10th Asia Pacific Conference on the Built Environment
Green Energy for Environment

The Design of Heat Pump Clothes Dryer

Kuei-Tien Lin and Kuo-Hsiang Chien

Energy and Environment Research Laboratories (EEL)
Industrial Technology and Research Institute (ITRI)
Jhudong Township, Hsinchu County, Taiwan.

Ambassador Hotel Kaohsiung, Taiwan
2009/11/5

Outline

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  - TOOL AND MATHEMATICAL MODEL
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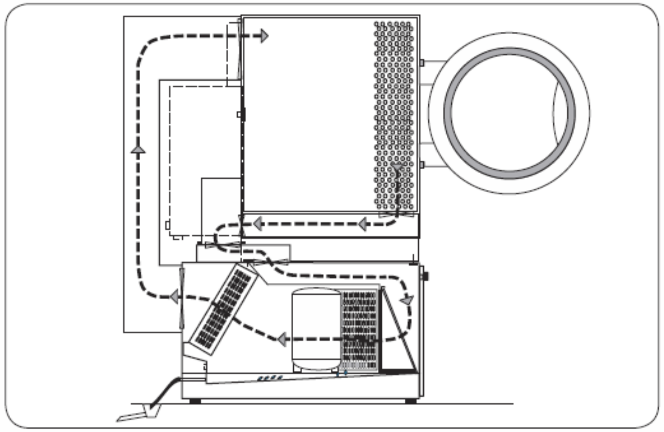

Ref. The operation manual of Electrolux clothes dryer LE4300

INTRODUCTION（1/4）

- Traditional clothes dryer
  - High temperature exhaust ⇒ Energy consumption
  - Humid exhaust ⇒ Humidity pollution to environment
- Condensed-type clothes dryer
  - Moisture condensed ⇒ No more humidity pollution
  - Energy consumption still there!!

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INTRODUCTION（2/4）

- Heat pump clothes dryer
  - Heating COP about 3~4
  - Reliability of compressor ⇨ Not popular before
  - Wash/dryer machine with heat pump is announced in 2005, Japan
  - 51.7% drying time and 65.2% operating cost is reduced
- Laundry in Taiwan
  - Gas-fired clothes dryer is mainstream
  - Potential of 12,264 unit in the market
  - Gas consumption of 122 million liter per year
  - 25% Energy saving ⇨ 30.5 million liter of gas saved ⇨ 53,070 tons CO_2 reduced

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INTRODUCTION（3/4）

- Prasertsan et al.(1996,1997) study the heat pump dryer characteristics by the model establishment, simulation analysis and experiment verification.
- The feasibility of an air heat pump (Reverse Brayton) cycle for tumbler clothes dryers is investigated by Braun et al.(2002).
- Solar-assisted heat pump dryer and water heater has been designed, fabricated and tested by Hawlader et al.(2003).
- Heat pump assisted dryer for wet wool is constructed and tested by Oktay(2003).
- Saensabai et al.(2003) analyze the heat pump assisted dryer of five configurations by simulation.

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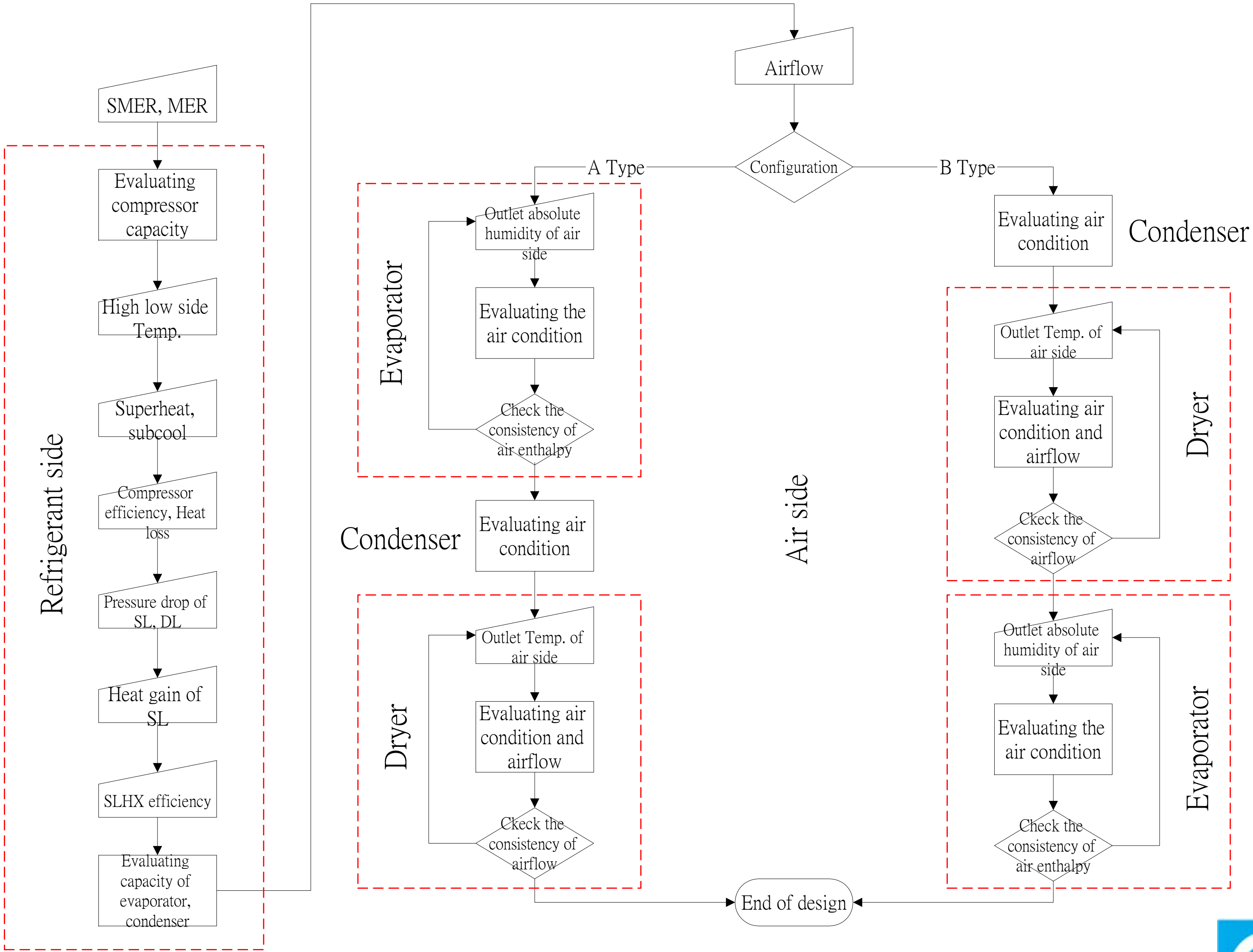
INTRODUCTION（4/4）

