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Building integrated solar air heating with waste heat utilization

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ABSTRACT

A novel waste heat utilization system, which consists of transpired solar collector panels and capillary tube heat exchanger, is studied; its function principle is described, and its experimental performance is presented for the first time. A test unit of capillary tubes was installed at the solar wall air heater at the factory of an automotive company in Turkey in 2012. Capillary tubes utilized waste heat energy which is obtained from heat recovery unit of an air compressor. Thermal power output, ambient temperature, temperature rise, collector cavity temperatures, and water supply temperatures were monitored over the course of two winters. The results showed that capillary tubes can provide 15 °C temperature rise during night-time operation. The heat exchange effectiveness in air cavity is found to be maximum 0.7. The results also show that waste heat energy utilization can reach up to 85% depending on operating conditions.

1. Introduction

Today the idea of building integrated energy solutions becomes more attractive for building owners especially when it comes to constructing vast buildings, such as factories, production complexes or other commercial buildings. Engineers and architects are constantly searching for new technical solutions to increase building energy efficiency. From thermal/photovoltaic solar walls to heat recovery systems, numerous systems are available on the market, but there is an increased need for new building-integrated technologies research and development projects. Building-integrated waste heat utilization is one of the methods which has become more popular recently in production facilities due to reduction of energy consumption. Industrial energy use efficiency can be significantly enhanced by better energy recovery, and integration has significant potential to reduce emissions at low cost [1]. Kampelis et al. analyzed the operational performance of industrial, residential and research/educational buildings, analyzed and optimized with the use of dynamic and quasi-dynamic simulation tools [2] and they showed that ventilation energy can be reduced significantly by using waste heat recovery. Thalfeldt et al. [3] studied the energy saving potential of mechanical supply and exhaust ventilation with heat recovery and exhaust ventilation with exhaust air heat pump for buildings in a cold climate. They found that system can covered the major needs of hot water. Weeber et al. [4] developed a methodological approach to assess energy saving potentials through an interconnection of different factory levels. They identified key areas for energy saving potentials such as on-site renewable energy production, energy storage and waste heat recovery. As stated by Gourlis and Kovacevic [5], ventilation and particularly infiltration rates are practically dominant factors regarding building envelope performance, yet for industrial buildings such rates are difficult to be determined and often require large-scaled equipment. D'Agostino et al. [6] reported [5] that one of the most applied energy efficiency measure is related to ventilation and cooling systems. The most common measure related to ventilation is heat recovery on ventilation plants while mechanical ventilation without heat recovery is assessed at 10%. According to D'Agostino [6], heat recovery plants can reduce energy consumption of HVAC systems, as they use heat exchangers to recover hot or cold air from ventilation exhausts and supply it to the incoming fresh air. Huang et al. [7] studied the performance of a novel heat recovery device designed to recover the heat that is released from the outer surface of heat pump compressors. Fiaschi et al. [8] presented a low temperature heat recovery network in industrial textile production facility. Tanczuk [9] studied waste heat recovery system in a sewage sludge dryer for industrial facilities. Kim [10] presented an economic study on energy saving technologies employed in a complex industrial building. It is found that energy saving technologies can save a total energy cost savings of 14%. Savings were achieved by using new heating, ventilation, and air conditioning technologies and lighting systems. On the other hand, fresh air ventilation can be responsible for a large percentage of facility complex heating load. Industrial ventilation is necessary for maintaining fresh air supply in the work area and dilution and removal of hazardous concentrations/contaminants of toxic materials in the air, as well as providing thermal comfort in the facility. Because of the wide-open plant areas and high

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Nomenclature

Abbreviations

c_p	specific heat capacity [J kg^{-1} °C^{-1}]
$\dot{m}$	mass flow rate [kg s^{-1}]
ΔT	temperature difference [°C]
$\dot{Q}$	heat transfer rate [W]
PP	payback period [years]
T	temperature [°C]

Subscripts and abbreviations

abs	absorber
col	collector
comp	compressor
con	convection
CT	capillary tube
cav	cavity
in	inlet
out	outlet
rad	radiation
sur	surroundings
w	water

Greek letters

ε	heat exchange effectiveness

ceilings solar air heating systems are used widely recently, particularly transpired solar air collector in industrial ventilation and energy savings [11–13].

