

Experimental Study on Thermoelectric Heat Pump for Energy Recovering and Local Heating in Buildings

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Abstract: The characteristic of building energy flow was analyzed. A thermoelectric (TE) heat pump is compatible with the energy flow of buildings in the aspects of space distribution and temperature range; it is a practicable way of local heating, especially supplying hot water. Experiments verified that a TE heat pump system is more efficient than an electrical heating device, for its heating coefficient reaches 1.6~5.5. For a practical engineering, some measures had to be adopted to meet the temperature demand and the quantity balance between applicable waste heat and heat demand in winter, such as heat pump cascade, auxiliary heating and heat storage.

Keywords: TE heat pump, temperature difference, energy recovering, energy efficiency

0. INTRODUCTIONS

Recently, new materials and synthesis techniques have reawakened interest in the use of thermoelectric (TE) technology^[1,2]. An increasing number and variety of promising TE products have been reported for specific applications in military, aerospace, instrument, biology, medicine and industrial or commercial fields^[3-6]. While being utilized for heating, a TE heat pump is an economizing device with relatively high efficiency in comparison with a resistance-heating device, especially on suitable temperature conditions^[7]. Some TE heat pump devices have been developed such as clothing dryer^[8], water heater^[9], and incubator^[10]. As environment protection and energy conservation are becoming the prior subjects for the sustainable development of societies, investigations on concerned technologies are in the ascendant. TE heat pump devices are extremely simple, have no moving parts, and use no greenhouse gases. It is of great practical interest in building energy efficiency, utilizing low-grade waste heat, supplying hot water, and local heating.

1. ANALYSIS OF BUILDING ENERGY FLOW

While energies are consumed largely in buildings, waste heat rejects intensify the *heat islands* of cities. Although a variety of energies are consumed in different forms, they are all rejected by means of air exhaust, water discharge and heat conduction through envelope. The energy consumption and release of buildings present some characteristic s as follows:

- (i) Centralizing and dispersing distribution co-exist, and the spots where energy are consumed are often near the spots where waste heat release.
- (ii) Utilizing and releasing are probably or absolutely simultaneous, which also present some periodicities.
- (iii) Energy levels are mainly low grade, and near in different phase of energy flow, and the temperatures of air exhaust or water discharge are often near room temperature.
- (iv) The pollution and corrosion to the heat exchangers resulting from air exhaust and water discharge are seldom very serious, except for

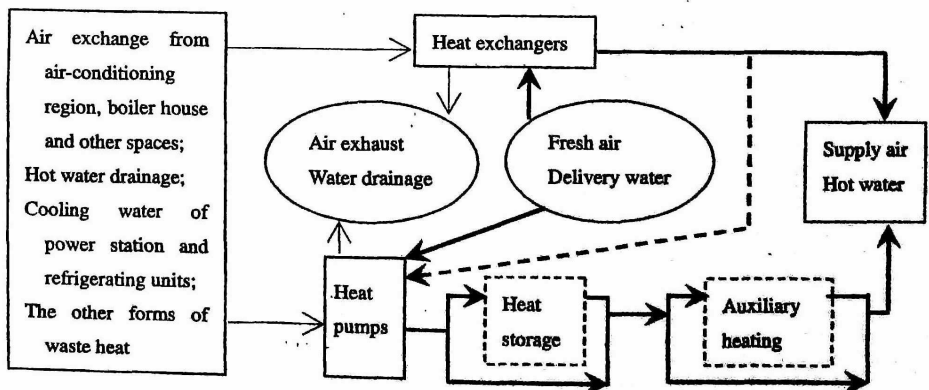


Fig.1 Schematic diagram of building energy recovery

situations of energy recovering in the hospitals, and some special factories.