- Teeboonma et al.(2003) study the optimum conditions of operation for heat pump fruit dryer and minimizing cost.
- Ameen and Bari(2004) conduct the investigation to determine the feasibility of drying clothes using the waste heat of condenser for a typical split type domestic air conditioner.
- In this paper
  - Parameter study
  - Analysis of operation cost compared to gas-fired clothes dryer
  - Guideline to build prototype of a 30lb heat pump clothes dryer

METHODOLOGY（1/5）



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METHODOLOGY（2/5）

- Tool and Mathematical Model
  - From the literature ⇨ Open type has higher MER ⇨ The base of design
  - Refrigerant side
    - Use CoolPack ⇨ Developed by Department of Energy Engineering, the Technical University of Denmark
    - The properties of refrigerant, capacity of compressor, evaporator and condenser are determined
  - Air side
    - Use the thermodynamics equation with MathCAD according to component

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METHODOLOGY（3/5）

- Condenser

$$T_{condout} = T_{condin} + \frac{Power_{cond}}{m_{air} \cdot C_p}$$

$$h_{condout} = \frac{m_{air} \cdot h_{condin} + Power_{cond}}{m_{air}}$$

- Dryer

$$\omega_{dryerout} = \eta_{dryer} \cdot (\omega_{dryersat} - \omega_{dryerin}) + \omega_{dryein}$$

$$m_{air} = \frac{MER_{dryer}}{\omega_{dryerout} - \omega_{dryerin}}$$

$$h_{dryerout} = \frac{m_{air} \cdot h_{dryerin} + h_{dryerwater} \cdot MER_{dryer}}{m_{air}}$$

- Evaporator

$$T_{evapout} = T_{evapin} - \frac{Power_{evap}}{m_{air} \cdot C_p}$$

$$MER_{evap} = m_{air} \cdot (\omega_{evapin} - \omega_{evapout})$$

$$h_{evapout} = \frac{m_{air} \cdot h_{evapin} - Power_{evap} - h_{water} \cdot MER_{evap}}{m_{air}}$$

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METHODOLOGY（4/5）

- Issue of study（1/2）
  - Refrigerant
    - R-134a, R-407C and R-410A
  - Ambient temperature
    - High and low temperature
  - Dryer efficiency
    - Dryer configuration, gradient of moisture concentration
    - 10%, 25%, 50% and 75%
  - Component arrangement
    - Two open type evaluated
    - Evaporator → Condenser → Drum
    - Condenser → Drum → Evaporator

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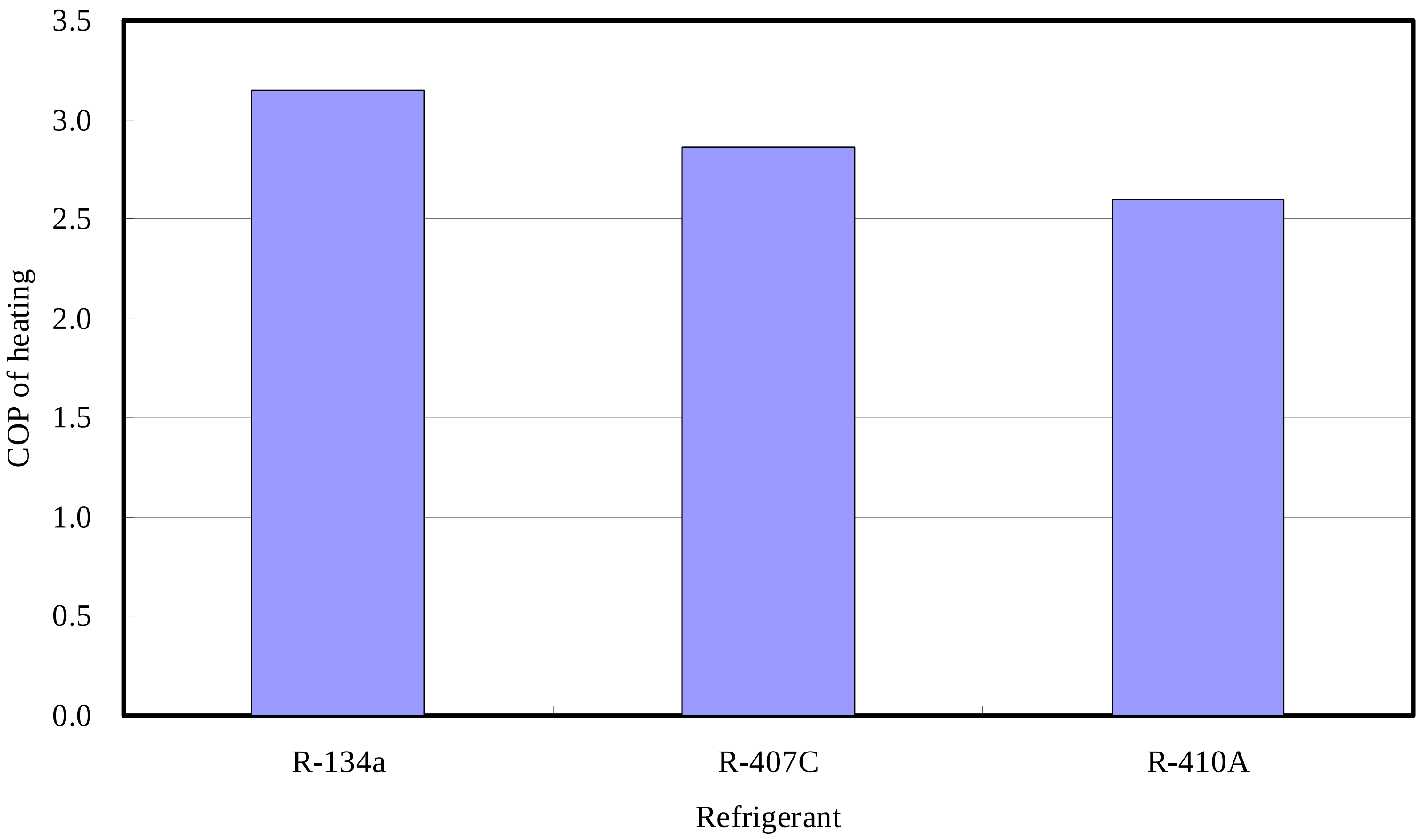
METHODOLOGY（5/5）