In this paper, thermal performance of a large-scale building-integrated solar air heater with capillary tube heat exchanger, which utilizes waste heat energy from a compressor, is studied experimentally. Capillary tube integrated transpired solar collector was tested previously by Eryener and Akhan [14]. A small-scale test unit under laboratory conditions showed that capillary tubes can be successfully integrated in a transpired solar collector, especially to utilize waste energy at nighttime or at low solar radiation. Within this study, a large scale transpired solar collector with capillary tube heat exchanger is tested for real operation and weather conditions for the first time. The large-scale test unit of capillary tubes was installed at a building integrated solar wall air heater of an automotive company in Turkey in 2012. Main target of the large-scale test unit was testing thermal performance of overall system which utilizes waste heat produced by compressor unit. The thermal performance had been monitored for two years. Heat exchange effectiveness of the capillary tube heat exchanger at the air cavity and waste heat recovery from compressor were determined and the potential of the system was analyzed.

2. System design

2.1. Overview of the experimental facility

In this study, the transpired solar collector has been applied by an automotive company in Turkey for testing the performance of heat exchanger. As seen in Fig. 1, factory building comprises one multi-storied manufacturing facility with 770 m^2 of building-integrated solar air heater and six supply air handling units of fresh air. The facility has been continuously occupied since August 2012. The solar air heating system has been designed for the purpose of pre-heating ventilation/make up air, improving the air balance and comfort of the factory building, and it is the first transpired solar collector installation in Turkey [13]. The heat exchanger system has been designed for supporting solar heated fresh air by recapturing waste energy from compressor. Table 1 summarises the building's features, location and climate characteristics.

2.2. System description

To study the thermal performance of solar air heating with heat exchanger, an experimental system is installed in the factory building which is shown in Fig. 1. System has three main components: transpired solar collector, capillary tube heat exchanger and plate heat exchanger for heat recovery from the compressor. As shown in Fig. 2, when the solar radiation is not enough to heat incoming fresh air through transpired solar air heater, hot water is produced from the waste heat of compressor, enters capillary tube heat exchanger and it heats the incoming fresh air within solar air collector, thus, heat exchanger works as a supplementary heater for fresh air.

2.3. Capillary tube heating and transpired solar collector

The capillary tube heating system, also called capillary mats, is a conventional radiant heating system which is integrated into construction elements in its regular application for heating and cooling building. The radiant capillary heating systems require low water temperature, because of the larger heat transfer area [15]. The capillary radiant heating systems use water temperatures as low as 35 °C and it can be used for distributing the solar energy for building heating during winter [16]. Capillary micro tube integrated in high performance concrete walls can supply the energy for heating and cooling requirements, which is very suitable for heating and cooling purposes of future low energy buildings [17]. Capillary tube systems with heat storage materials are useful for low temperature solar hot water heating systems [18]. A solar-assisted capillary radiant heating system has been tested experimentally during winter season [19] and result show that solar capillary mats can provide an energy saving performance for heating office buildings. One the most important advantages of radiant capillary tubes are virtually non-existent noise [20]. The selection and assessment of capillary tubes is characterized for different type of radiant systems with dynamic thermal performance of radiant systems [21]. Internal wall surface temperature of a building can be neutralized from the outdoor conditions by using embedded capillary tubes [22].

The transpired solar collector (TSC) is a perforated solar wall also solar air collector, which is installed at 10–30 cm of distance onto the building's façade to heat ventilation air for buildings [23]. Kutscher

Fig. 1. Building-integrated solar heating systems in factory complex.