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# Potential application of glazed transpired collectors to space heating in cold climates

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ABSTRACT

Although unglazed transpired collectors (UTC) succeed in industrial ventilation applications, solar fraction is very low when they are used in space heating in cold climates due to the lower exit air temperature. Considering the potential for glazed transpired collectors (GTC) using recirculated air for space heating applications in cold climates, a mathematical model is developed for predicting the thermal performance of GTC. Simulation results show that although glazing results in optical loss, it could decrease convective heat loss resulted from high crosswind velocities effectively. For a solar radiation of 400 $W/m^2$, an ambient temperature of $-10\,°C$, and a suction velocity of 0.01 m/s, the exit air temperature of GTC is higher than that of UTC for crosswind velocities exceeding 3.0 m/s. By comparison with a conventional flat-plate solar air collector operating under the same conditions, the thermal performance of GTC shows a significant improvement. For a five-storey hotel building located in the severe cold climate zone of China, case study shows that the annual solar fraction of the GTC-based solar air heating system is about 20%, which is two times higher than that of the flat-plate collector-based system and nearly nine times higher than that of the UTC-based system respectively. Hence, an enormous amount of energy will be saved with the application of GTC to space heating in cold climates.



## 1. Introduction

There are many usages of solar energy, among them one of the most potential applications is in the form of solar air heaters [1]. Solar air heaters are used for many purposes, such as drying agricultural products [2–4], and heating buildings to maintain a comfortable environment especially in the winter season [5]. Solar air heaters are classified according to collector cover, absorber materials, shape of absorbing surface, absorber flow pattern, flow shapes, hybrid collectors and their applications [6].

Flat-plate solar air heaters are the simplest and most basic type of solar heaters [7], and have been widely used for low to moderate temperature applications [8]. However, thermal performance of flat-plate solar air heaters is poor due to high heat losses and low convective heat transfer coefficient between absorber plate and air stream. Therefore, a lot of attempts have been made to improve thermal performance of flat-plate solar air collectors. Gill et al. [9] studied the thermal performance of two low cost solar air heaters which have flat-plate absorbers of fiber-glass. For flow rate of 0.02 $m^3/s$ per $m^2$ aperture area, the maximum average thermal efficiency was 37.45% for single glazed and 24.07% for double glazed solar heater during summer. Corresponding data for winter were 30.29% and 45.05% respectively. Experimental and numerical investigations showed that considerable improvement in collector efficiency was obtained for double flow solar air heaters with fins compared to single flow operating at the same flow rate [10,11]. Alta et al. [12] compared the performance of three types of flat-plate solar air heaters, two having fins and the other without fins, one of the heater with a fin had single glass cover and the others had double glass covers. Energy and exergy analyses showed that the heater with double glass covers and fins is more effective and the difference between the input and output air temperature is higher than of the others. The effect of external recycle on the thermal performances of flat-plate solar air heaters with internal fins attached was investigated [13]. It was found that considerable improvement in collector efficiency was obtained with an external recycle. Jaurker et al. [14] studied heat transfer and friction characteristics of rectangular solar air heater duct using rib-grooved artificial roughness experimentally. Results showed that the heat transfer coefficient for rib-grooved arrangement is higher than that for the transverse ribs, whereas the friction factor is slightly higher for rib-grooved arrangement as compared to that of rectangular transverse ribs of similar rib height and rib spacing. Kumar et al. [15] experimentally studied the heat transfer and friction characteristics in solar air heater duct roughened with discrete W-shaped

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## Nomenclature

| | |
|---|---|
| $A$ | area ($m^2$) |
| $c_p$ | the specific heat at constant pressure (J/kg K) |
| $d$ | hole diameter (m) |
| $D_h$ | hydraulic diameter (m) |
| $F$ | view factor |
| $h$ | convective heat transfer coefficient ($W/m^2$ K) |
| $I$ | solar radiation ($W/m^2$) |
| $k$ | thermal conductivity (W/m K) |
| $m$ | mass flow rate of air (kg/s) |
| $Nu$ | Nusselt number |
| $P$ | hole pitch (m) |
| $Q$ | quantity of heat (W) |
| $R$ | thermal resistance ($m^2$ K/W) |
| $Re$ | Reynolds number |
| $S$ | absorbed solar radiation (W) |
| $T$ | temperature (K) |
| $U$ | overall heat transfer coefficient ($W/m^2$ K) |
| $v$ | velocity (m/s) |
| $\Delta T$ | air temperature rise (°C) |