- Issue of study（2/2）
  - Airflow rate
    - High and low flow rate
  - Condenser temperature
    - High and low temperature
  - Ideal and non-Ideal vapor compression
    - pressure drop in the pipeline, compressor efficiency, heat loss from compressor, heat gain to suction line
  - Suction line heat exchanger
    - Use or not use
    - About 30% efficiency
  - Operation cost between gas-fired and heat pump

RESULTS（1/9）



- With the same power input
- Heat output : R-134a > R-407C > R-410A

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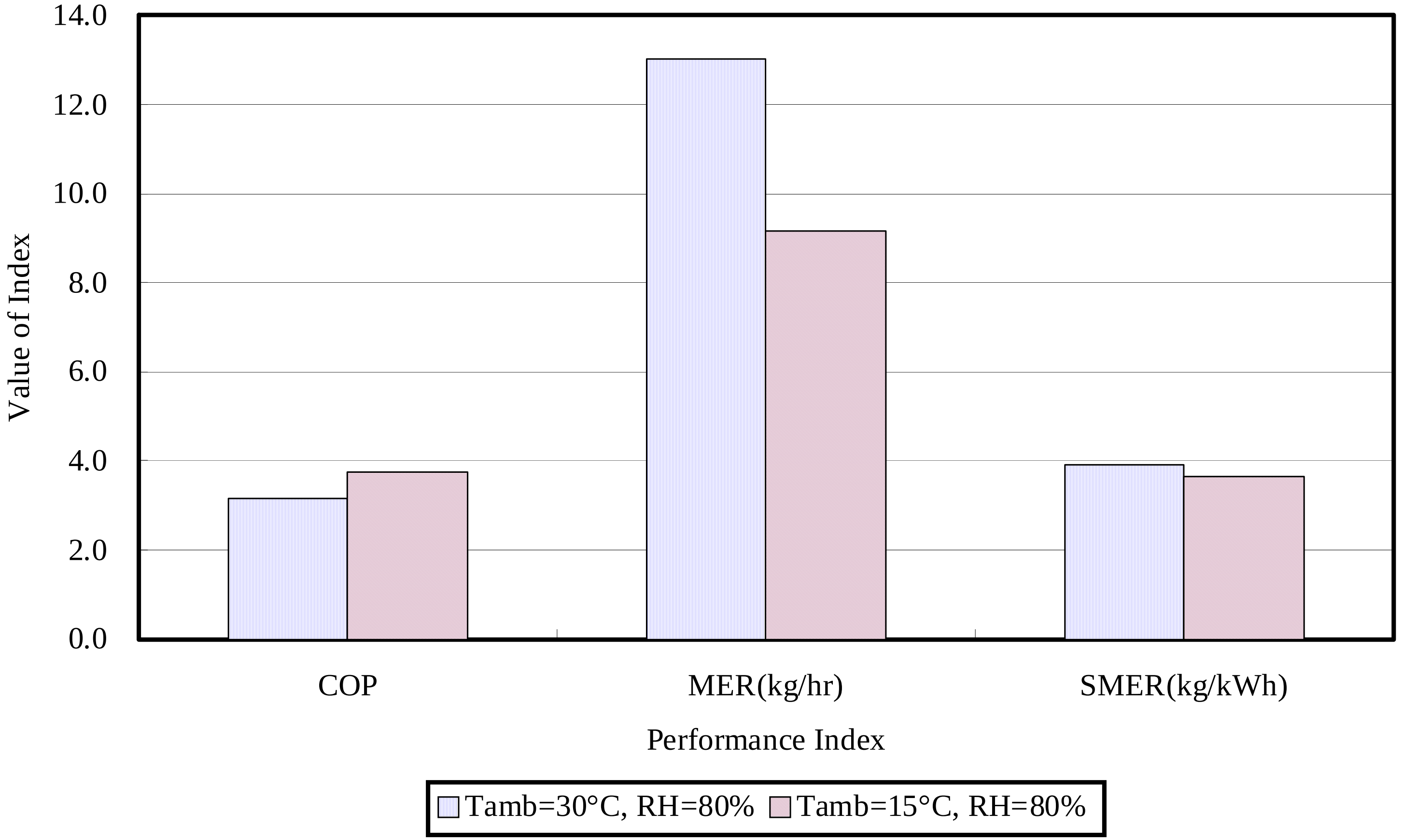
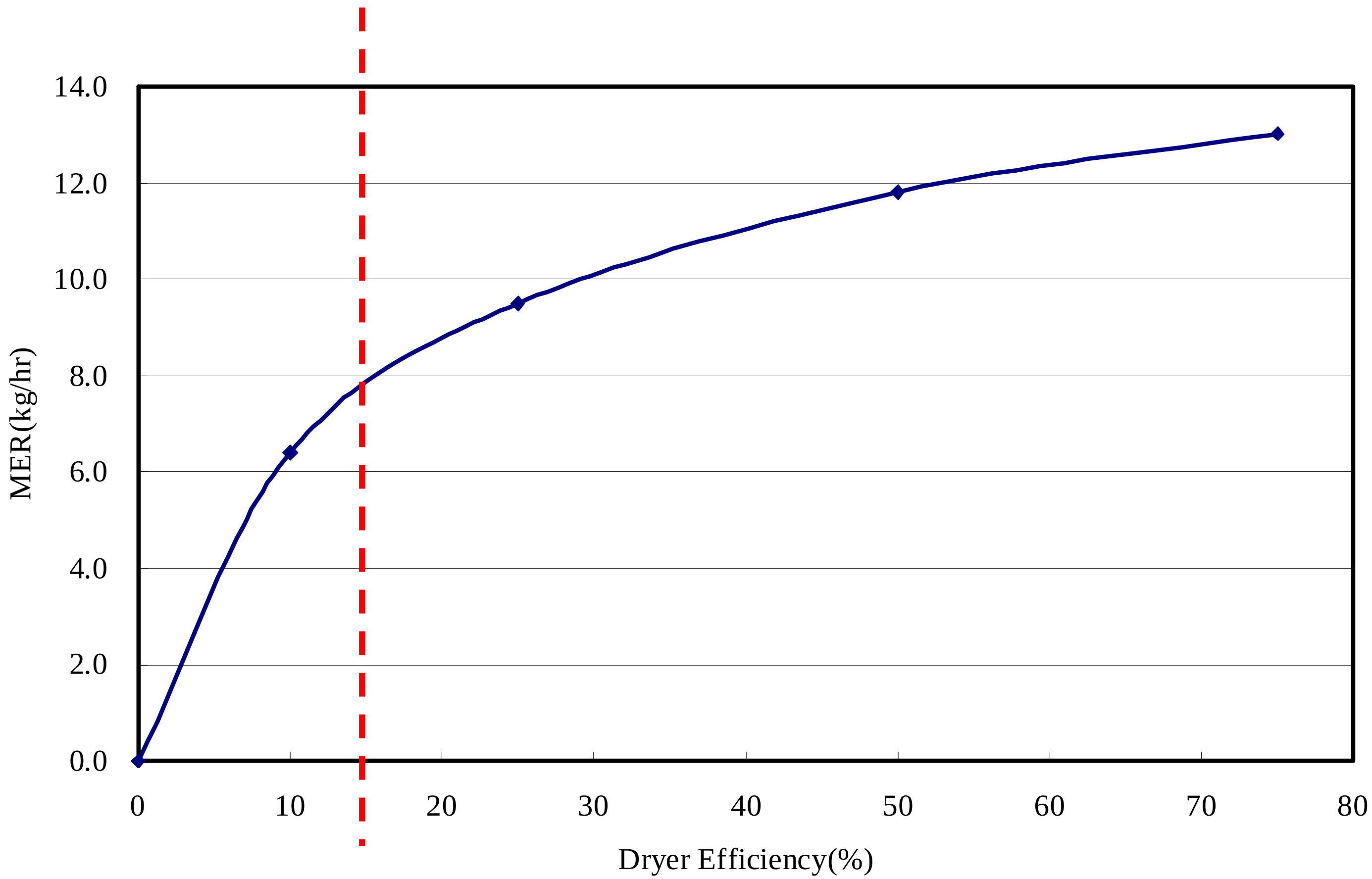
RESULTS （2/9）



