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ScienceDirect

Energy Procedia 95 (2016) 167 – 174

Energy Procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2015, 14-16 October 2015, Riga, Latvia

Validation of unglazed transpired solar collector assisted air source heat pump simulation model

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Abstract

Due to the rising demand for high comfort standards and efficient energy use, heat pumps and solar technologies have drawn a great deal of attention as means through which significant energy reductions can be achieved . During the last decade, a number of investigations have been conducted on the design and modelling of different heat pump systems. This paper examines the performance of a solar assisted air source heat pump (ASHP) system for cold climate. The study compares the operation of a stand-alone ASHP against the solar assisted ASHP. The experimental measurements are used to test the performance of the ASHP system in different operating conditions. In addition, using TRNSYS (Transient Systems Simulation) software, simulation models were developed. The simulations using TRNSYS are compared to experimental data. Validation results for system modes of operation are included which demonstrate good conformity between model and experimental performance.

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.

Keywords: air source heat pump; unglazed transpired solar collector; COP; TRNSYS; simulation; model validation

1. Introduction

Various heat pump systems provide sustainable and efficient solutions to provide energy for space heating or cooling and domestic hot water in buildings [1]. There are millions of such systems installations worldwide and any improvement in heat pump systems, their operation and maintenance can save a considerable amount of energy, cost, and reduce global CO_2 emissions [2, 3]. Air source heat pumps (ASHPs) are widely applied as an economic

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Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.
doi:10.1016/j.egypro.2016.09.039

form of heating [4]. However, one of the largest problems in ASHP systems is evaporator frosting, and the subsequent need for defrosting at low ambient temperatures and high humidity. Frost formation on the outdoor heat exchanger of an ASHP occurs when the surface temperature is both below the dew point of the moist air and the freezing point and periodic defrosting is necessary [5].

The frosting-defrosting process causes significant problems (reduced energy efficiency, increased pressure drop on air-side and heating shutdown) [6–9]. Different solutions to delay frosting and improve defrosting efficiency were proposed (system with integrated solid desiccant, reverse-cycle defrosting, electric heating defrosting, hot water spray, etc.) [3, 8–11]. Reverse cycle defrosting is currently the most widely used defrosting method [3, 11]. The energy used for reverse cycle defrosting comes from three sources: the input power to compressor, the input power to indoor air fan and the thermal energy from indoor air [11]. The energy consumption due to the defrost cycles should be considered in calculating the heat pump performance. However, the calculation methods proposed by the European standards ignore this effect [8, 12].

Many studies report on the performance of the ASHP system under frosting conditions [3–7, 10–13]. The energy efficiency of ASHP systems can be increased by not only optimizing the operational parameters of existing systems but also by integrating new elements into such system or looking for new technical solutions. Cabrol and Rowley [13] suggested a floor-embedded heating system coupled to a modern ASHP that could reduce running costs and CO2 emissions. Touchie and Pressnail [14] presented the operation of an ASHP in thermal buffer zone created by an enclosed balcony space. Such solution can improve the coefficient of performance (COP) in cold temperatures. Kamel and Fung [15] developed a TRNSYS model to integrate a photovoltaic/thermal collector in a roof and coupled it with ASHP. This suggestion enables a highly efficient heating system in winter conditions.

Despite the large number of studies on the performance and technical solutions of an ASHP system, defrosting causes the periodic interruption of outdoor heating and degradation in winter heating efficiency. Therefore, this study suggests the idea of solar assisted ASHP to prevent the heat pump from frosting. Unglazed transpired solar collector (UTSC) technology is integrated with ASHP. Although UTSC is a relatively new development in solar collector technology, it can serve as an energy saving measure in building engineering systems [16]. The aim of this work is to determine the performance benefits of operating an ASHP with UTSC. TRNSYS simulation software is used to model the operation of ASHP and integrated system of ASHP with UTSC. Simulated results are compared with experimental data gathered in the Laboratory of Building Energy and Microclimate systems (BEMS) in Vilnius Gediminas Technical University. The results from this study could be used to improve the operation process of the ASHP system.

Nomenclature

COP	coefficient of performance	$X_{measured}$	measured value
c_p	specific heat capacity of fluid, kJ/(kg·K)	$X_{simulated}$	simulated value
I	electrical current, A		
t	temperature, ºC	*Greek letters*	
t_{in}	fluid temperature at the inlet, ºC	Δ_{curr}	deviation at current time step
t_{out}	fluid temperature at the outlet, ºC	$\Delta_{\max}$	maximum deviation
U	voltage, V (230 V)	ρ	fluid density, kg/m^3
$\dot{V}$	volumetric flow rate, m^3/h	τ_{period}	time period, min
WRMSE	weighted root mean square error	$\cos(\varphi)$	power factor (0.82)

2. Systems description

Analyzed systems are used in the BEMS Laboratory in Department of Building Energetics of Vilnius Gediminas Technical University. This laboratory (113 m^2) is equipped with a number of renewable energy technologies and equipment which use renewable energy. An air-to-water heat pump (HP) as well as UTSC are used for heating of laboratory [16]. Fig. 1 illustrates the systems used in experiments.