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Experimental Study on Heat Transfer of Air Source Heat Pump with Novel Finned-tube Evaporator

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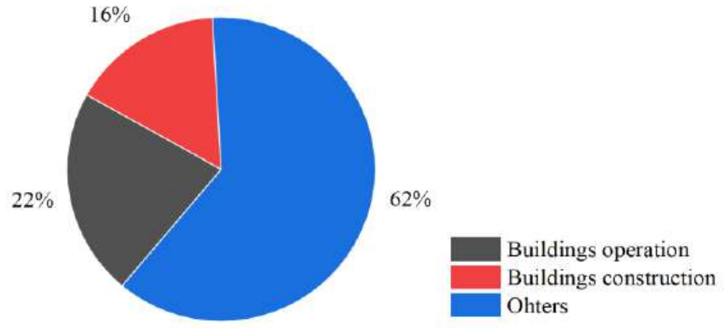
01 Introduction

Background

High energy consumption and carbon dioxide emissions of buildings

- Building operations consume 30% of global final energy and contribute to 26% of global energy-related emissions[1].
- Buildings and building construction industries accounted for more than 30% of the total CO_2 emissions in China[2].



Contributions of CO_2 emissions from the buildings industry in China in 2019.

Building energy conservation and carbon reduction policy orientation

Action Plan for Achieving Carbon Peak by 2030,State Council of the People's Republic of China

（国务院《2030年前碳达峰行动方案》）:

- Strengthen the research and promotion of energy-saving and low-carbon technologies suitable for different climate zones and different building types.
- Promote clean heating in cold areas; implement clean and low-carbon heating such as heat pumps, biomass energy, geothermal energy and solar energy in light of local conditions.
- Promote the scientific heating in hot summer and cold winter areas, and adopt clean and efficient heating methods according to local conditions.
- Promote clean heating in rural areas.

Introduction

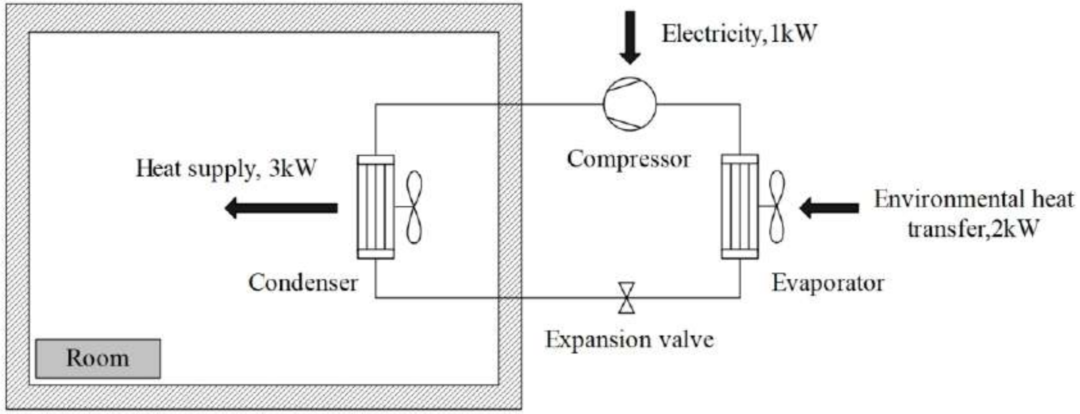
[1] International Energy Agency. Buildings, https://www.iea.org/energy-system/buildings
[2] Tsinghua University Building Energy Conservation Research Center. 2021 Annual Report on China Building Energy Efficiency

Background

Heat pumps: central technology for sustainable heating.

The heat pump systems help to convert the low-level heat source that cannot be directly used (such as the heat energy contained in air, shallow surface, water, industrial waste heat, etc.) into the high-level heat energy that can be used, so as to achieve the purpose of saving part of the high-level energy.

Heat pumps globally have the potential to reduce global carbon dioxide emissions by at least 500 million tons in 2030 [3].



Operating principle of a basic air-to-air ASHP system.

In regions with hot summers and cold winters, the air conditioning period is long in summer, resulting in a large cooling load, while the heating period is relatively short in winter with a smaller heating load. Air source heat pumps(ASHPs) are generally suitable as a heat source for winter heating.

Introduction

[3] International Energy Agency. Heating, https://www.iea.org/energy-system/buildings/heating

Research questions

Problems existing in the operation of ASHPs

- The heating capacity of the system decreases as the outdoor temperature decreases, while the heat capacity required increases, resulting in the inability to provide the required heat.
- When the surface temperature of the outdoor heat exchanger is lower than the air dew point temperature and freezing point temperature, frosting happens on the surface of the evaporator, which seriously affects the operation efficiency.
- Defrosting results in energy consumption, while defrosting intervals also have a negative impact on indoor side heating.