- Assume the same overall heat transfer coefficient of evaporator and condenser
- Assume 10% heat transfer reduction of condenser

RESULTS（3/9）



- MER reduced sharply at certain dryer efficiency

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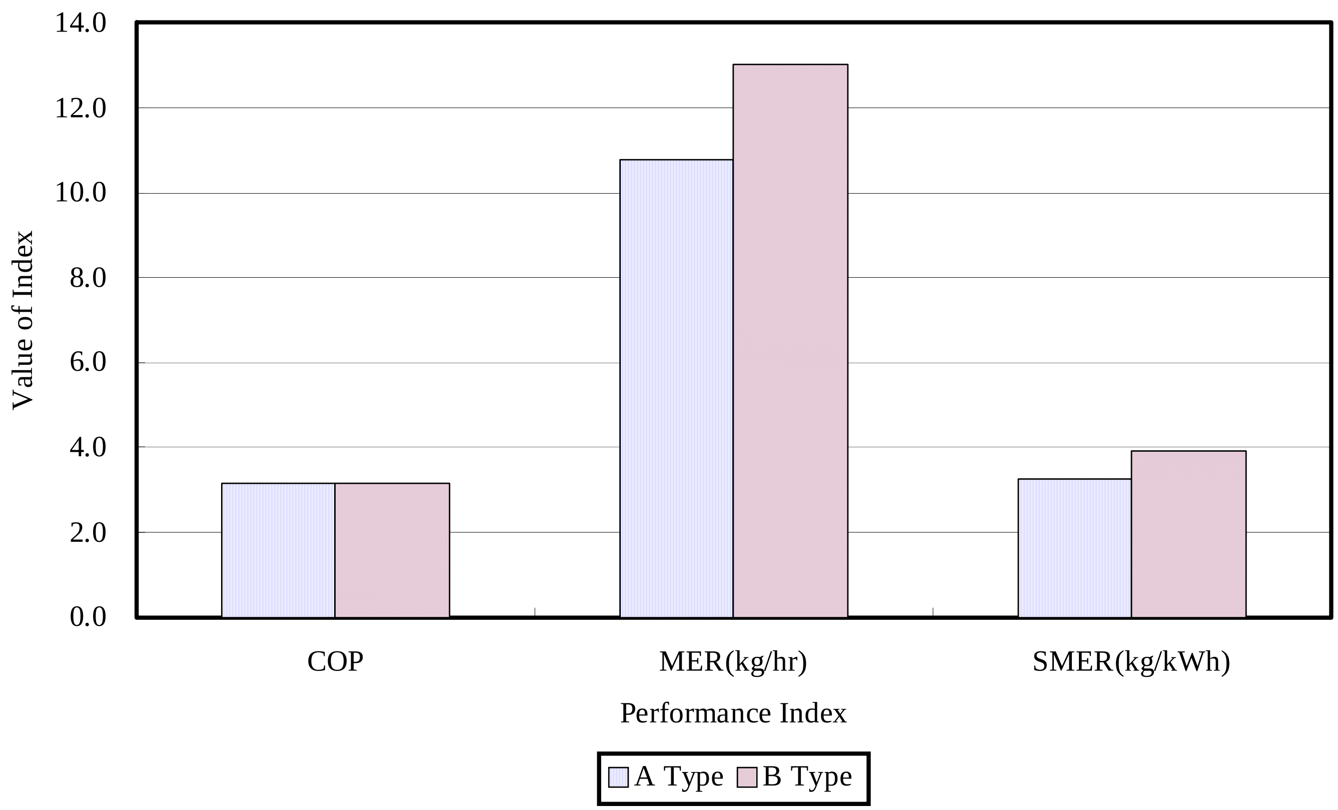
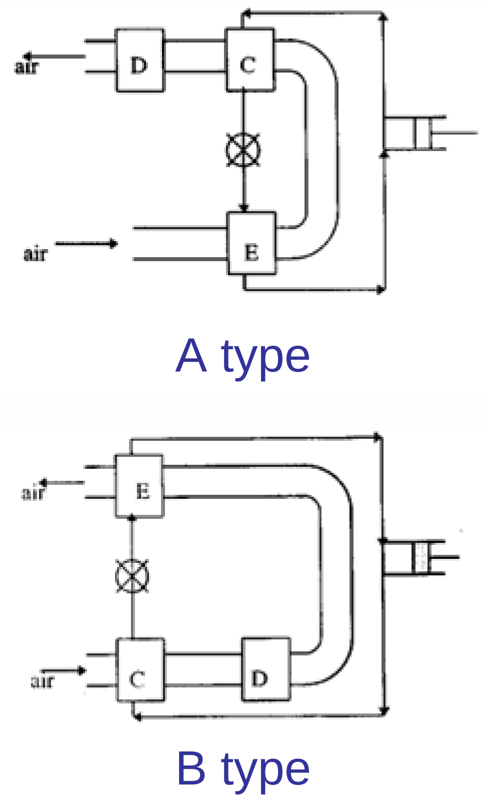
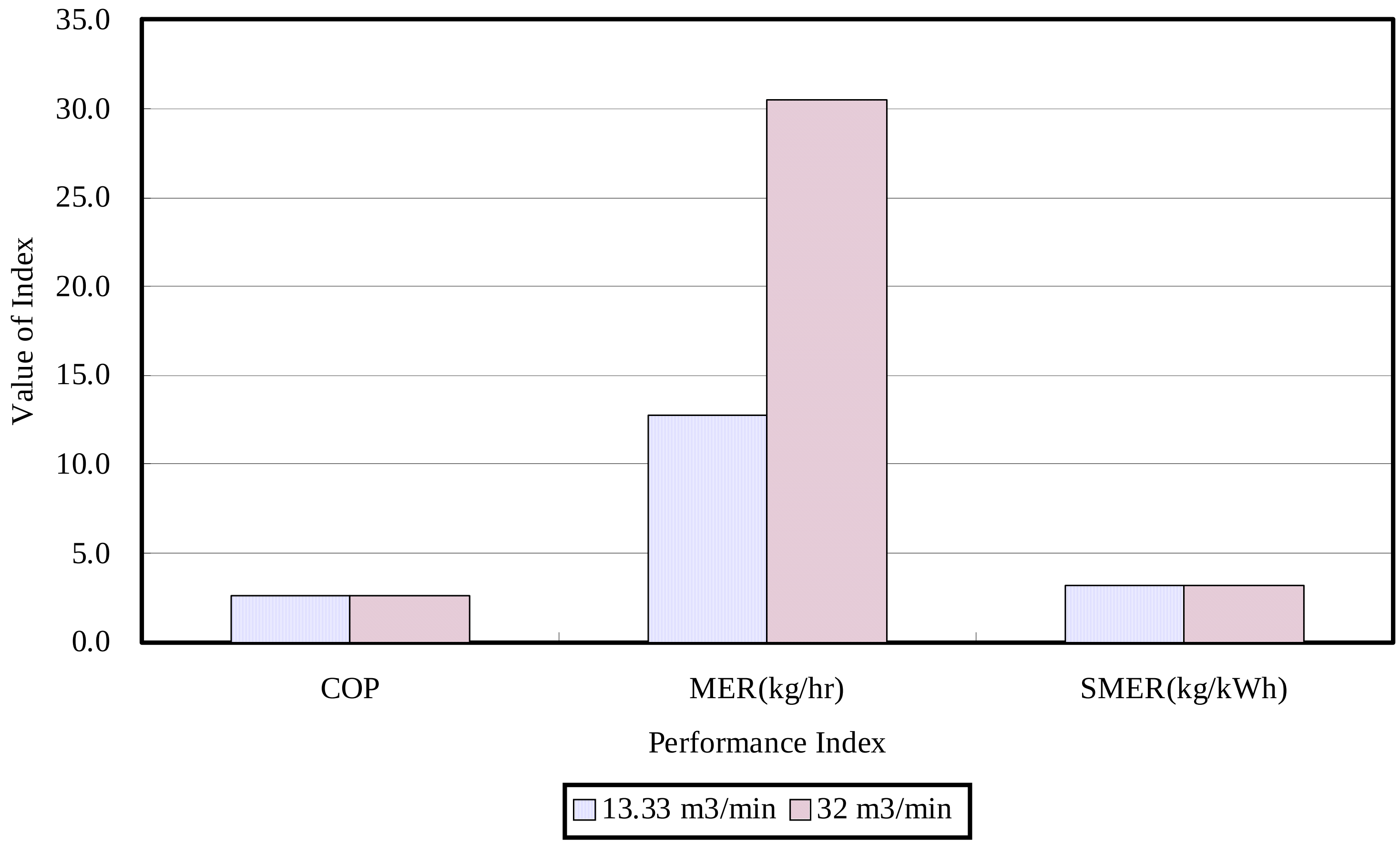
RESULTS（4/9）





