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Investigation of prototype thermoelectric domestic-ventilator

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ABSTRACT

Applications of thermoelectrics had been enlarged from conventional single refrigeration or generation to waste heat recovery with tough energy consumption of the world. With improvement of living standard more and more domestic air-conditioners are used in Chinese families now. Percentage of power consumption of domestic air-conditioner caused by heat load of fresh air supply increased after SARS, which could be prevented efficiently with sufficient fresh air supply, broke out in China in 2003. A novel prototype thermoelectric domestic-ventilator with heat recovery of exhaust of air-conditioned room had been made in Hunan University thermoelectric lab. A thermoelectric heat exchanger and a flat-fin cross flow heat exchanger were integrated in this ventilator. This ventilator was investigated and its cooling (and heating) performance were evaluated in terms of the coefficient of performance, cooling and heating powers, and being handled temperature difference of fresh air. The coefficient of performance of this ventilator was found to be over 2.5 in the whole experiment. The optimal working parameters of this ventilator were studied in this paper. The potential improvements in performances and market prospects were also discussed in this work.

1. Introduction

The technology of thermoelectricity began during the World War Two when Soviet Union, under the Academician Ioffe's inspiration, produced 2–4 watt thermoelectric generators to be capable of powering a small radio from a small cooking fire [1]. Thermoelectric generation had been employed for NASA missions on the moon and the Mars, also found in the nuclear-powered thermoelectric cardiac pacemaker battery [2,3]. Thermoelectric refrigeration had been employed in various cooling applications of small-volume devices, typical of which were to stabilize the temperature of solid-state lasers, to cool infrared detectors and charge-coupled devices, and to increase the operating speed of integrated circuits [4–6]. During recent decades, due to major factors: increasing awareness of the deleterious effect of global warming on the planet's environment, a renewed requirement for long-life electrical power sources, substantial progress had been made in employing thermoelectrics as an environmentally friendly method of recovering industrial waste heat [7–10] and automobile waste heat of engines and exhaust [11–13].

Following development of China's economy, its energy consumption had been very intensive. For example, domestic air-conditioners had been widely used in Chinese families. Power consumption of domestic air-conditioners had been a big part burden for China's power supply. Further more, power consumption of air-conditioner caused by heat load of fresh air supply couldn't be neglected. Especially, it was proved that sufficient fresh air supply could be an efficient way to prevent SARS outbreak.

Fresh air supply of air-conditioned room in China had been solved by simply opening window or ventilating through ventilators with passive heat recovery. The first way resulted heat loss of air-conditioned room. The latter way was high energy efficiency. However, thermal comfort of being handled fresh air was hardly close to indoor ambient in this way for its passive heat recovery limited by thermal parameters of fresh air and exhaust.

Thermoelectric application in this field could be competitive for its novel character. When a direct power supply was connected with the thermoelectric modules, a hot side and a cold side could be set simultaneously. As being a cooler, the hot side was negative effect. In application of thermoelectric ventilator, cold exhaust could weaken its negative effect in summer and cooling performance could be enhanced at the same time. In winter, as being a heater, the cold side could be used to recover heat of exhaust. Under thermoelectric ventilator's active heat recovery, fresh air could be handled close to indoor air thermal parameter in high energy efficiency.

So a novel concept of domestic thermoelectric ventilator had been studied and tested. In this study, a prototype thermoelectric ventilator had been constructed based on commercially available ventilators. The objectives of this study were intended to provide an evaluation of energy efficiency and market prospects of thermoelectric ventilator and to identify areas for further improvement.

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Nomenclature

Q_c	cooling rate of thermoelectric module (W)	P_f	power consumption of fans (W)
Q_h	heating rate of thermoelectric module (W)	P_t	power consumption of thermoelectric modules (W)
α_{ab}	seebeck coefficient for a module	G_1	fresh air volume (m^3/h)
T_c	cold side temperature of thermoelectric module (K)	i_1	enthalpy of fresh air before being handled (KJ/KG)
T_h	hot side temperature of thermoelectric module (K)	i_2	enthalpy of fresh air after being handled (KJ/KG)
I	electrical current (A)	ΔT	temperature difference (K)
R	electrical resistance (Ω)	COP	coefficient of performance
K	thermal conductance (W/K)		

2. Prototype

This thermoelectric ventilator was composed of two centrifugal fans, a flat-fin cross flow sensible heat exchanger made of aluminium, air duct, a thermoelectric modules heat exchanger made by thermoelectric modules and flat-fin heat sinks made of aluminium. The overall dimension of heat sink was 120 × 120 × 13 mm with 18 fins. The dimensions of the fins were 120 × 12 × 1 mm. The overall dimension of the flat-fin cross flow sensible heat exchanger was 120 × 120 × (13 × 8) mm. The overall dimension of the thermoelectric modules heat exchanger was 120 × 120 × (13 × 8 + 3.8 × 3) mm. Different from market available ventilators with passive heat recovery, this ventilator was integrated with a flat-fin cross flow sensible heat exchanger and a thermoelectric modules heat exchanger to enhance heat recovery from exhaust. As a domestic application, this ventilator should be compact enough to match Chinese's small apartment. So, how to optimize this ventilator's structure and meet the basic requirement of ventilation had been paid more attention. This ventilator's overall dimension was 400 × 310 × 260 mm.

