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An experimental investigation of a two-dimensional prototype of a transparent transpired collector

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ABSTRACT

This paper presents an experimental investigation of the thermal performance of a two-dimensional reduced scale prototype designed to simulate the essential features of a novel type of solar air collector involving a transparent transpired cover. Another objective is to analyze the effects of varying key parameters such as plenum thicknesses, pitch spacing, slots width, irradiation, and air mass flow rate in term of collector efficiency. A multi-level factorial design of experiments is used for this investigation. It is found that the air mass flow rate has the strongest effect on the efficiency of the transparent transpired collector. The irradiation, slots width, pitch spacing and plenum thicknesses seems to have a moderate effect.

1. Introduction

Solar air heating systems are becoming more and more popular as they provide many possibilities for energy savings and for pre-heating air in various applications. They use solar energy to heat and ventilate indoor air spaces. Implementation of these systems in new or existing buildings has been the object of a relatively broad range of applications in the last decade.

1.1. A new type of collector

A new type of solar collector has recently emerged on the market. It is called transpired transparent collector (hereafter TTC). The TTC includes all the usual components of a typical unglazed transpired collector (UTC). The main difference is that instead of a perforated metal absorber, a perforated glazing is used. Basically, the TTC consists of a transparent panel perforated by tiny holes, installed several centimeters (10–15 cm) from a masonry wall. A large part of the solar radiation is transmitted through the perforated glazing and absorbed by the dark surface of the building wall, namely the absorber wall. The remaining part of the incident radiation is either absorbed by the transparent cover or reflected back to the surroundings. On the top, a fan creates a negative pressure in the air space between the panel and the building wall (plenum), drawing cold air through the glazing perforations. This generates an upward air movement in the plenum. Heat collected at the absorber wall as well as part of that which is absorbed by the transparent cover itself is transferred to air that flows in the plenum, which exits from the top of the building wall. The heated air is then ducted into the building via a connection to the ventilation intake.

This type of solar collector can be installed on new and existing façades of buildings. It offers the potential advantages of low weight, simplicity of manufacturing and resistance to corrosion, as well as better aesthetic integration compared to metallic absorber. Furthermore, it can be used in conjunction with windows, overhang, double skin façade and other building design elements. A schematic of a TTC mounted on a typical brick wall construction is shown in Fig. 1. Another advantage of making the TTC as a part of the building façade is that the perforated panel can recapture building wall heat loss. As the building wall reemits the heat in the thermal infrared (~10 μm), there is not much radiative losses because the perforated glazing is almost opaque at these wavelengths. At this point, the radiation emitted by the absorber plate is absorbed at the back face of the cover and the sucked air through the perforations picks up this heat and brings it back into the plenum.

Fig. 1 shows transparent perforated panels placed in front of brick wall construction (the absorber surface), with an airspace in between, and air exhausting fan (at its top center).

Abbreviations: ATF, active transparent facade; UV, ultraviolet wavelength; VIS, visible wavelength; NIR, near infrared wavelength; MIR, mid infrared wavelength; FIR, far infrared wavelength.

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Nomenclature

A_{coll}	collector area (m^2)
A_{cs}	pipe cross section surface area (m^2)
b	slot width (m)
C_p	specific heat capacity of air (J/(kg K))
D_f	degree of freedom
G_T	incident irradiation on the collector (W/m^2)
$\dot{m}$	air mass flow rate (kg/s)
L	pitch spacing between slots (m)
SST	sum of squares
T_{sky}	sky temperature (°C)
T_{amb}	ambient air temperature (°C)
T_{out}	exit air temperature (°C)
T_{abs}	average absorber wall temperature (°C)
T_g	average perforated glazing temperature (°C)
w	plenum thickness (m)
V_{wind}	laboratory air velocity (m/s)
k	number of factors with 3 levels
l	number of factors with 2 levels

Greek symbols

ρ_{air}	air density (kg/m^3)
λ	thermal conductivity (W/m·K)
η_{coll}	collector efficiency
τ_g	transmissivity of perforated glazing
ρ_g	reflectivity of perforated glazing
$\tau_{ir,g}$	thermal infrared transmissivity of perforated glazing
α_{abs}	the total hemispherical absorptivity of absorber plate
ε_{abs}	thermal emissivity of the absorber plate