Presently, the approaches of energy recovering in buildings are generally classified as two sorts by equipments, namely via heat exchangers or heat pumps, as illustrated in Fig.1. Water delivery can be pre-heated by waste heat reclaiming from cooling water or other water discharge with high temperature, and fresh air of air-conditioning can exchange heat with exhaust air. Water delivery and fresh air can also be heated by heat pumps, which extract heat from air exhaust or water discharge. Heat storage, reheating and auxiliary heat source should be considered to meet the temperature demand of water delivery because energy utilization may be inconsistent with waste heat release in time or space distribution. The performance of a heat pump would considerably decrease if supplying water were directly heated to 50~60°C or more in winter. In Fig.1, thin arrows mark the flow paths of air or water discharge, and thick arrows mark delivery paths. Real and broken lines respectively indicate indispensable and selective paths.

2. EXPERIMENTAL STUDY ON A TE HEAT-PUMP

There is no intrinsic difference between a TE refrigerator and a TE heat pump, except for different utilizations. The half Joule heat transferring to the cold end will counteract a fraction of cooling capacity, while the half Joule heat transferring to the hot end will add to the heating capacity, so a TE device is more efficient while being utilized as a heat-pump than as a refrigerator.

We should make great efforts on three aspects to improve the performances of a TE heat-pump, i.e. (i) to gain high figure of merit (Z), (ii) to reduce the junction temperature difference ($\Delta T = T_h - T_c$), (iii) to raise the running temperatures (T_h and T_c) suitably.

An important parameter of thermo-elements is the figure of merit Z , which synthetically characterizes the TE material's thermal and electrical properties. Up to now, the range of Z is $1.5 \sim 3.0 \times 10^{-3} \text{K}^{-1}$ for practical applications. While ΔT is less than 50°C, the heating coefficient reaches 1.5~7.0, which means that the heat rejection of a TE heat pump equals 1.5~7.0 times of a electrical heating device. More over, the heating

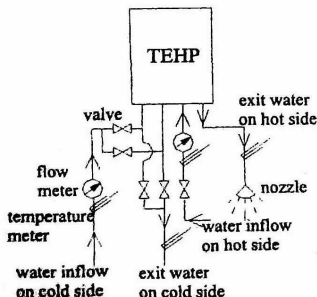


Fig.2 Experimental testing system of a TE heat pump

coefficient of a cascade TE heat pump can increase further^[6].

A TE heat pump is compatible with the energy flux of buildings in the aspects of space distribution and temperature range, so it may be utilized for energy recovering and local heating, such as supplying hot water, drying clothing.

A TE heat-pump testing system was established for experimental investigation, as illustrated in Fig.2. TE modules are sandwiched between heat exchangers manufactured from a type of special shape aluminum. Configurations of heat exchangers are alike on hot and cold sides. Tests consist of 3 groups with different parameter variations, namely: (i) flow rate of heat medium; (ii) temperature difference between heat mediums; (iii) input power. We controlled the temperatures of heat mediums below 55°C to meet the temperature demands of supplying water and to fit in with the operating temperature range of commercial single-stage TE modules. Further details concerned are discussed in reference^[11].

Fig.3 illustrates TE heat-pump heating performance (COP) with respective variations of flow rate on hot or cold side (G_h , G_c). Flow rates on cold or hot side (G_c , G_h) are correspondingly fixed to 5 l/min or 3 l/min respectively, so Fig.3 represents 4 subgroups of test data. The initial temperatures of heat mediums on two sides were the same and shown in legends of the figure, as well as the power inputs of different subgroups.