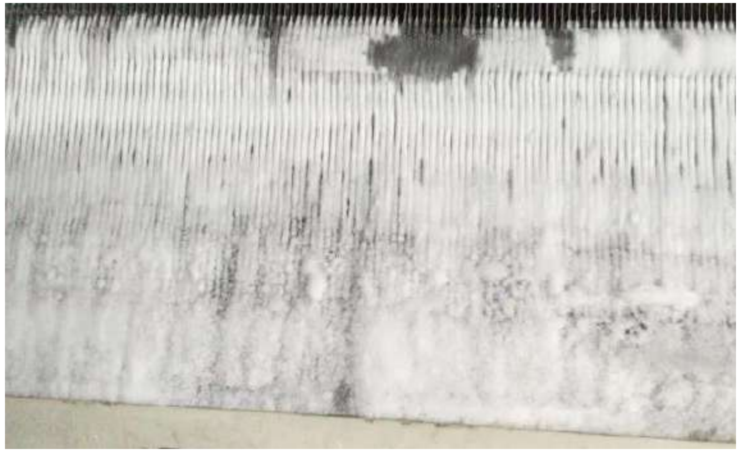
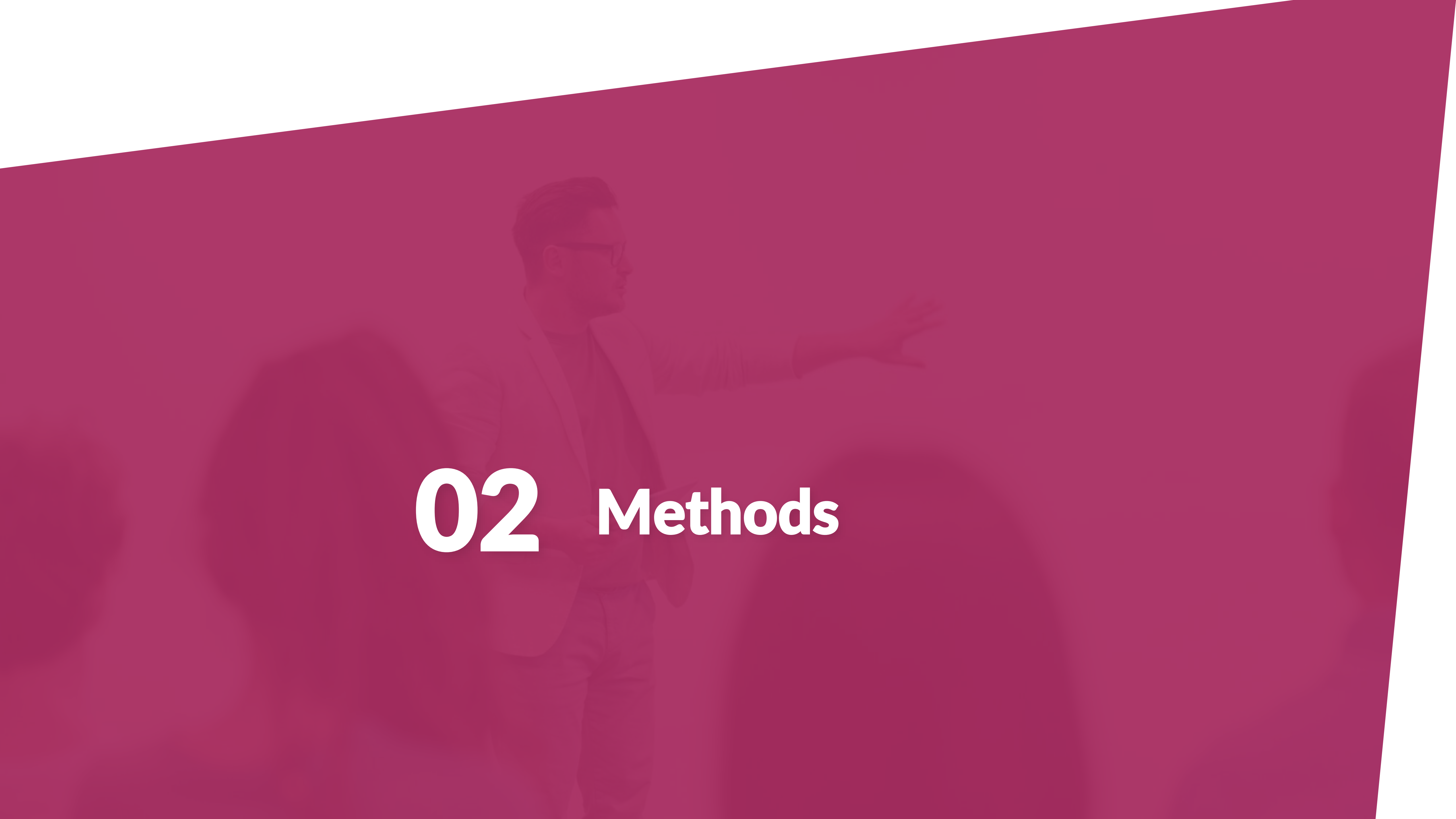


Diagram of the frost on the evaporator.

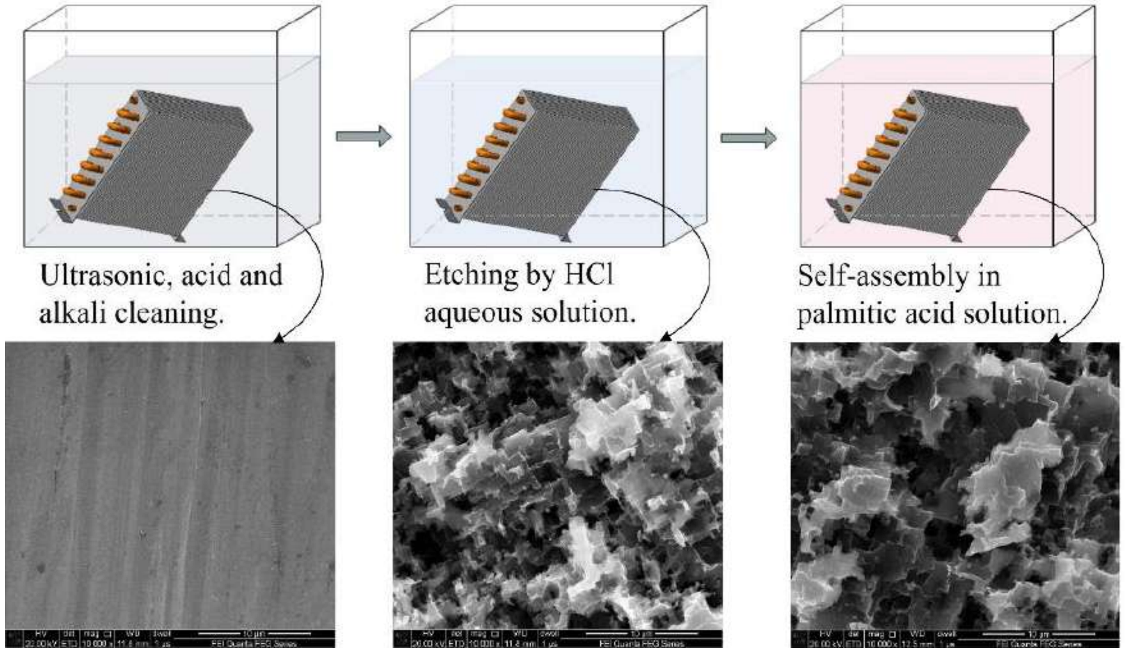
Key approaches to achieving the goal of efficient heating with ASHPs:

- **Increasing the heat supply of the unit**
- **Extending the heating operation cycle**
- **Reducing defrosting energy consumption**
- **Minimizing the impact of defrosting on the indoor side**

