Energy and Buildings 113 (2016) 133–138

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A novel roof type heat recovery panel for low-carbon buildings: An experimental investigation

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ARTICLE INFO

Article history:
Received 24 November 2015
Accepted 13 December 2015
Available online 25 December 2015

Keywords:
Buildings
Polycarbonate
Heat exchanger
Waste heat recovery
Efficiency

ABSTRACT

Energy saving and its efficient utilization is of prime interest in today's world due to the limited energy resources and growing significance of environmental issues. Despite the intensive efforts to narrow the gap between conventional energy sources (wood, coal, gas, oil, etc.) and renewables, renewable energy resources currently supply only about 14% of total world energy demand. In this regard, energy management and optimization are considered compulsory as much as the clean energy generation. Recent works indicate that the buildings play a significant role on global energy consumption. They are responsible for about 40% of global energy demand. Among the different building types, domestic buildings have the largest share with 63% and most of energy is utilized for heating, ventilation and air conditioning (*HVAC*) systems in those buildings. Energy consumption levels of buildings can be notably reduced through waste heat recovery in *HVAC* systems. There are several attempts in literature addressing the possibility of decreasing energy consumption of buildings via waste heat recovery technologies. The heat recovery technologies are cost effective and user friendly applications. The use of heat recovery systems aims at mitigating the energy consumption for *HVAC* applications as well as the greenhouse gas emissions, and hence decreasing the adverse effects of global warming on the Earth. It is well-documented in literature that the heat recovery systems are very promising for domestic applications. In this paper, experimental results of a novel heat recovery system developed for low-carbon buildings are presented. The proposed heat recovery system consists of a plate-type heat exchanger, blower fans and ducts. The parallel-flow arrangement is used to run the system. The system is designed as under roof application. The aim of the system is to recover waste heat and to preheat fresh air using stale air. The experiments of the system are carried out in winter season in Kent, UK. The study aims to investigate the coefficient of performance (*COP*) of the system as well as the heat recovery efficiency. The results show that the heat recovery efficiency of the proposed system is around 89% while the *COP* is 4.5. The proposed system can be used in both winter and summer conditions without requiring additional work. Its labor cost is extremely low, so it is cost-effective and user friendly.

1. Introduction

Ventilation constitutes a significant part of total energy consumed in buildings as a consequence of rising thermal comfort levels of occupants. In this point, good insulation of building envelope is crucial to reduce heating and cooling loads. It is reported in literature that even well insulated and tight buildings consume about 60% of total annual energy demand for *HVAC* [1–3]. However, roughly 20–40% of the overall energy consumption of *HVAC* system is utilized for the ventilation air conditioning purposes in most of the commercial building sector [4]. That is why the building sector is responsible for the major energy depletion worldwide and this issue is rising continually [5]. It is clearly underlined in literature that it is possible to make a significant contribution to mitigate the energy consumption of buildings by using heat recovery technologies along with the insulation. Heat recovery technologies are in fact user friendly and cost effective for buildings with insignificant maintenance issues. Besides, the heat recovery technologies are up-and-coming for further developments and the importance of

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http://dx.doi.org/10.1016/j.enbuild.2015.12.024

Table 1
Space heating requirement in multi-family building [10].

Case	Heating requirement[a] (kWh/m^2)
Before renovation	80
After renovation	46
After renovation, assuming 90% heat recovery	19

[a] 20 °C indoor set-point temperature, internal gains of 5 W/m^2 normal Danish climate conditions are assumed.

energy recovery applications is increasing continuously [6]. Energy is used to cover the heat losses due to the ventilation air and to move the ventilation air for mechanical ventilation [7]. It is reported that the ventilation heat losses can reach 35–40 kWh/m^2 a year in residential buildings, and 80–90% of this can be recovered [8]. Mechanical ventilation systems can meet the energy requirement for ventilation via recovering waste heat to mitigate heat losses and energy use [7,9]. Space heating requirement before and after renovation is illustrated in Table 1 [10].