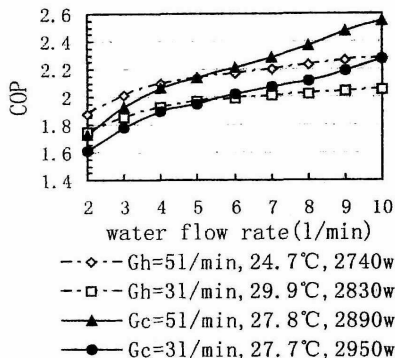
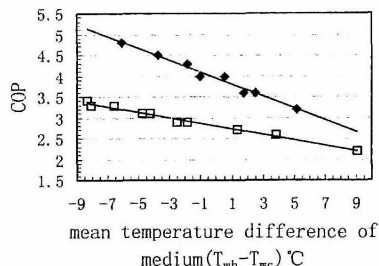


Fig.3 TE heat-pump performances with flow rate variations of heat mediums

Increasing flow rates intensified the heat exchange between exchangers and mediums, and the TE heat-pump performance turned better further. Since heat-flux on hot side is $[COP(COP-1)]$ times of the value on the cold side, variation of flow rates on hot side influence the TE heat-pump performance more noticeably than the case on cold side.

Fig.4 displays TE heat-pump performance (COP) with variations of the mean temperature difference between heat mediums ($T_{wh} - T_{wc}$) on two sides. The flow rates of heat mediums on two sides are both fixed to 6 l/min. The initial temperatures of heat mediums on hot side (T_{hi}) and the power inputs (P) of different

subgroups are presented in legends.



◆ Thi=15.5°C, P=840W □ Thi=16°C, P=1860W

Fig.4 TE heat-pump performances with variations of the mean temperature difference of heat mediums ($T_{wh}-T_{wc}$)

Increasing mean temperature difference of heat mediums ($T_{wh}-T_{wc}$) results in linearly decreasing COP, and the decreasing trend is more remarkable in the case of less power input than in the larger power input. The TE heat pump is more efficient in low load than in high load, however, the relative variation of junction temperature difference (T_h-T_c) is larger in the former case than in the latter case.

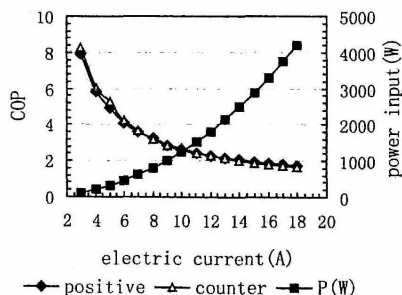


Fig.5 Performance comparisons between positive and counter current

Fig.5 presents the TE heat-pump performance (COP) comparisons between cases of positive and counter current of TE modules. The power inputs are also shown with current variations.

Exchanging relative current direction results in reverse polarity of TE effect, but brings no distinct effect on TE heat-pump performance because heat exchangers on two sides are similar. Increasing power input causes decreasing COP, and the decreasing trend is more remarkable in the case of less power input than in the case of larger one.

3. PROBLEMS NEED TO BE SOLVED IN PRACTICAL HEATING UTILIZATIONS

The heating coefficient of a TE heat-pump reached 1.6~5.5 if the temperature difference of heat mediums was limited in the range of -10~15°C. In comparison with an electric heating device, a TE heat pump is more efficient, which brings new ideas on local heating, utilizing low-grade waste heat and energy saving in buildings. But some problems need to be solved in practical heating utilizations.

In summer, the most available and abundant heat source is cooling water of air conditioning systems, while in winter, it is mainly the waste water from kitchen, boiling room, transformer substation, power station, washing room, and so on.

The heat rejection of a refrigerating unit is (1+COP) times of the power consumption, and it could be some times of energy consumption of hot water for commercial buildings such as hotel, hospital, marketplace and apartments. The temperature of cooling water is 35~37 °C or so, supplying water can be heated to 40~55°C by a TE heat pump devices which extract heat from cooling water. This technique eliminates heat pollution to environment, and it further saves the investment cost of boilers.

Water storage ponds should be constructed for wastewater and delivery water respectively to meet the balance between available waste heat and heat demand. The demand of hot water fluctuates with time, so a smaller scale TE heat pump system should be selected to decrease investment cost, and an auxiliary heater should also be set to make up heat demand. The performances of a TE heat pump would decline if delivery water were directly heated to 40~55°C in winter, so the heat pump should be cascaded to meet the temperature demand in such situations.

