Applied Thermal Engineering 39 (2012) 121–131

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Numerical investigation of passive cooling in open vertical channels

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ARTICLE INFO

Article history:
Received 3 June 2011
Accepted 2 January 2012
Available online 11 January 2012

Keywords:
Heat transfer
Passive cooling
BIPV
Natural convection
Vertical channels

ABSTRACT

Numerical simulations have been carried out in order to investigate natural convection flow and heat transfer in vertical channels which are relevant to passive cooling of building-integrated photovoltaics (BIPV) systems. The numerical results have been validated against existing experimental data available in literature. It has been found that narrow vertical channels with different aspect ratios exhibit varied heat transfer behaviours, implying its significance in the design of passive cooling applications. In addition, the different behaviours of heat transfer may be explained by the turbulence quantities obtained through large-eddy simulations (LES). Based on the current numerical results, a correlation for turbulent natural convection in vertical channel has been determined to predict the average Nusselt number in terms of the relevant dimensionless parameters for the geometry considered in this study.

1. Introduction

In recent years, the design of passive cooling for electronic equipment utilizing natural convection in vertical channels has gained considerable attention due to its energy efficiency. In such conditions, since the channels are relatively short and the Rayleigh numbers are not high, the flow is usually laminar. Hence, the physical phenomena involved can be studied in detail by either experimental or numerical techniques. For instance, Elenbaas [1] pioneered an experimental investigation of natural convection of air within a vertical parallel-plate channel. Subsequent studies have focused on the physical phenomena commonly encountered in such a configuration (for example the transient development [2,3] and flow reversals [4,5]) while several other studies have concentrated on developing correlations for heat transfer [6–10].

Nevertheless, vertical channels with larger dimensions and aspect ratios are more frequently encountered in other applications these days. One prominent example of such systems appears in building-integrated photovoltaics (BIPV). In these channels, comparatively complex physical phenomena such as turbulent flow imply that the heat transfer within the channel is substantially altered through the fluid motions. Thus, work is still required to investigate the effect of turbulence and develop more reliable expressions regarding the heat transfer in such channels.

In most BIPV applications, particularly vertical PV facades ventilated by natural convection, the interest has been to accurately predict the PV surface temperatures which affect its electrical conversion efficiency since increasing PV temperature results in a substantial decrease in converted power [11,12]. In order to provide further insights into the temperature distribution as well as heat transfer behaviour of such system, natural convection in vertical channels with one-sided heating is considered in this study. The buoyancy generated induces air flow within the channel which is able to provide improved heat transfer and passive cooling in these systems.

One of the first experimental investigations dealing with turbulent natural convection in vertical channels was reported by Miyamoto et al. [13]. Their experimental setup consisted of an insulated plate and a plate with uniform heat flux (UHF). Several turbulent intensity profiles presented at a location downstream of the channel had indicated substantial amount of turbulence. Subsequent investigations [14,15] and more recent experimental studies [16–23] have also reported on a similar configuration, but have only concentrated on vertical channels with moderate aspect ratios.

In parallel with experimental investigations, a number of investigators have studied turbulent natural convection in vertical channels numerically [24–32]. Most of these studies have assumed two-dimensionality and modelled turbulence through the Reynolds-averaged Navier–Stokes (RANS) approach by invoking the Boussinesq approximation. However, it is well-known that when the RANS approach is adopted, detailed flow behaviours and particularly the unsteady turbulent structures could not be sufficiently captured. Furthermore, the use of the Boussinesq approximation may not be appropriate especially if the temperatures

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doi:10.1016/j.applthermaleng.2012.01.001