1.2. A transparent cover

The use of polymers in the design of solar collector systems is not new concept, there is a relatively long history on their utilization [1]. A number of researchers have adopted the use of polymers in solar collector design [2]. Two of the earliest reports on the use of polymer materials in solar collector systems were by Tabor and Zeimer [3] and Whillier [4]. Tabor and Zeimer [3] tested a cylindrical concentrator made of inflated polymer films, for the production of industrial process heat. A review of candidate materials is provided in [5]. Plastics of thicknesses from 0.5 mm to 3.2 mm are used as cover in solar collectors. These plastics have a transmission coefficient for short wave radiation that varies from 0.89 to 0.97 [6]. The thermal behavior of a polymeric solar collector for heating air has been investigated by Njomo [7,8]. Solar optical properties of a polymeric cover material are an important parameter that affects the amount of solar energy absorbed by a solar collector. Polymeric covers for solar collector with black absorber have to be selective in the solar and infrared wavelength range. A good cover material should have a high transmittance in the visible range of the electromagnetic spectrum and a low transmittance to infra-red radiation in order to trap efectively the re-radiated heat from the absorber plate [9]. The solar optical properties of such materials have been investigated in depth by Balocco et al. [10] and Oreski et al. [11,12]. The use of polymeric cover in solar collectors is preconditioned by their durability and weatherability. The details of their reliability, durability and long-term performance have been reported by Raman et al. [5] and Köhl et al. [13]. The effects of environmental variables on the performance properties of polymeric materials are reported in reference [14].

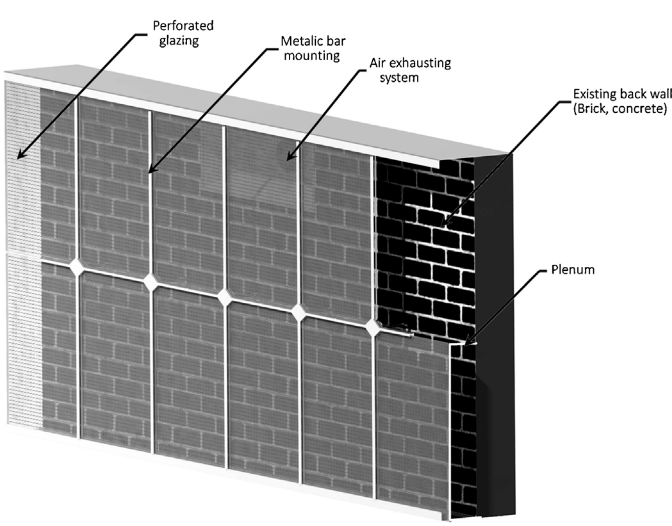

Fig. 1. Schematic of the transparent transpired collector mounted on a typical brick wall construction.

1.3. The performance of a TTC

The air passage through the TTC perforations forms tiny jets exiting the transparent perforated glazing. These jets disturb the vertical flow in the plenum and give birth to various coupled thermal (conduction, convection and radiation) and aerodynamic phenomena. The thermal performance and the specific temperatures (T_g, T_{abs}, T_{out}) of the various TTC components are the result of these phenomena which depend on design; thermo-physical and optical properties; and operating conditions of the various components of the TTC structure, environmental conditions and of the building itself. Table 1 summarizes the parameters affecting the performance of TTCs. This table presents the parameters classified in geometric, thermo-physical, optical and operating parameters.

The performance of a TTC depends on many parameters (Table 1) for which the influence has to be determined. Without this knowledge, an inadequate design could result. The overall performance could then be inconvenient leading to:

- Significant solar gains possibly overheating the buildings during summer time.
- Poor flow distribution across the whole system, which causes hot spots, where the radiative losses will dominate.
- Reversal flow due to natural convection, in which the air drawn into the plenum is expelled outdoor at the top of the unit.
- Significant thermal heat loss, resulting from poor optical solar and infrared properties of the TTC surface components.

The proper knowledge of the influence of each parameter enables one to increase the heat recovery, reduce costs or adapt their design to a particular context. To the best of the knowledge of the authors, no study has been published on the evaluation of the thermal performance of the TTCs as well as the main parameters that affect the performance in these devices. Therefore, it is essential to conduct a detailed research in this area.

The objective of the work presented here is to provide measurements from a reduced-scale prototype that can be used to estimate the thermal performance of TTCs and to determine the effect of some design and operation parameters such as geometrical properties, irradiation, and air mass flow rate in terms of collector efficiency (η_{coll}). To determine these parameters effects, this experimental work uses a multi level full factorial plan of replicated 48 tests. No attempt was made to derive an overall efficiency model for this collector.