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Experimental study of wind effects on unglazed transpired collectors

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Abstract

High wind velocity affects the performance of unglazed transpired collectors (UTC); indeed, wind flow on the collector's surface reduces useful heat transferred to the collector fluid by effectuating convection losses and suction in the pores and thereby outflow from the plenum. Wind does not impinge uniformly on all points on a large area; the velocity distribution depends on wind direction and surroundings of the concerned area. The paper describes an experimental and analytical parametric study to assess the effect of wind on UTCs. Velocity measurements obtained using wind-tunnel experiments were applied to analytical models of UTC performance evaluation and were found to influence UTC performance. The assumption that a reference wind speed acts uniformly throughout the UTC area, as opposed to the more realistic non-uniform distribution, resulted in the overestimation of heat exchange effectiveness up to 50% and underestimation of convective heat transfer coefficients up to 20%. The importance of using actual velocity distribution, as opposed to an assumed uniform velocity distribution in building simulation, has been discussed.

Keywords: Wind tunnel; Unglazed transpired collector; Wind velocity distribution; Convective heat loss

1. Introduction

Sustainability gained immense importance over the past few decades. There has been commendable growth, worldwide, in the solar thermal energy generation capacity – an average annual growth of approximately 15% since 2000 (IEA, 2013) – due to both the abundance of solar energy in several parts of the world and technological innovations that make this energy accessible. High performance of solar thermal devices is brought about by reducing heat loss to a minimum. In this regard, wind-induced convection heat loss is a major concern and extensive studies with improved wind simulations are necessary to arrive at generalized guidelines for efficient system design.

UTCs are one of the most efficient solar heating technologies available today. Introduced in 1989 (NREL, 1998), UTCs consist of a dark absorber cladding with 0.5–2% of the area made up of perforations (Dymond and Kutscher, 1997) installed about 10–20 cm off the equator-facing wall of a building, forming a plenum behind the cladding – see schematic in Fig. 1. Heat absorbed by the metal cladding forms a layer of warm air on either of its sides. Warm air is drawn in through the perforations by means of a fan located behind the cladding at the top and transferred through a distribution duct system into indoor spaces. In addition to space-heating, UTCs are known to have been used for crop-drying in barns and heating swimming pools.

Abbreviations: BIPV/T, building-integrated photovoltaic/thermal; CFD, computational fluid dynamics; CHTC, convective heat transfer coefficient; JMSB, John Molson School of Business; UTC, unglazed transpired collector.

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Nomenclature

a,c,e,f	constants in Eqs. (5)–(7)
c_p	specific heat of air at constant pressure (J/kg K)
D	UTC hole diameter (m)
h_c	convective heat transfer coefficient (W/m^2 K)
h_r	radiative heat transfer coefficient (W/m^2 K)
P	UTC hole pitch (m)
Pr	Prandtl number
Q_{conv}	convective heat loss (W/m^2)
Q_{30}, Q_{50}	Thermal energy collected at 30% and 50% UTC thermal efficiency (W hr/m^2)
Re	Reynolds number $Re_w = \frac{V_{wind}P}{v}$ $Re_s = \frac{V_sP}{v}$ $Re_b = \frac{V_sP}{v\sigma}$ $Re_h = \frac{V_sD}{v\sigma}$
t	UTC plate thickness (m)
T_{amb}	temperature of ambient air (°C)
T_{back}	temperature of the air coming out at the back of the collector (°C)
T_{coll}	temperature at the collector surface (°C)
V_{10}	reference wind velocity at 10 m height in the upstream undisturbed flow (m/s), usually measured at a weather station
V_∞	free stream velocity parallel to the UTC (m/s)
V_{loc}	magnitude of local wind velocity vector (m/s)
V_{normal}	component of V_{loc} normal to the building or UTC surface (m/s)
V_{ref}	reference wind velocity measured above the roof (m/s)
V_s	suction velocity in the UTC pores (m/s)
V_{wind}	approach wind velocity (m/s)
W	width of the collector (m)
α	power law exponent
α_s	solar absorptance of the collector surface
ϵ	UTC plate heat exchange effectiveness
ϵ_f, ϵ_h, ϵ_b	heat exchange effectiveness at the front, hole and back of the plate respectively
η	UTC thermal efficiency
v	kinematic viscosity of air (m^2/s)
ρ	density (kg/m^3)
σ	UTC porosity

The U.S. Department of Energy claims this technology to be the most efficient air heating system available today – 75% efficiency as claimed by Solarwall® (Heinrich, 2007).

2. Background knowledge

2.1. Wind effects on UTC

UTC performance is governed by a number of factors such as ambient temperature, wind speed, properties of the absorber plate, pitch and diameter of the perforations, and air suction rate, most of which have been addressed in various past research studies. One of the first studies of wind effects on UTCs was by Kutscher (1992) followed by Kutscher et al. (1993) who theoretically examined different modes of heat loss from UTCs and derived relations for convective heat loss Q_{conv} and thermal efficiency η, a term that defines how much of the available thermal energy the collector converts into useful form by heating air:

$$Q_{conv} = 0.82\left(V_\infty v/V_s^2\right)W\left[\rho c_p V_s(T_{coll} - T_{amb})\right] \tag{1}$$

$$\eta = \alpha_s\left[1 + (h_r/\epsilon + h_c)\left(\rho c_p V_s\right)^{-1}\right]^{-1} \tag{2}$$

where V_∞ is the free stream wind velocity, V_s is the velocity with which air is drawn through the UTC perforations, T_{coll} and T_{amb} are temperatures of the collector surface and ambient air respectively, h_r and h_c are coefficients of heat transfer by radiation and convection respectively and ϵ is the plate heat exchange effectiveness. Air exiting at the back of the plate, i.e. the outlet air, is at a lower temperature than the plate surface. Plate heat exchange effectiveness, the air heating effect of the plate, relates the outlet air temperature T_{back} to the plate surface temperature and ambient air temperature:

$$\epsilon = (T_{back} - T_{amb})/(T_{coll} - T_{amb}) \tag{3}$$

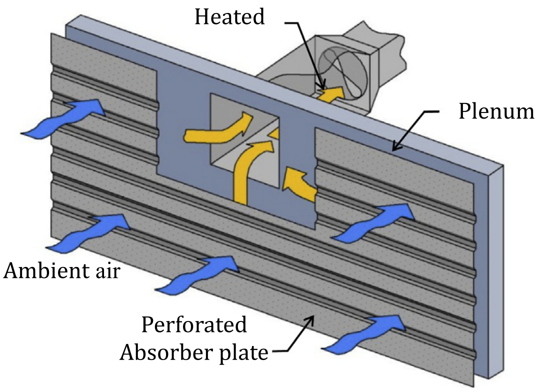

Fig. 1. Schematic of a UTC.

The research was extended to experimental analysis in a wind tunnel to assess the effect of cross-wind (Kutscher, 1994) and later on a numerical model, validated by wind tunnel tests and hotwire anemometry (Gawlik and Kutscher, 2002).

Van Decker et al. (2001) studied the effect of plate thickness, pore size, shape and orientation on the heat exchange effectiveness ϵ of the UTC. On the basis of experimental measurements and theoretical models available in previous literature, the study developed predictive models for heat exchange effectiveness at the front ϵ_f, holes ϵ_h, and back ϵ_b, of the collector plate and ϵ was expressed as follows: