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Theoretical study of a thermoelectric-assisted vapor compression cycle for air-source heat pump applications

Lin Zhu*,Jianlin Yu

Xi'an Jiaotong University,China

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xjtulinda@gmail.com

Introduction and Background

Air-source heat pump water heaters (AHPWH) is an attractive saving technology in either domestic hot water or space heating applications. [Hepbasli and Kalinci, 2009; Bourke and Bansal, 2010]

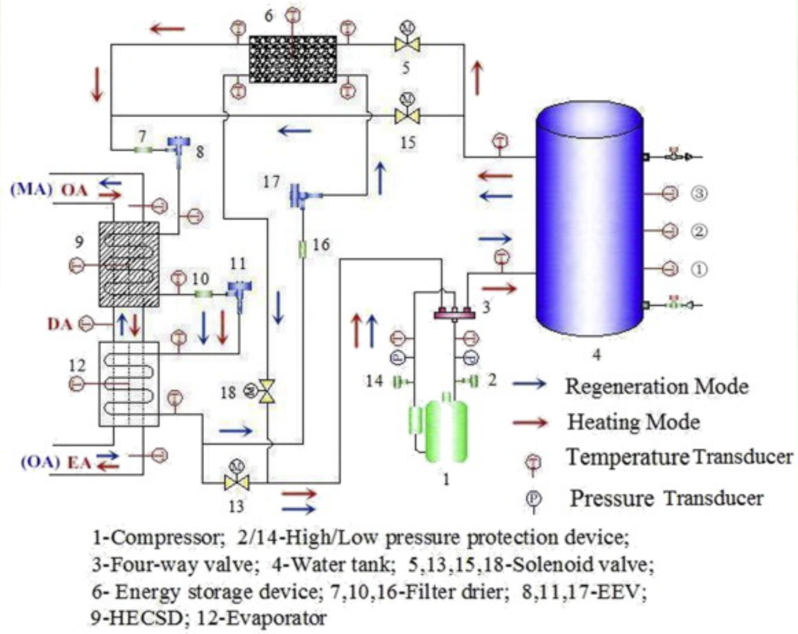

Fig.1 Schematic diagram of the novel frost-free ASHPWH system

But:

Under a low ambient temperature condition, heating capacity and COP will degrade [Bertsch and Groll, 2008]

Introduction and Background

Previous work has shown:

- Refrigerant injection technique, ejector enhanced heat pump systems have potential for improving the heating performance of AHPWH: Heo et al., 2011; Chua et al., 2010; Wang et al., 2009

- Multistage and hybrid heat pump systems can enhance the overall system energy efficiency

  -Dual source coupled systems : Lazzarin, 2012
  - Compression/absorption heat pump systems: Satapathy and RamGopal, 2008

Introduction and Background

- Thermoelectric cooling systems can combine with vapor compression to improve the overall system efficiency :Schoenfield, 2012; Okuma, 2012; Sarkar, 2011; Vián and Astrain , 2009.

- At a smaller operating temperature difference , thermoelectric coolers can provide higher efficiency.

Objectives

Develop a thermoelectric-assisted vapor compression cycle (TVCC) system to improving the heating performance of the AHPWH.

-Investigate the heating performance of the TVCC.

-Compare with that of a basic vapor compression system (BVCC).