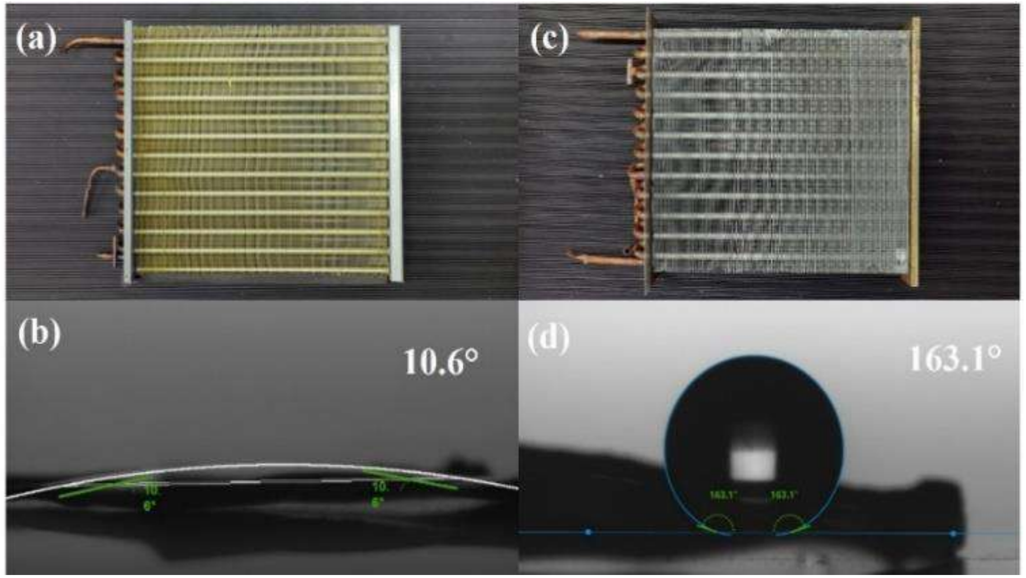


02 Methods

Surface construction process and characterization of finned-tube heat exchangers



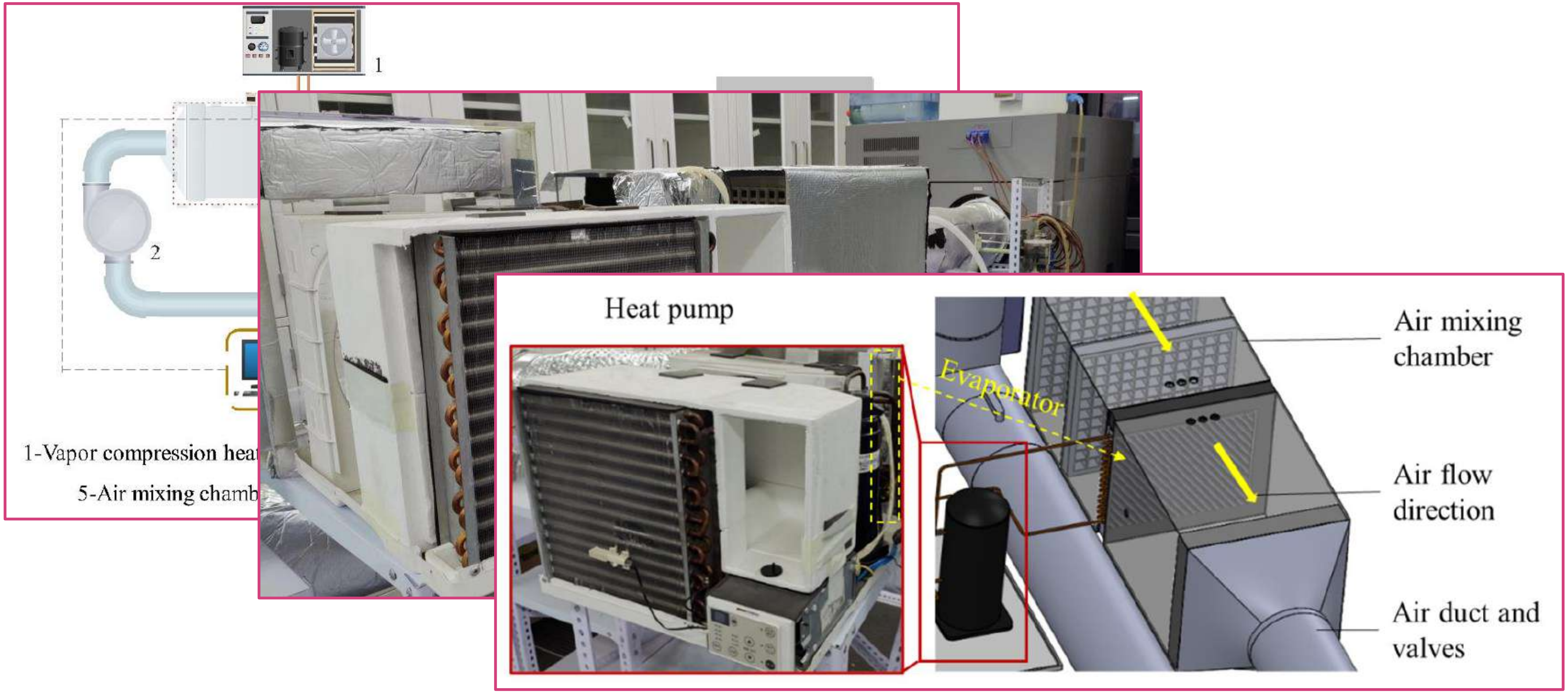
Fabrication process of the superhydrophobic finned-tube heat exchanger.



Evaporators and contact angles characterization:

(a) commercial evaporator; (b) contact angle of the commercial evaporator; (c)superhydrophobic-treat evaporator; (d) contact angle of the superhydrophobic-treat evaporator.

Visualized wind tunnel experimental platform for evaporators



Data collection and calculation

The ASHPs' heat capacity was evaluated by the air-enthalpy test method. This approach quantifies the supply air parameters, return air parameters, and circulating air volume of the ASHP unit.

$$Q_{in} = \frac{\rho_{in} q_{v,in}\left(h_{a,in2} - h_{a,in1}\right)}{1 + d_{in}}$$

Heating/cooling capacity:

$$Q_H / Q_C = \int_0^t Q_{in} dt$$

$$q_{v,\mathrm{in}} = v_{in} A_{\mathrm{in}}$$

$$h_a = 1.01 T_a + d_a\left(2500 + 1.84 T_a\right)$$

$$d_a = 0.622 \frac{\varphi p_s}{p_0 - \varphi p_s}$$

$$p_s = \varphi \cdot \exp(C_1 / T_a + C_2 + C_3 T_a + C_4 T_a^2 + C_5 T_a^3 + C_6 \ln T_a)$$