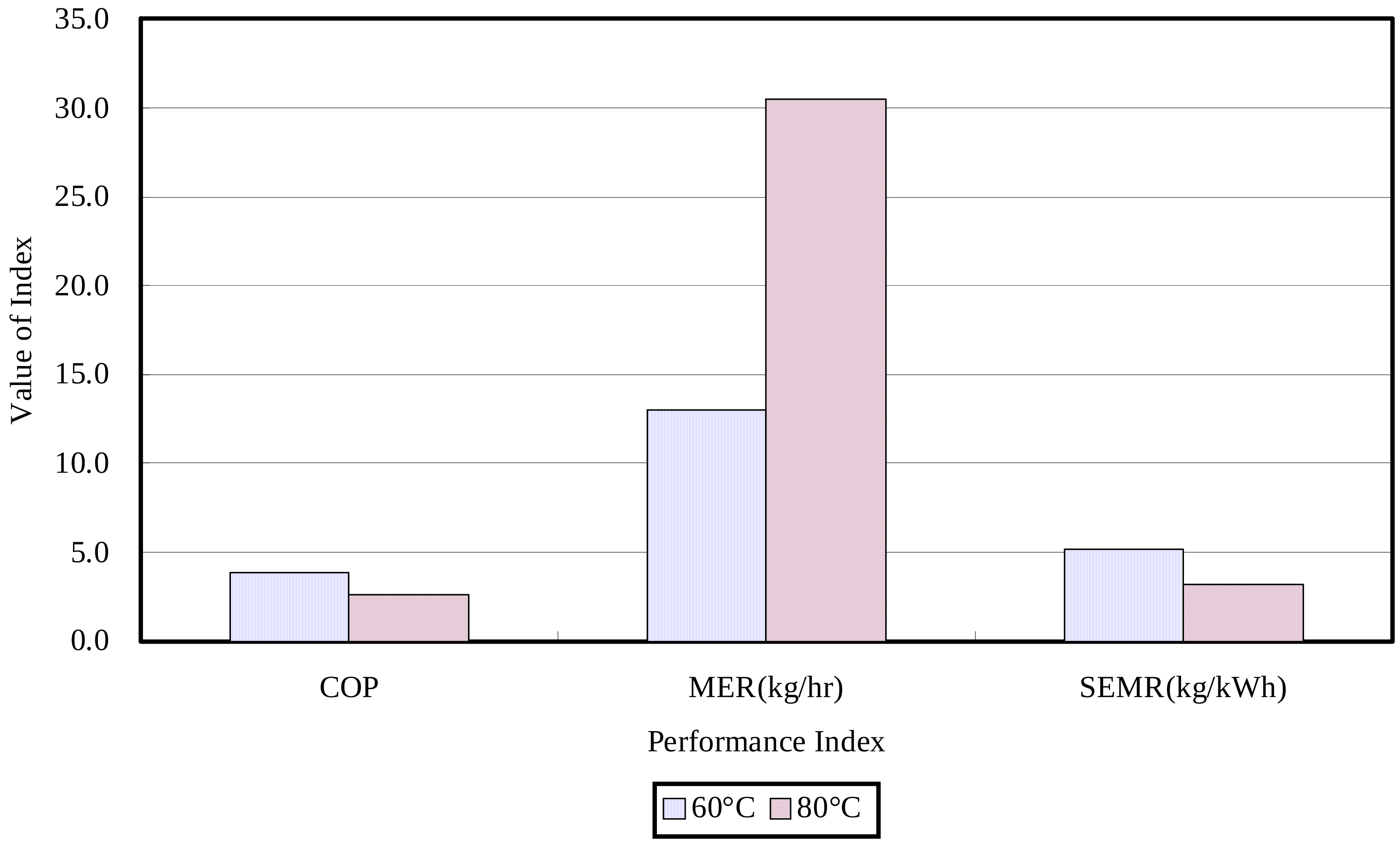
- Temperature is the domination factor than humidity