Method

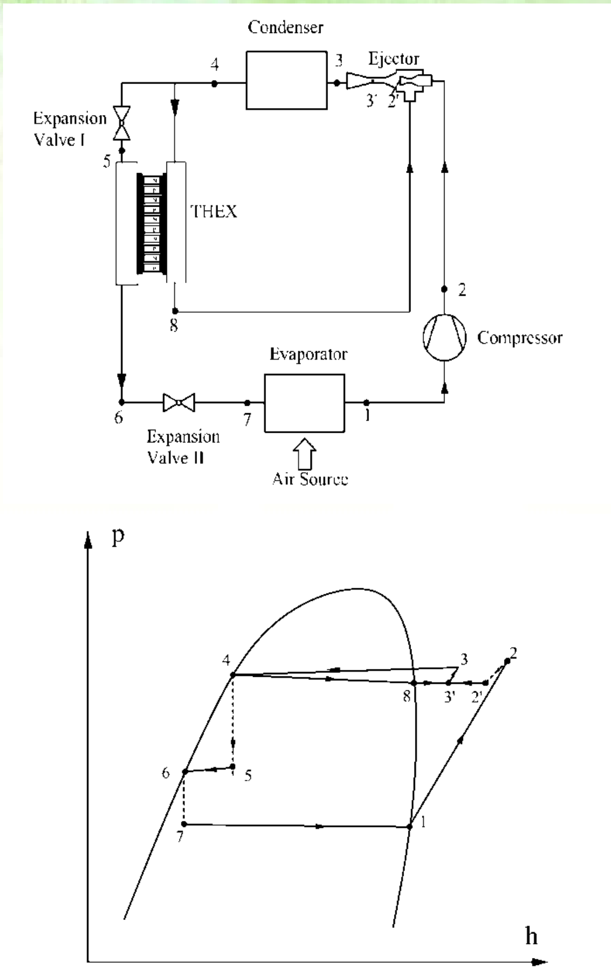

Fig2. The schematic diagram of TVCC
Pressure-enthalpy diagram for the TVCC

Build the mathematical model of the TVCC and solved it by program which is written in FORTRAN language .

- A main refrigerant circuit and a bypass refrigerant circuit are combined by thermoelectric heat exchanger (THEX)
- The THEX pump heat from the main circuit to the bypass circuit, so that rejected heat of the condenser increase .
- As power consumption of the TVCC increase, COP also be effected.
- The ejector is used for driving the refrigerant to flow through the bypass circuit.

Analytical Model

The absorbed and rejected heat at cold and hot sides of a TEM

$$\begin{cases} Q_{\mathrm{c,TEM}} = N_t[\alpha I t_{\mathrm{c,TEM}} - K(t_{\mathrm{h,TEM}} - t_{\mathrm{c,TEM}}) - \frac{1}{2}RI^2] & (1) \\ Q_{\mathrm{h,TEM}} = N_t[\alpha I t_{\mathrm{h,TEM}} - K(t_{\mathrm{h,TEM}} - t_{\mathrm{c,TEM}}) + \frac{1}{2}RI^2] & (2) \end{cases}$$

Cold and hot junction temperatures of the TEM

$$\begin{cases} t_{\mathrm{c,TEM}} = t_6 - \Delta t_{\mathrm{c}} & (3) \\ t_{\mathrm{h,TEM}} = t_8 + \Delta t_{\mathrm{h}} & (4) \end{cases}$$

Heating capacity of condenser

$$Q_{\mathrm{h}} = \left(\dot{m}_1 + \dot{m}_8\right)\left(h_3 - h_4\right) \quad (5)$$

Analytical Model

Input power of compressor

$$P_C = \frac{\dot{m}_1\left(h_{2s} - h_1\right)}{\eta_C} \tag{6}$$

Energy balances for the THEX

$$\dot{m}_1(h_5 - h_6) = N_{TEM} Q_{c,TEM} \tag{7}$$

$$\dot{m}_8(h_8 - h_4) = N_{TEM} Q_{h,TEM} \tag{8}$$

$$P_T = N_{TEM}\left(Q_{h,TEM} - Q_{c,TEM}\right) = \dot{m}_8(h_8 - h_4) - \dot{m}_1(h_5 - h_6) \tag{9}$$