Coefficient of performance (COP): $\mathrm{COP} = \frac{Q_H}{W}$

Frost formation quantity：

$$D = \left(d_{a,out1} - d_{a,out2}\right) m_a$$

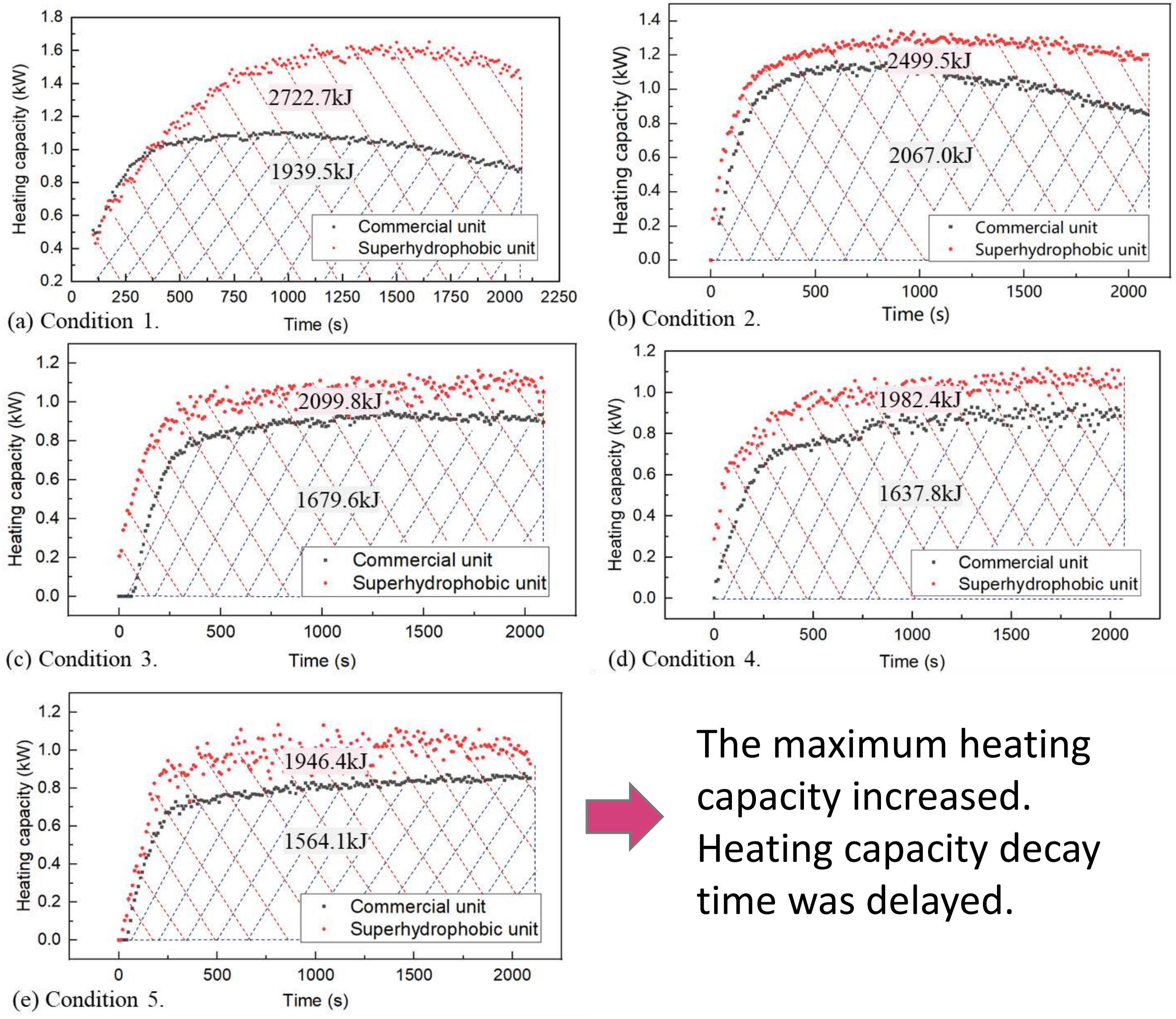
$$m_a = q_v \rho_a = q_v \left(\frac{353.183}{273.15 + t_a}\right)$$

Uncertainty calculation：

$$\frac{\Delta y}{y} = \frac{1}{y}\sqrt{\left(\frac{\partial f}{\partial x_1}\Delta x_1\right)^2 + \left(\frac{\partial f}{\partial x_2}\Delta x_2\right)^2 + \cdots + \left(\frac{\partial f}{\partial x_n}\Delta x_n\right)^2} = \frac{1}{y}\sqrt{\sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\Delta x_i\right)^2}$$