RESULTS（5/9）



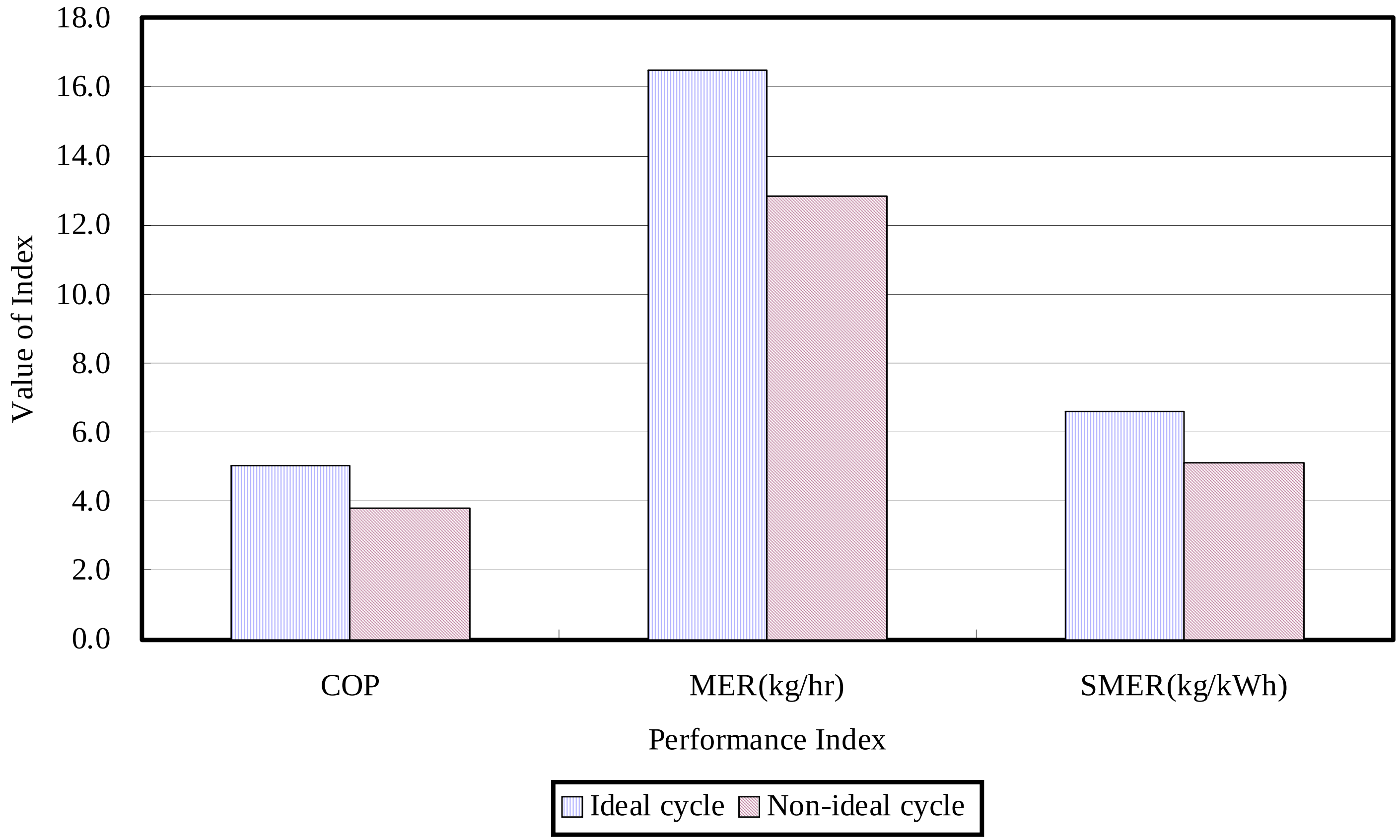
- The temperature of condenser and evaporator maintained the same
- MER dramatically increased, while COP and SMER maintained the same

RESULTS（6/9）



- COP and SMER decreased; MER increased

RESULTS（7/9）



- Non-ideal condition: evaporator superheat of 5K, condenser subcool of 2K, compressor efficiency of 70%, heat loss of 400W from compressor, pressure drop about 7kPa in suction line, heat gain of 72W at suction line from ambience, and pressure drop about 20kPa in discharge line
- 24.7% reduction of COP; 22.3% reduction of MER and SMER

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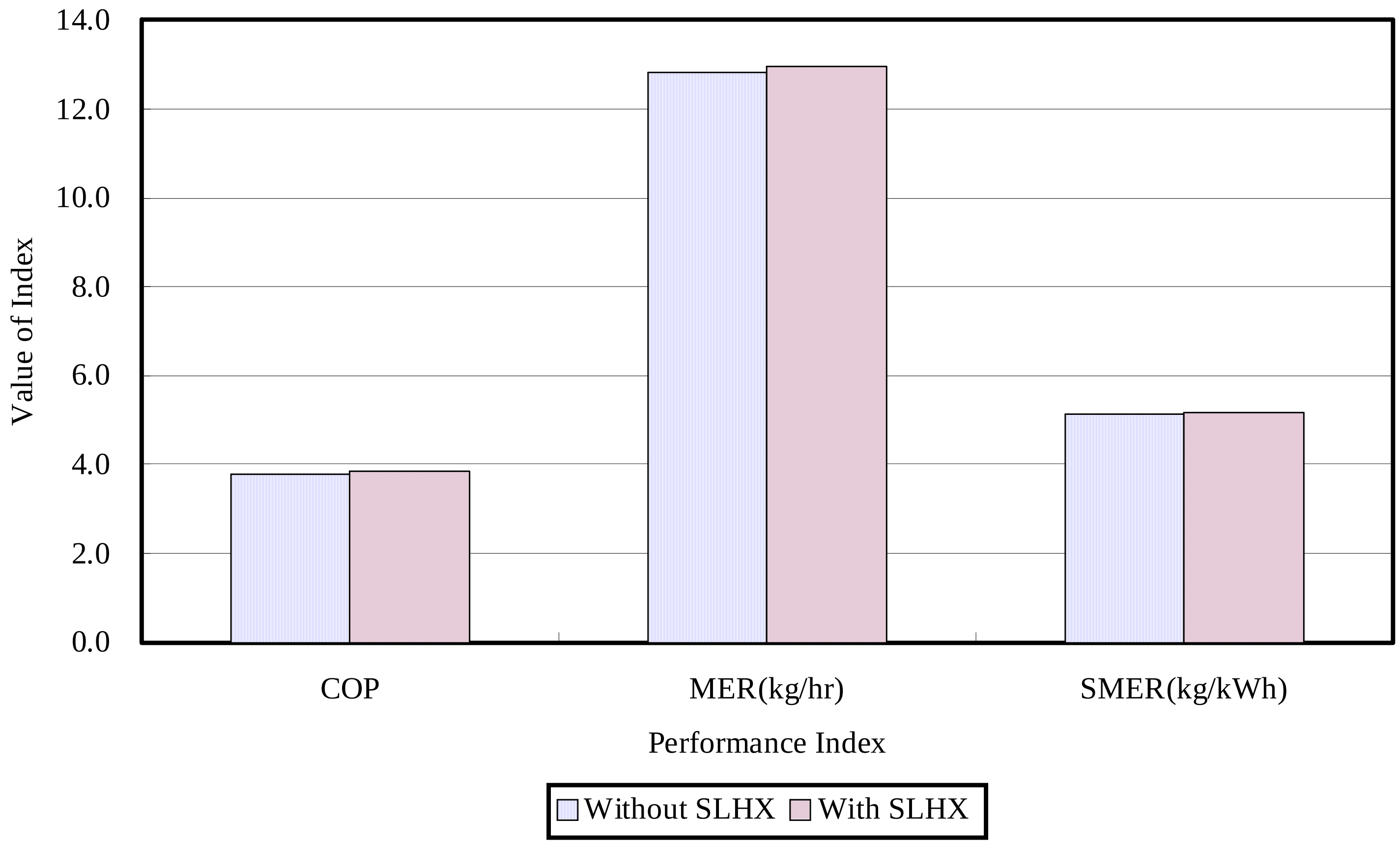
RESULTS（8/9）