*Greek symbols*

| | |
|---|---|
| $\alpha$ | absorptivity |
| $\beta$ | absorber porosity |
| $\varepsilon$ | emissivity |
| $\varepsilon_{hx}$ | heat exchange effectiveness |
| $\eta$ | thermal efficiency |
| $\mu$ | viscosity (kg/m s) |
| $\rho$ | density ($kg/m^3$) |
| $\sigma$ | Stefan–Boltzmann constant |
| $\tau$ | transmissivity |

*Subscripts*

| | |
|---|---|
| *a* | air |
| *ag* | between air and glazing |
| *ahea* | after heat exchange with absorber |
| *amb* | ambient |
| *asp* | between air and side plates of the plenum |
| *aw* | between air and wall |
| *cd* | conductive heat transfer |
| *cv* | convective heat transfer |
| *ex* | exit |
| *g* | glazing |
| *gg* | between glazing and ground |
| *gnd* | ground |
| *gs* | between glazing and sky |
| *gsur* | between glazing and the surroundings |
| *hole* | hole |
| *ia* | indoor air |
| *is* | inner surface |
| *it* | inlet |
| *os* | outer surface |
| *p* | absorber plate |
| *pa* | between absorber plate and air |
| *pg* | between absorber plate and glazing |
| *pl* | plenum |
| *pw* | between absorber plate and wall |
| *r* | radiative heat transfer |
| *sky* | sky |
| *sp* | side plates of the plenum |
| *spsur* | between side plates of the plenum and the surroundings |
| *suc* | suction |
| *w* | wall |
| *wd* | wind |
| *wia* | between wall and indoor air |
| 1 | plenum 1 |
| 2 | plenum 2 |

roughness and developed correlations for heat transfer and friction as a function of roughness and flow parameters. Karim and Hawlader [16] experimentally studied the performance of three types of solar air heater, namely flat plate, finned and V-corrugated solar air heaters. The V-corrugated collector was found to be most efficient while the flat plate collector was the least efficient. Lin et al. [17] and Gao et al. [18] studied the thermal performance of cross-corrugated solar air heaters. Results showed that cross-corrugated solar air heater had a significant superior thermal performance in comparison to that of the flat plate solar air heater. Akpinar and Koçyigit [19] investigated the performance of flat-plate solar air heater having three different obstacles of triangular, leaf and rectangular shape and without obstacles experimentally. The highest collector efficiency and air temperature rise were achieved by the solar air heater with leaf obstacles, whereas the lowest values were obtained for the solar air heater without obstacles, i.e. flat plate collector. Packed bed absorbers have also been used to improve the thermal performance of solar air heaters. Wire mesh/wire screen matrix [20–27], limestone and gravel [28,29], and recyclable aluminum cans [30,31] were used as packed bed materials.

Unglazed transpired collectors (UTC) introduced in the early 1990s for ventilation air heating are a relatively new development in solar collector technology [32]. UTC is usually constructed from metal plate, which is perforated and covered with selective coating. The collector is mounted out 100–200 mm from the exterior wall (roof) of a building or a bottom plate to form a plenum. Fan draws outdoor air through the transpired absorber plate into the plenum and then into the building or dryer. Outdoor air is heated when it is drawn through the small holes on the collector's surface. Convective heat loss is eliminated in UTC because the convective boundary layer is continuously sucked off. In addition, the intimate heat transfer between the plate and the sucked air keeps the plate temperature low, minimizing the radiative loss. Thus, the glazing traditionally used for reducing the plate's convective and radiative losses is not required in UTC [33]. A large number of UTC-based ventilation air heating system, crop drying system and cogeneration system have been installed in Canada, USA, Europe, Asia, and Latin America [1,34–36]. Monitoring work revealed that UTC outperforms the traditional glazed solar panels and at lower capital costs [37].

Most of the industrial ventilation air preheating systems have been based on higher air flow rates. The purpose of these systems is to achieve a reasonable temperature rise, but not to be heated much above room temperature [37]. Different from industrial ventilation applications, a higher air temperature rise is necessary to increase solar fraction [5] for space heating. UTC should be operated under lower air flow rates to achieve a higher air temperature rise. However, crosswind velocity has a significant effect on the exit air temperature at low and moderate air flow rates, and this effect can be eliminated by increasing suction velocity to 0.03–0.05 m/s [38,39]. Although increasing suction velocity prevents convective heat loss from the absorber, it also prevents the air from remaining in contact with the absorber long enough to reach very high temperatures. Air temperature would only be raised 12–13 °C