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Large scale test of a novel back-pass non-perforated unglazed solar air collector

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ABSTRACT

This paper describes large scale tests conducted on a novel unglazed solar air collector system. The proposed system, referred to as a back-pass solar collector (BPSC), has on-site installation and aesthetic advantages over conventional unglazed transpired solar collectors (UTSC) as it is fully integrated within a standard insulated wall panel. This paper presents the results obtained from monitoring a BPSC wall panel over one year. Measurements of temperature, wind velocity and solar irradiance were taken at multiple air mass flow rates. It is shown that the length of the collector cavities has a direct impact on the efficiency of the system. It is also shown that beyond a height-to-flow ratio of 0.023 $m/m^3/hr/m^2$, no additional heat output is obtained by increasing the collector height for the experimental setup in this study, but these numbers would obviously be different if the experimental setup or test environment (e.g. location and climate) change. An equation for predicting the temperature rise of the BPSC is proposed.

1. Introduction

The operational energy of non-residential buildings accounted for 40% of the European Union's energy consumption and carbon emissions in 2010 [1]. Of this, 50% was used for heating, ventilation and air conditioning services (HVAC). In the UK, the Government target for carbon emissions is to achieve an 80% reduction by 2050 [2]. One of the means of achieving this reduction is through the use of renewable energy systems. However, only 1.8% of operational energy is supplied from renewable energy sources in the UK at present [3].

Energy efficiency measures have been included in part L of the UK Building Regulations [4], which are aimed at reducing energy consumption and therefore reducing CO_2 emissions. One of the major challenges for the UK construction industry is to develop more efficient and effective technologies based on renewable sources of energy, such as solar energy. Additionally, effective energy storage systems must be developed to satisfy the energy demands of end users, as and when it is required, because most renewable energy sources are transient in nature.

Solar energy can potentially be absorbed and converted by using solar collectors to provide space heating in commercial buildings and in large enclosures, such as warehouses and superstores. Technologies, such as solar air collectors (SACs), can therefore result in the building envelope becoming a producer of energy for space heating [5].

SACs are a special type of heat exchangers that absorb incident solar radiation, and convert it to useful thermal energy via a photothermal process (see Fig. 1). In a SAC, the absorber transfers the energy from the solar irradiance to the air flowing through the collector by forced or natural convection, depending on the collector configuration. This heated air inside the collector is then transported as circulating air directly into the building. SACs were first described by Hollick and Peter [6] who used solar radiation to preheat air for ventilation. However, it was in the last three decades that effective solar air collector technologies have been developed

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Nomenclature

A_o	orifice area (m^2)
ΔP	orifice differential pressure (Pa)
β	orifice diameter/duct diameter (d/D)
C_p	heat of air ($Kj/kg\ ^\circ C$)
d	orifice diameter (m)
D	duct diameter (m)
E_{dir}	direct radiance incident on tilted surface (W/m^2)
E_{dir}	diffuse radiance incident on tilted surface (W/m^2)
E_{ref}	reflected irradiance incident on tilted surface (W/m^2)
E_L	incident long wave radiation on the collector in W/m^2
F_R	collector efficiency factor
f	enhancement factor
G_{solar}	global solar radiance incident on surface (W/m^2)
G_{tot}	total solar radiance incident on surface (W/m^2)
M	molar mass ($kg/kmol$)
m_{air}	air flow rate (kg/s)
NO	universal gas constant ($kJ/kmol.K$)
P_a	atmospheric pressure (kPa)
P_s	saturated vapour pressure over water (kPa)
P_{sc}	corrected saturated vapour pressure (kPa)
P_u	orifice upstream pressure (Pa)
P_v	partial vapour pressure (kPa)
R	specific gas constant for moist air (kJ/KgK)
RH	relative humidity (%)
t	temperature ($^\circ C$)
t_{in}	inlet temperature ($^\circ C$)
t_{out}	outlet temperature ($^\circ C$)
t_a	ambient temperature ($^\circ C$)
U_L	heat loss coefficient (W/m^2K)
ε	expansibility factor
σ	Stefan–Boltzmann constant ($=5.67 \times 10^{-8}\ W/m^2K^4$)
$\tau\alpha$	effective transmittance-absorptance factor
η	instantaneous efficiency (%)
ν	kinematic viscosity (m^2/s)
ρ_u	density of moist air (kg/m^3)
α	flow rate coefficient
γ	isentropic exponent for air(~1.4)

[7]. Since then more than one thousand SACs have been installed in over 30 countries [8].