Heating COP of the TVCC

$$\mathrm{COP} = \frac{Q_h}{P} = \frac{Q_h}{P_T + P_C} \tag{10}$$

Results

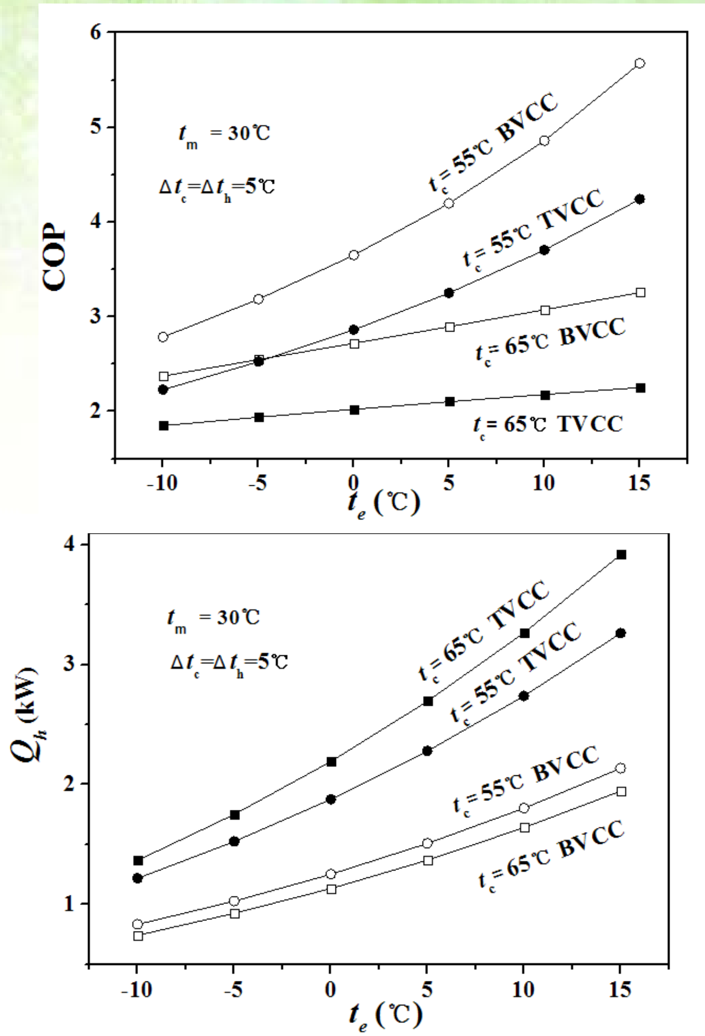

Fig.3 Effects of t_e on the COP and Q_h at different t_c

➢Compared with the BVCC:

When t_e ranges from -10 to15°C,

TVCC has **46.3%-103.0%** increase and **14.7%-52.5%** reduction in Q_h and COP respectively.

When t_c ranges from 55 to 65°C,

The improvement of Q_h for the TVCC can be achieved from **46.3%-53.4%** to **83.9%-103.0%,** whereas the decrement of COP is changed from **14.7%-48.7%** to **16.9%-52.5%,** respectively.

➢Compared to the BVCC with an assistant electric heater:

TVCC can also achieve an improvement of **16.4%-21.7%** in both the heating COP and capacity.

Results indicated that:

- Both under the high t_e or t_c conditions, the TVCC has better improvements in heating capacity.

- At a low ambient temperature, the advantage of TVCC in heating capacity could be beneficial to the applications in small heat pumps

