Available online at www.sciencedirect.com
SCIENCE DIRECT
Solar Energy 80 (2006) 89–103
SOLAR ENERGY
www.elsevier.com/locate/solener

Design procedure for cooling ducts to minimise efficiency loss due to temperature rise in PV arrays

B.J. Brinkworth [a,*], M. Sandberg [b]

[a] Cotswold, 11 Wellesley Close, Waterlooville, Hants, UK
[b] Department of Built Environment, KTH Research School, University of Gavle, Sweden

Received 9 November 2004; received in revised form 12 May 2005; accepted 13 May 2005
Available online 13 October 2005

Communicated by: Associate Editor Brian Norton

Abstract

The principal variable to be fixed in the design of a PV cooling duct is its depth, and hence the hydraulic diameter of its cross-section D. Analysis of the flow and heat transfer in the duct under still-air (buoyant flow) conditions, when the temperature rise is greatest, is validated by measurements on a full-scale test rig. It is shown that there is an optimum value of this design variable, such that for an array of length L the minimum temperature occurs when the ratio L/D is about 20. The optimum value is not affected much by other quantities, including the slope of the array.

In practical situations, the flow is obstructed by devices across the duct inlet and outlet to exclude insects, birds and rain, and by structural support members crossing the duct interior. It is shown that the latter are no cause for concern, since the effect of the reduction in the flow-rate due to their presence is more than offset by an increase in heat transfer through additional turbulent mixing.

It is also shown that array temperatures are strongly reduced by wind effects, which increase both the heat lost from the front surface of the array and by enhancement of the flow in the duct. Though the trends are clear, limitations are encountered in the present state of knowledge in both areas.
© 2005 Elsevier Ltd. All rights reserved.

Keywords: Photovoltaics; Building integration; Operating temperature; Optimum duct depth; Obstructions

1. Introduction

The general arrangement of a PV array, with a cooling duct fitted behind it, is represented in Fig. 1. Most of the absorbed solar energy appears passively as heat, raising the temperature of the cells and thus reducing the efficiency with which the active part is converted into electricity. Measured losses of peak output power of around 1/2% per K temperature rise have been reported for monocrystalline silicon cell arrays (Brinkworth et al., 1997). The raised temperature of the array causes heat to be lost from the front face into the surroundings, and from the rear face into the cooling duct. Buoyancy due to the warming of the air in the duct induces an upward flow, so that the inwardly-transmitted heat

* Corresponding author. Tel.: +44 2392 266547.
E-mail addresses: bjb@cots.freeserve.co.uk (B.J. Brinkworth), Mats.Sandberg@hig.se (M. Sandberg).

0038-092X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.solener.2005.05.020

Nomenclature

a	constant in Eq. (23) ($Wm^{-2}K^{-1}$)
c	coefficient in Eq. (23) ($Wm^{-2}K^{-1}$ per $m\,s^{-1}$)
c_p	specific heat capacity of air ($J\,kg^{-1}K^{-1}$)
D	hydraulic diameter of duct cross-section (m)
d_h	distance from rough wall to plane of zero heat flux (m)
d_m	distance from rough wall to plane of zero shear stress (m)
F	view factor of duct opening from point on wall of duct
f_r	Darcy friction factor for rough wall
G^+	wall roughness coefficient for heat transfer
g	acceleration due to gravity ($m\,s^{-2}$)
g	exponent in Eq. (20)
H	height of duct (m)
h	height of rib or cross-member (m)
h_0	convective heat transfer coefficient at heated surface ($Wm^{-2}K^{-1}$)
h_b	convective heat transfer coefficient at adiabatic surface ($Wm^{-2}K^{-1}$)
h_r	heat transfer coefficient for radiative heat transfer ($Wm^{-2}K^{-1}$)
h_{ec}	external heat transfer coefficient due to convection ($Wm^{-2}K^{-1}$)
h_{er}	external heat transfer coefficient due to radiation ($Wm^{-2}K^{-1}$)
h^+	roughness Reynolds number for rough wall, Eq. (19)
k	thermal conductivity of air ($Wm^{-1}K^{-1}$)
k_h	hydraulic loss coefficient
L	length of duct (m)
Nu_c	Nusselt number for duct heated from one side
n	convective heat flux partition ratio q_b/q_0
q	total heat flux into duct air (Wm^{-2})
q_b	convective heat flux at rear adiabatic wall (Wm^{-2})
q_0	convective heat flux at front heated wall (Wm^{-2})
q_s	solar heat flux incident on array (Wm^{-2})
Re_D	Reynolds number referred to duct hydraulic diameter
R^+	roughness parameter for wall friction
R	coefficient in Eq. (16)
r	exponent in Eq. (16)
S	air temperature stratification parameter, Eq. (2)
St_r	Stanton number for convection at rough wall
s	spacing between ribs, or pitch (m)
T_a	temperature of ambient air (K)
T_b	temperature of rear adiabatic wall (K)
T_m	bulk mean temperature of air in duct (K)
T_i	representative wall temperature (K)
T_0	temperature of front heated wall (K)
U	mean velocity of air flow in duct ($m\,s^{-1}$)
U_a	overall heat loss coefficient for array to ambient ($Wm^{-2}K^{-1}$)
V_{10}	meteorological wind speed, 10 m height ($m\,s^{-1}$)
W	width of duct (m)
w	width of rib (m)
x	distance along duct from entrance (m)
α	solar absorptance of array
Δp_w	pressure difference between ends of duct due to wind effects ($Pa\,m^{-2}$)
ε	thermal emittance of array/wall
ε_{eff}	effective emittance for radiative heat exchange between walls
η	energy conversion efficiency for array
θ	slope of duct (inclination to horizontal)
θ^*	influence coefficient for convective wall heat flux
ρ	density of air ($kg\,m^{-3}$)
σ	Stefan–Boltzmann constant (5.67×10^{-8} $Wm^{-2}K^{-4}$)
ν	kinematic viscosity of air (m^2s^{-1})

is also removed into the surroundings, thus lowering the temperature of the array and restoring some of its efficiency. The induced flow may be assisted or opposed by pressure differences between the inlet and outlet apertures of the duct, due to local wind effects at those points.

Several features of this situation have been analysed and modelled over the last decade or so, in which the treatment of the induced flow and the heat transfer at the duct surfaces has been progressively refined (Cross et al., 1994; Brinkworth et al., 1997, 2000; Brinkworth, 2000a,b, 2002; Sandberg

Download English Version:

https://daneshyari.com/en/article/1552339

Download Persian Version:

https://daneshyari.com/article/1552339

Daneshyari.com