Heat recovery systems are widely studied by numerous researchers both theoretically and experimentally. For instance, Hviid and Svendsen [11] investigate the heat recovery efficiency of a liquid coupled heat exchanger. Their results indicate that, the heat exchanger efficiency changes between 64.5% and 75.4%. Another empiric study reveals that it is possible to achieve 8% of energy saving when membrane based heat recovery system is used rather than conventional *HVAC* in humid climatic conditions [12]. An experimental investigation of an air-to-air heat recovery unit equipped with a sensible polymer plate heat exchanger for balanced ventilation systems in buildings is conducted by Fernandez-Seara et al. [13]. The results reveal that the thermal efficiency of the system is 80%. It is also found that the heat transfer rate in the heat exchanger linearly decreases when the inlet fresh air temperature increases. In another study, Zhang et al. [14] use an air dehumidification system combined with membrane based enthalpy heat exchanger and the simulation results demonstrated that 33% of primary energy saving is achieved. Table 2 shows the total economic savings after implementation of a mechanical ventilation system. Gong et al. [15] experimentally investigate a new heat recovery technique and the test results indicate that the system has relatively large coefficient of performance (*COP*) around 6. Use of the passive and low energy systems in residential buildings provides to maintain the thermal comfort of the dwelling with the cheapest way [16]. In this paper, an experimental study of a novel heat recovery unit is presented in detail. The efficiency, practicality, reliability and sustainability of the system are discussed.

2. Description of the system

The system that is presented here aims at cooling or heating the stale air from indoor environment to be able to reduce or increase the temperature of intake fresh air in the counter-flow heat exchanger as it is seen in Fig. 1. Moreover, polycarbonate shows good chemical resistance to mineral acids, organic acids, greases and oils [17]. Its service temperature is the range of −4 to 135 °C which is suitable for *HVAC* applications. In the proposed heat recovery system, the polycarbonate sheet has been used to generate a heat exchanger because of its lightweightiness and cost effectiveness. A multi-channel heat recovery plate internally places under the roof of the test house as seen in Fig. 2. The system is well insulated both internally and externally to prevent the unwanted heat loss. The test house externally has 7 m length, 3 m width and 4.3 m height. It has two windows plus a velux window on the roof and a double door all double glazed. The walls, the roof and the floor have 150 mm mineral wool insulation. Four polycarbonate heat exchanger sheets have been constructed. Two of them have been placed at the front of the building while the rest

Table 2
Total economic savings after implementing a mechanical ventilation system with 90% heat recovery, air changer rate of 0.5 h^{-1} and an electricity consumption of 3 kWh/m^2 [10].

Reference system	Construction expenses (€/m^2)	Predicted savings over 30 years (€/m^2)			
		I1[a]	I2[a]	B1[a]	B2[a]
Energy price (€/kWh)		0.08	0.16	0.08	0.16
Real interest rate (%/a)		2.5	2.5	0	0
Natural (single-family house)	40	−26	19	3	67
Natural (residential block)	18	13	57	35	98
Exhaust only (residential block)	7	40	91	63	137

[a] Scenario.

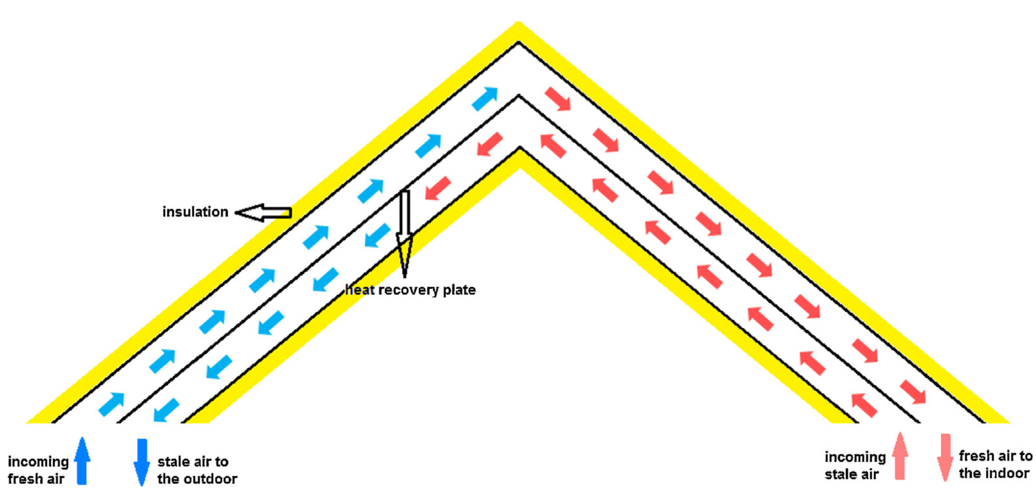

Fig. 1. Schematic of the heat recovery system.