Results

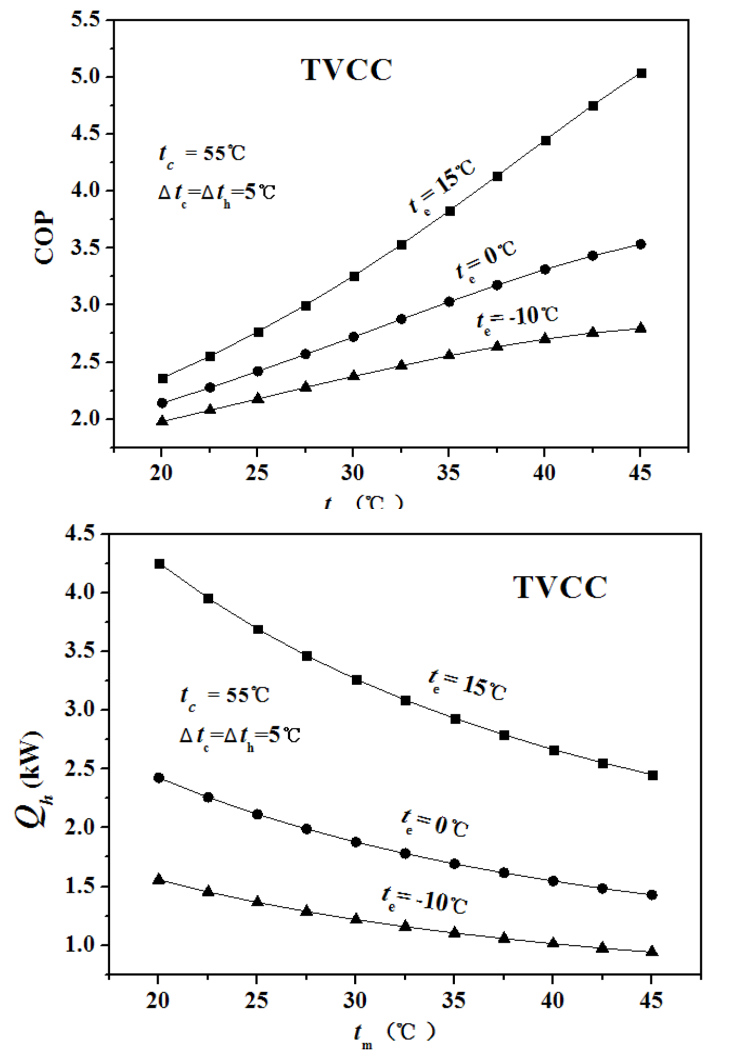

Fig.4 Effects of t_m on the COP and Q_h at different t_e

- When t_e =0 °C, t_m varies from 20 to 45 °C :
  the Q_h is decreased from 2.425 to 1.428kW, but the COP is increased from 2.14 to 3.53 .

- When COP of the TVCC and BVCC are almost equal, the TVCC still has the 13.0% improvement in Q_h better than that of BVCC.

Designing the intermediate temperature t_m should consider the trade-off between the Q_h and COP .

Results

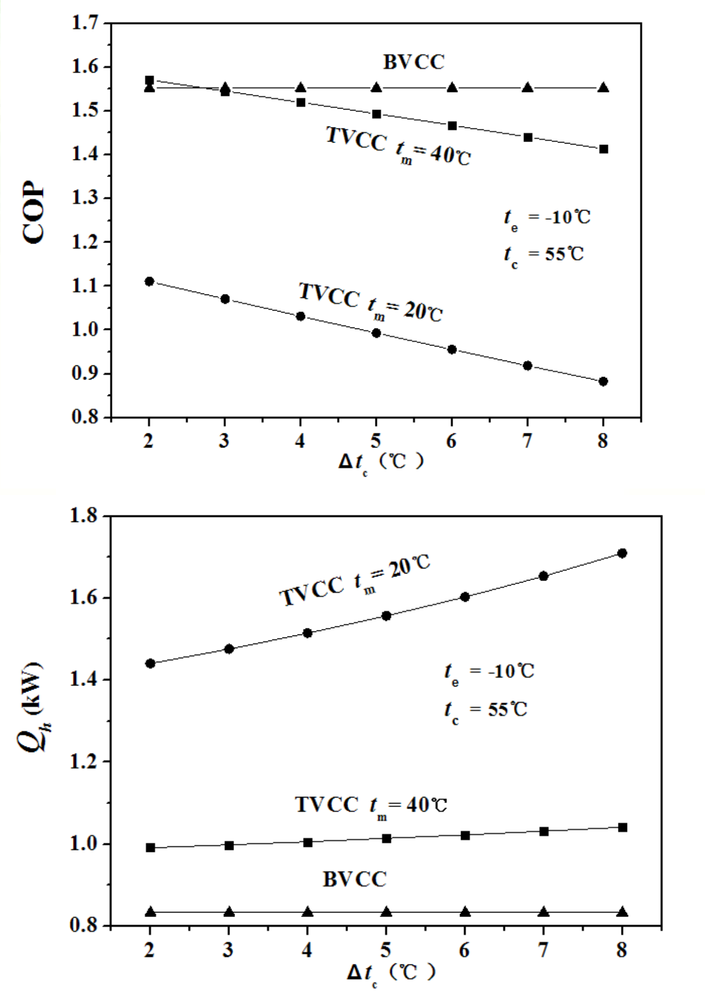

Fig.5 Effects of $\triangle t_c$ on the COP and Q_h at different t_m

To simplify theoretical study, $\triangle t_c$ and $\triangle t_h$ are assumed to be equal.