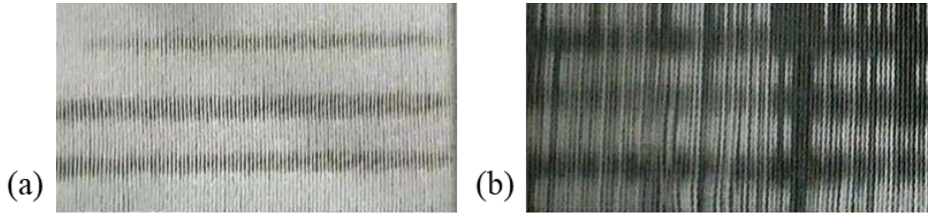
03 Results and discussion

Comparative experiments based on the frosting process visualization

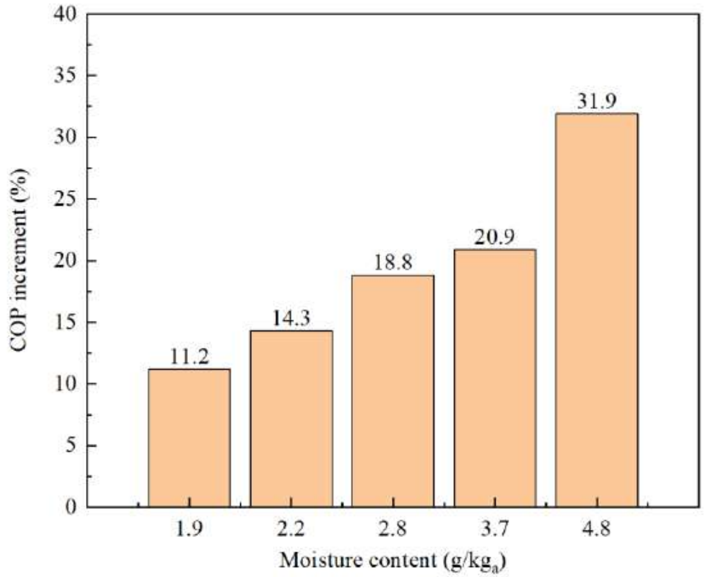


Variation of heat transfer rate of different conditions during a single frosting period.

The maximum heating capacity increased. Heating capacity decay time was delayed.



The frost formation of the two units after running for 25 minutes under Condition 1.



COP increment of the superhydrophobic finned-tube unit under frosting conditions.

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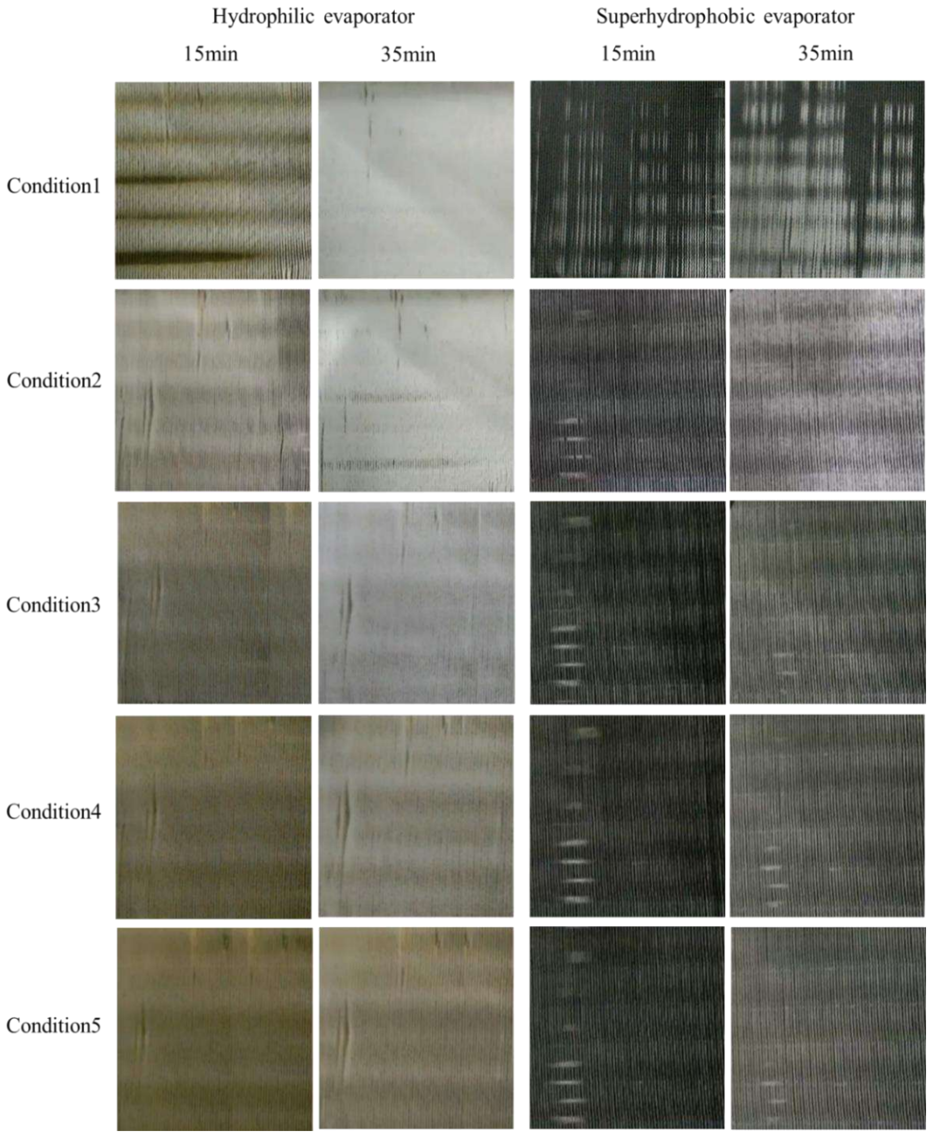
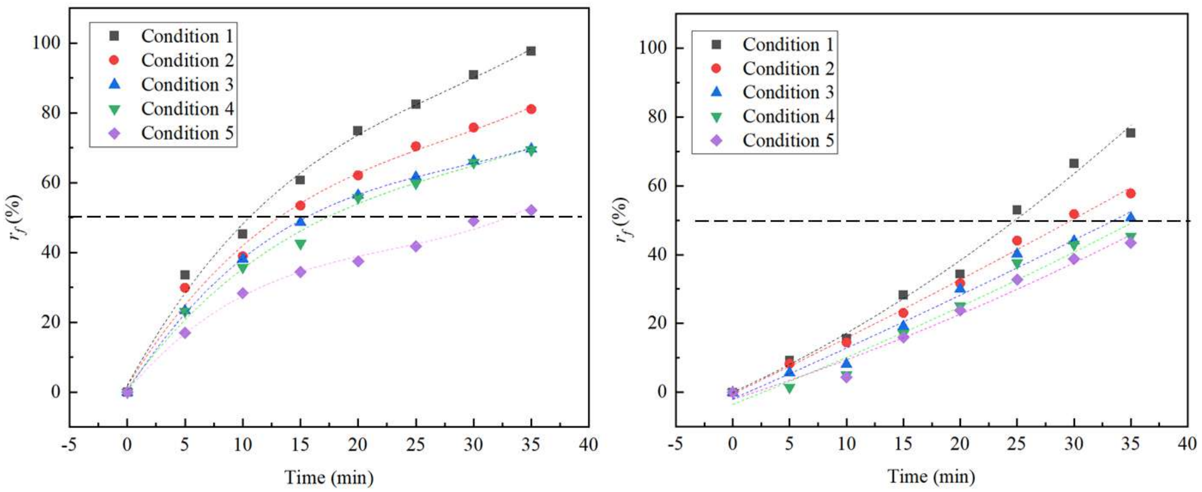
Comparative experiments based on the frosting process visualization



