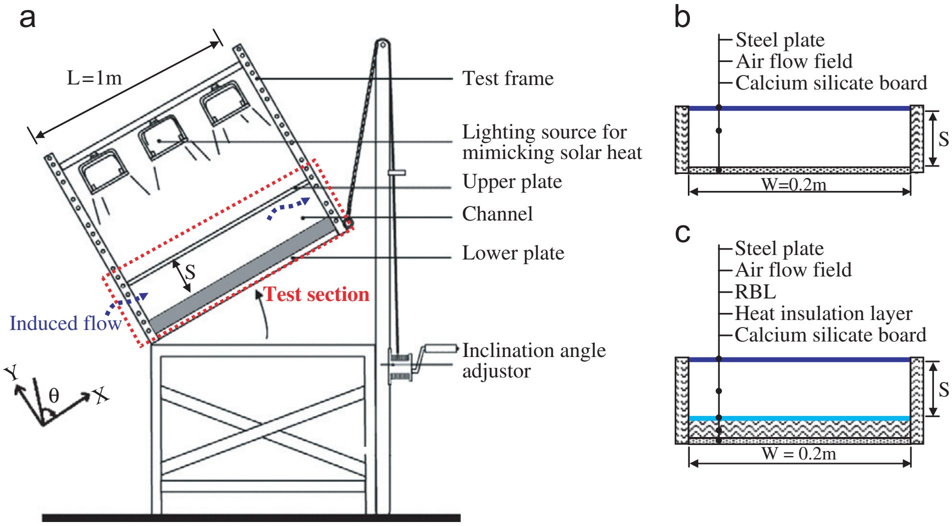

Fig. 1. Experiment facility and test sections. (a) Experiment facility; (b) cross-section view without RBL; (c) cross-section view with RBL.

were proven to be accurate and consistent to each other. However, these correlations are failed to predict the optimal spacing between two plates.

Morrone et al. [8] numerically calculated the heat transfer of a channel flow between two parallel plates. The plates were symmetrically heated by uniform heat flux, and the computation domain was enlarged from regular domain (flow zone between plates) to include two large rectangular domains placed upstream of the entrance and downstream of the exit. The aggregate sub-domains could accommodate the diffusion phenomena by both momentum and energy that occurs outside the channel. The correlation of optimal spacing obtained by this study is believed more accurate than that calculated by Anand [9], in which the diffusion effect was not considered.

In this study, open-ended parallel plates were exposed to lighting radiation to simulate a double-roofs subjected to solar heat. The vented heats carried out by the ventilation flow were calculated by the measured data. The optimal spacing was obtained when the vented heat is maximum under a fixed heat intensity and a fixed inclination angle.

2. Experiments

Fig. 1 illustrates the test facility, in which six 500W/2A/220V infrared ray-less halogen light bulbs were used to mimic solar radiation. Its radiation wave spectrum falls between 0.4 and 2.4 μm, and would approximately simulate the thermal radiation strength of sunshine on the roof. The main test section, inclined parallel plates, is installed directly under the lighting bulbs. The cross-section view of test sections, shown in Fig. 1(b) and (c), respectively, represent the structure and material of parallel plates with and without radiant barrier layer (RBL). The test section is 1 m long with both ends opened, and 0.2 m wide with both side walls made by polywood plus 0.04 m polystyrene for insulation. The upper plate, with black color, is made by a kind of steel plate coated with zinc–aluminum alloy. The basic bottom plate, with white color, is simply a kind of calcium silicate board. For the tests with RBL, an aluminum foil plus 0.03 m thick polystyrene will be placed on the top of calcium silicate board. The thermal properties of these materials are listed in Table 1. The location among six lighting bulbs and the distance between the bulbs and the upper plate were carefully adjusted such that the average incident power density on plate is uniformly close to 650 W/m^2. This value was kept unchanged during the entire course of various tests. The inclination angles θ between the parallel plates and the vertical axis (shown in Fig. 1a) were set to be 30°, 45°, and 60° to simulate different roof slopes. In each inclination angle, different testes were conducted by changing the spacing size (the distance, S, between the upper plate and the lower plate) at $S = 2.5$, 4.37, 5, 6.56, 7.5, 8.56 cm.

Table 1
Thermal property of the materials in test section

	Zinc coated steel plates	Calcium silicate board	Polystyrene
Density ρ (kg/m^3)	6755	800	35
Conductivity (W/m °C)	47	0.15	0.027
Absorptivity α	0.95	0.25	–
Emissivity ε	0.95	0.25	–
Specific heat C (J/kg °C)	473	1085	1210

3. Measurement apparatus and procedure

Plate temperatures along the centerline axis of parallel plates and both temperatures and velocities of channel air at channel entrance and exit were measured by K-type thermocouples and hot-film anemometers. The locations of those instruments are depicted in Fig. 2. The accuracy of