- Increase of COP, MER and SMER are insignificant

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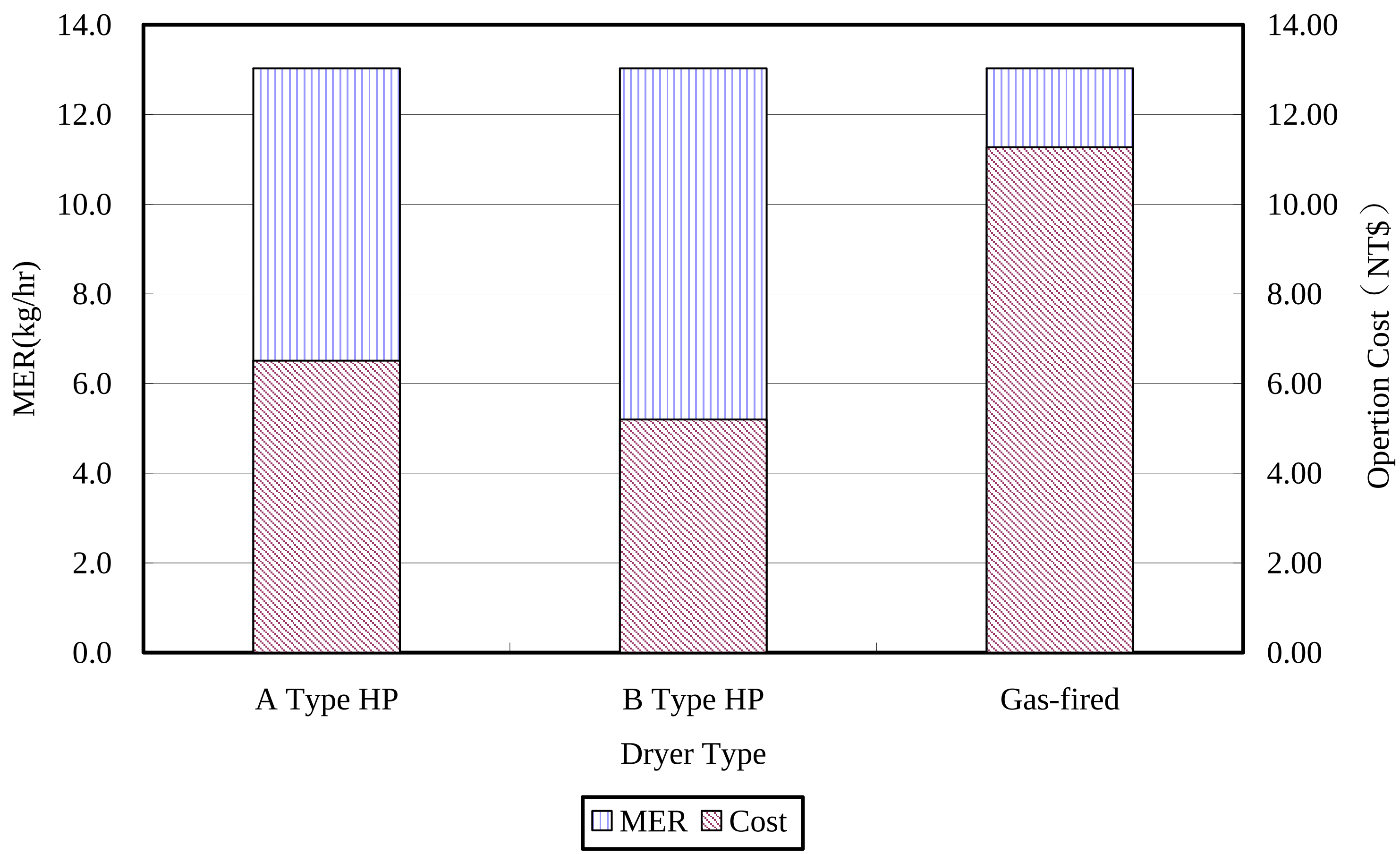
RESULTS（9/9）



- With the same MER, cost of gas type > heat pump

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DISCUSSIONS（1/3）

- Need high temperature ⇨ R-134a is the better choice
- The performance with low ambient temp. is only 70% compared to that with high ambient temp. ⇨ Careful to choose design point
- In our case
  - Dryer efficiency above 15% open type configuration
  - Dryer efficiency below 15% semi-close type configuration
- MER and SMER of B type are 21% higher than A type with the same COP ⇨ Temperature is the main driving force for clothes dryer

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DISCUSSIONS （2/3）

- Increasing airflow rate properly ⇨ MER increasing dramatically without sacrifice of COP and SMER
- Higher condenser temperature
  - 31.5% COP and 38.2% SMER reduction
  - 135% MER augmentation
- 25% deviation between ideal and non-ideal analysis ⇨ For accuracy, consider every factor

DISCUSSIONS （3/3）

- For cost down SLHX may be ignored
- Advantage of heat pump clothes dryer compared to gas-fired clothes dryer
  - Lower operation cost
  - Avoid the industrial safety affair like management of gas bottle

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CONCLUSIONS

- Higher condenser temp. and COP → R-134a is more suitable than others
- To conquer the drawback caused by low ambient temp. → Variable capacity of compressor and fan are critical
- For design of energy saving → Transformation of air duct configuration may be a solution
- Temperature is dominate → B type is the first choice
- SLHX can be ignore for cost down
- Heat pump clothes dryer has more advantage than gas-fired clothes dryer

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Energy and Environment Laboratories

Residential & Commercial Energy-saving Technology Div.

Home Appliance Research Department

Researcher

Kuei-Tien Lin

E-mail：KTLin@itri.org.tw