SACs can be classified as glazed and unglazed depending on the material of the absorber plate. Glazed SACs recirculate the internal air of the building through a solar air glazed panel in which the air is heated and then directed back into the building. Unglazed SACs consist of a bolt-on dark-coloured metal absorber plate, through which ambient air outside the building is passed, before being drawn into the building to provide pre-heated fresh air for both ventilation and heating purposes. The most common applications of this technology are the transpired solar air collectors (TSC).

A TSC consists of an unglazed solar air system with a perforated absorber layer. Unglazed transpired solar air collectors (UTSC) use solar energy to heat the absorber surface, which transmits thermal energy to the ambient air (Fig. 2). The absorber surface is generally a metal sheet (usually steel or aluminium), which can be attached to the building facade. The contact surface between the metal skin and air is increased by drawing air through multiple small perforations in the solar absorbing sheet into the cavity between the skin and facade. The heated air is then drawn into the building to provide space heating.

A number of studies on the layout of UTSC perforations in the solar absorbing sheet have been conducted to evaluate heat transfer, efficiency, airflow distribution, and pressure drop. Leon and Kumar [9] developed a mathematical model to predict the thermal efficiency of a “bolt-on” UTSC over a range of different operating conditions. It was reported that the main factors affecting the heat exchanger effectiveness and air temperature rise ($\Delta T^\circ C$) were: (i) air flow rate (ms^{-1}), (ii) solar radiation (Wm^{-2}), and (iii) solar absorptivity (α) by the collector. Efficiencies of up to 65% were reported in this work. Gunnewiek [10] studied the flow distribution in UTSC using CFD simulations. Gawlik [11] studied the performance of low-conductivity unglazed, transpired solar collectors numerically and experimentally.

As an alternative to the UTSC, Othman [12] developed a “bolt-on” prototype solar drying system using back-pass solar collector (BPSC) technology and found that the controlled air flow could maintain the output temperature from the collector constant even if the solar radiation intensity varies to certain degree.

The integration of a BPSC into an insulated wall panel (see Fig. 3) has both on-site installation and aesthetic advantages over

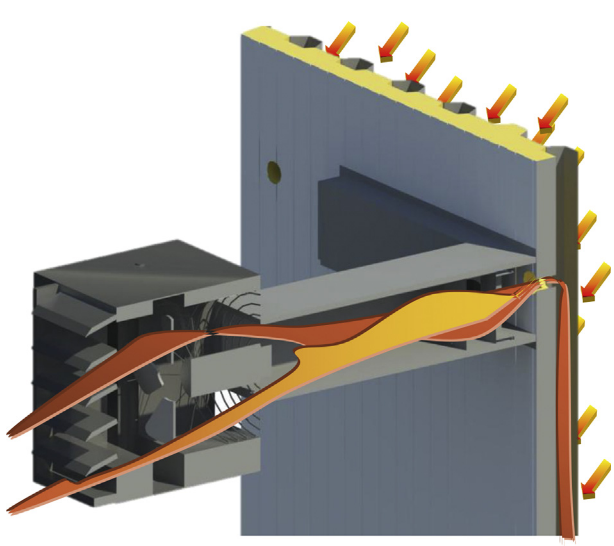

Fig. 1. Wall integrated solar air collector.

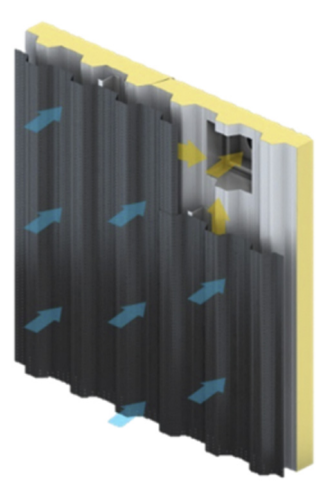

Fig. 2. Unglazed transpired solar collectors (UTSC).