4. DISCUSSIONS

Some measures of heat recovering can improve the performances of a TE heat pump considerably. The most feasible approach is heat recovering from wastewater. Firstly, if heat mediums on two sides were water, the TE heat pump system would be compact, and its investment cost could be decreased further. Secondly, water can be easily collected and stored, and the utilization ratio of devices is further high.

If wastewater could be used as heat reservoir on the cold side, and delivery water as heat sink on the hot side, the mean temperature difference of heat mediums would be very less, and the performances of a TE heat pump may be improved remarkably.

Since the operating temperature range of the most commercial single stage TE modules is -150~80°C, the TE modules would be damaged by thermal stress if their operating temperature is too high or low. As all the physical properties of the TE material are dependent on temperature, the module's performance is temperature dependent and increases with temperature over the operating hot junction temperature range, 123K(-150°C) to 353K(+80°C). The maximum parameters at an optimum hot junction temperature of T_h (K) can be estimated roughly from following equations; the subscript of 300K indicates the parameter based on hot junction temperature at 300K(+23°C)^[12].

$$(\Delta T_{\max})_{T_h} = 67 + 0.4(T_h - 300) \quad (1)$$

$$(\dot{Q}_{c,\max})_{T_h} = (\dot{Q}_{c,\max})_{300K} + 2.0(T_h - 300) \cdot G \cdot N \quad (2)$$

24% increase of the maximum refrigerating capacity and 29% enhancement of the maximum temperature difference can be reached when the hot junction temperature rises from 0 °C to 60 °C. Compared to conventional TE cryogenic coolers, the performance of the system described as Figure 2 can be improved considerably because the operating temperature of thermo-elements is higher. In the present investigation, the temperature of hot water was below 55 °C, and the hot junction temperature was below 67.3 °C.

It is surveyed that energy consumption of heating water accounts for a remarkable proportion of the total value of building energy consumption in China, specifically, 2.7% to office buildings, 10.7% to shopping centers, 31% to hotels, 41.8% to hospitals and 20% to apartments [13]. Since technologically consuming electric or gas water heaters are essentially *high-grade kettles* with unsatisfactory efficiency and other defects, developing heat-pump water heaters may be an approach to increase the energy efficiency of heating water. A TE heat-pump water heater presents distinctive advantages of reliability, high efficiency, no pollution, and so on.

The temperature drops of hot water due to shower have been tested in typical bathroom in Changsha at different climate temperatures of 6 °C, 10 °C, 15 °C respectively. The flow rate was 6 l/min, and temperature was $(42 \pm 1)^\circ\text{C}$ before shower, while water temperature was still $(35 \pm 1.2)^\circ\text{C}$ after shower, and the ratio of heat loss by drainage was about 80%.

The above data suggest that the potential of heat recovering from wastewater is considerable. It is of great significance to apply TE heat pumps to local heating, such as supplying hot water, drying clothing.

5. CONCLUSIONS

A TE heat pump is compatible with the energy flow of buildings in the aspects of space distribution and temperature range, so it may be a practicable way of energy recovering and local heating in buildings.

The heating coefficient of a TE heat-pump reached 1.6~5.5 if the temperature difference of heat mediums was limited in the range of -10~15 °C. Some measures of heat recovering can improve the performances of a TE heat pump considerably.

Some measures, such as heat storage, cascade heat pump and auxiliary heater, should be adopted for practical utilizations to meet the temperature demand, and to meet the balance between available waste heat and heat demand.

NOMENCLATURE

G: the geometric factor of thermo-elements (m);
N: the number of the TE couples of a TE module;
 $Q_{\max,h}$: the maximum heating capacity of a TE heat-pump(W);
 T_c : the temperature of the cold junctions (K);
 T_h : the temperature of the hot junctions (K);
Z: the figure of merit (K^{-1});
 $\Delta T_{\max}$: the maximum junction temperature difference of thermo-elements (K)

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