- When the $\triangle t_c$ increases, the heating capacity of the TVCC increase, whereas the COP decreases.
- when there is no significant difference in COP among the two cycles, TVCC also could achieve Q_h improvements of 19.0% over the BVCC.

Results

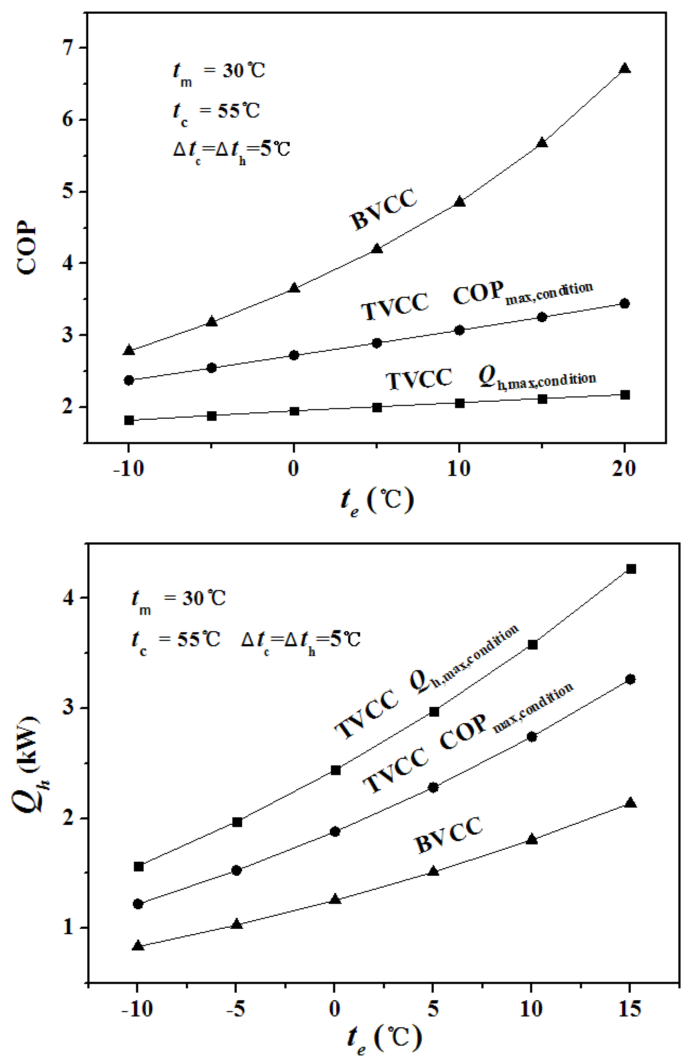

Fig.6 Effects of t_e on the COP and Q_h under two different conditions

Under the maximum condition of the TEMs,

- 87.8%-101.3% increment in Q_h
- 34.6% to 67.6%decrement in COP

Under the maximum heating capacity condition of the TEMs , TVCC can provide much more Q_h than under the maximum COP condition. Whereas this effect also leads to very significant reductions in the COP of the TVCC

An appropriate operating condition for the THEX should be globally considered

Conclusion

◆Compared with the BVCC, TVCC has dramatic improvement in heating capacity and a certain amount of reduction in COP, particularly at higher evaporating or condensing temperature.

◆Even when the COP of the two cycles are almost equal, the TVCC still outperform the BVCC in heating capacity by selecting an appropriate intermediate temperature.

◆Because the COP and heating capacity of the TVCC are both higher than those of the BVCC with an assistant electric heater, TVCC would be a good choice for the air-source heat pumps when they needs extra electric heat at a lower ambient temperature.

Thank You ！