As shown in Fig. 1, a cross flow sensible heat exchanger and a thermoelectric modules heat exchanger had been made in cubical shape separately. They were placed as shown in Fig. 1. Air tunnel of intake and outlet were connected by air ducts. With this placement, condensed water from air could be collected and the ventilator's pressure loss could be lessened. The thermoelectric modules heat exchanger's performance was determined by its construction directly. Reducing of contact resistance and cold bridge were focused. Thermal conduct grease was filled in the contact surface of modules and sinks. Screw bolts with thermal insulating casing were used to connect heat sinks and modules as a whole. Thermal insulating material was filled on the surface of the thermoelectric heat exchanger. Thermal insulation was Armaflex with 5 mm thick and a conductivity of 0.03 w/m.k.

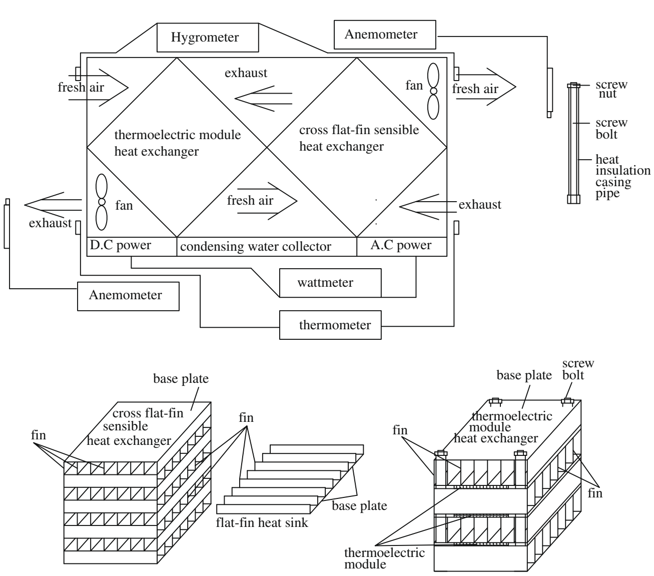

Fig. 1. Schematic of thermoelectric domestic-ventilator.

As a ventilator, ventilating volume was an important work parameter. Being a household application, three people's family was considered here. According to basic healthy specification that everyone needs 20 m^3/h in an air-conditioned room, air volume of this ventilator ranges from 70 to 60 m^3/h.

Compact profile dimension of the ventilator meant pressure of fans could be wasted to overcome system resistance. Fans could hardly reach theirs standard gauge values. Two centrifugal fans with high pressure were chosen here, with standard gauge values: 120 m^3/h, 140 Pa, 58 W, 0.16 A, 2000 r/min, 50 db.

Thermoelectric modules used in this study were manufactured by Hualeng, China [14]. Size of thermoelectric modules was 40 × 40 × 3.8 mm, with 127 thermoelectric couples of bismuth telluride and ceramic surface, type of TEC12706. There were 10 TEC12706 modules used here. Every two modules were in serial as a team and five teams were in parallel as a whole.

D.C power supply's voltage ranged from 0 to 24 V, with maximum power output 240 W, size of 199 × 110 × 50 mm. Its ripple coefficient of voltage was less than 1%.

3. Experimental methodology

Two hot ball anemometers (range: 0–10 m/s, accuracy 0.05 m/s) were used to measure the air velocity, which were located in the outlet of fresh air and exhaust, respectively. From collected data, it can be found that air volumes of fresh air and exhaust were the same for the symmetry of both air tunnels placement. Both fans was connected with an adjustor of velocity, which was used to change the air volume from 70 to 60 m^3/h.

Two thermocouples thermometer of type TM-902C(range: −50 to 130 °C, accuracy ±1 °C), located in outlet and inlet of exhaust, were used to measure its changes of temperature.

Two hygrometers of type TES-1360(range: −20 to 60 °C, 10–95%, accuracy ±0.8 °C, ±3%), located in outlet and inlet of fresh air, were used to measure its changes of temperature and relative humidity.

A wattmeter of type JB2170-77(range: 0–1500 watt, accuracy ±5 watt) was used to measure power consumption of thermoelectric modules and centrifugal fans.

The experiment of this study included the winter part and the summer part. The instrumentation's distribution of sensors for temperature, relative humidity, air velocity, and power output was shown in Fig. 1. In each part of the test, in order to find optimal air volume and voltage of the thermoelectric modules, ventilator's performances were compared, respectively. The air volumes were set in turn from 70(hi), 65(me), to 60(lo) m^3/hour and fans' power consumption were from 60, 45, to 30 watt. The voltages of the