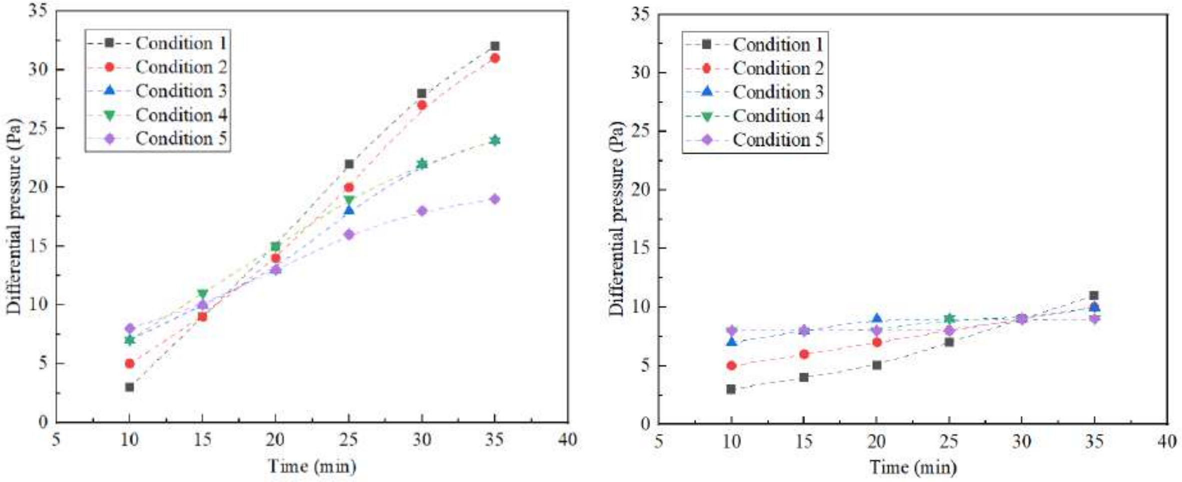
Windward side frosting photographs of different conditions.



(a) Commercial evaporator unit

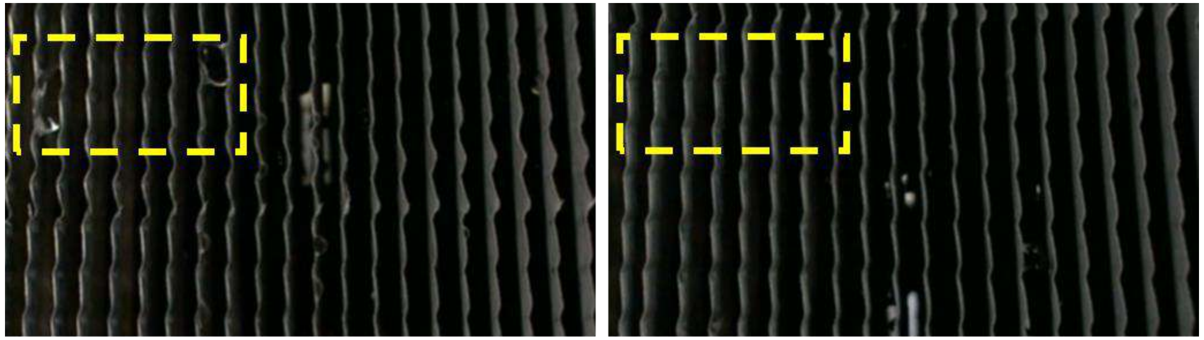
(b) Superhydrophobic evaporator unit

Variation of r_f during the frosting processes.



Variation of differential pressure of the inlet and outlet of the evaporators during the frosting processes.

Frosting/defrosting cycles and anti-frosting characteristics of superhydrophobic evaporator



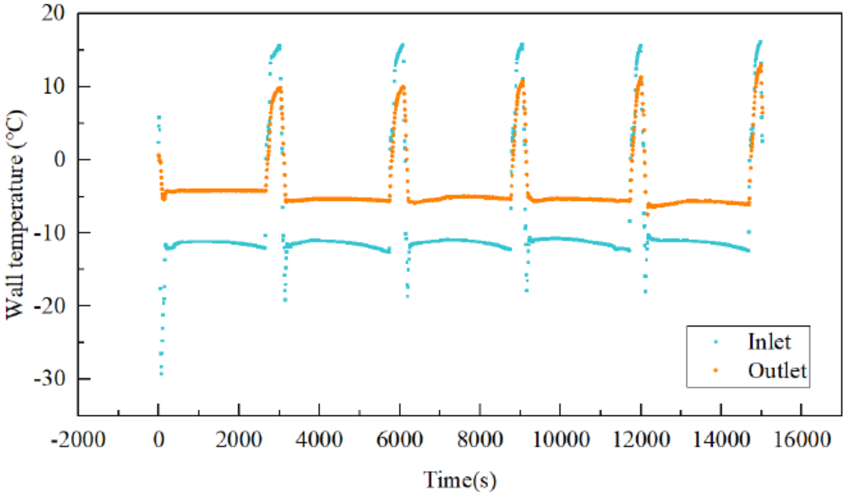
(a) After the first defrosting process. (b) After the second defrosting process.

Detachment of the ice bridges.

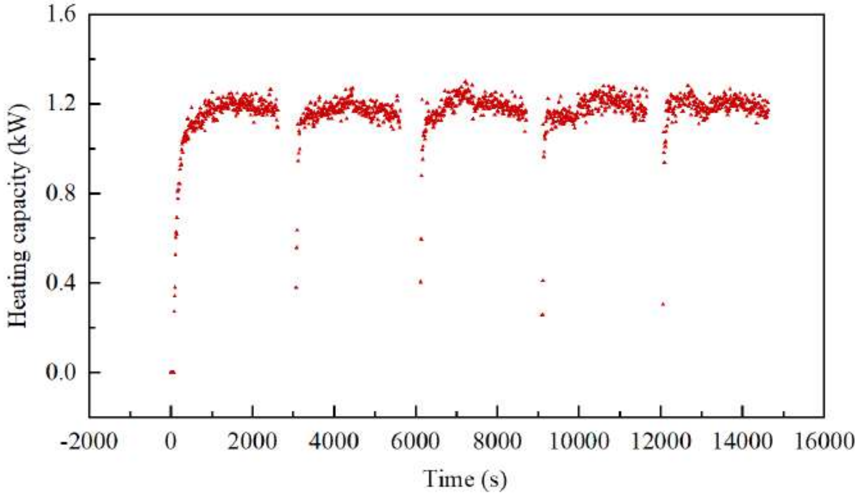
Water bridges

⬇

Detach from the surface during the subsequent defrosting procedure



Refrigerant inlet and outlet wall temperature of the evaporator copper tube.



Heating capacity of the frosting/defrosting cycles.

The maximum heat transfer fluctuation was only 0.8%.
The overall heat supply saw a variation of around 2.5%.
The COP findings of the cycles exhibited erratic fluctuations with a range of 2.6%.
After multiple frosting/defrosting cycles, the superhydrophobic evaporator unit kept a steady heating supply performance.

04 Conclusions

Conclusions

An optimized method for constructing superhydrophobic surfaces based on chemical etching and self-assembly of long-chain fatty acids was proposed.

- Superhydrophobic surfaces with contact angles stable above 160° can be obtained. A balance between the etching degree and reliability has been established, making the modified Al fins more superhydrophobic and durable. The reaction mechanism of the preparation process has been elucidated.

A visualization wind tunnel platform for frosting/defrosting testing of ASHP evaporators was constructed. The surface-modified finned-tube heat exchanger was applied to fixed-frequency ASHP units, and performance tests based on environmental control on the evaporator side were carried out.

- The increase in the maximum heating capacity and the delay in the decay period of the heating capacity are significant causes for the superhydrophobic evaporator unit's increased total heat supply. The maximum heating capacity of the superhydrophobic evaporator unit increased by 17% to 44% compared to the hydrophilic evaporator unit, and the COP increased by 11% to 32%. Multiple frosting/defrosting cycles of the superhydrophobic evaporator unit proved the reliability of the superhydrophobic finned-tube evaporators used in ASHP units.

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Thanks for your attention！

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