Air Dehumidification with Vacuum-Driven, Vapor-Selective Membranes for Efficient Separate Latent Cooling

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Abstract: Cooling and ventilating buildings is estimated to account for 10% of global electricity consumption, and dehumidification for buildings is often inefficient owing to the large heat of condensation and low evaporator temperatures required to cool below the dew point of the air. Thus, separate latent cooling technologies have gained significant interest in recent years to increase the efficiency of building HVAC processes. This presentation covers my work on vacuum membrane dehumidification, including new materials and novel system concepts to achieve potential energy savings up to 50% in buildings with high ventilation rates.

1 Introduction
- Buildings consume ~40% of all primary energy in the United States
- Greenhouse gas (GHG) emissions from HVAC are expected to grow
- Dehumidification can contribute to more GHG emissions than sensible cooling in many climates (Fig. 2)

2 Selective Membrane Materials
- Actively remove water vapor by combining selective membranes with a partial pressure difference
- Membrane dehumidification can be a high-efficiency technology for separate latent cooling.

3 Vacuum Membrane Dehumidification and AMX Concept
- Vacuum membrane dehumidification with sensible cooling and latent cooling in 2030 assuming static emissions intensity and building efficiency.
- Membrane dehumidification systems:
  - Low compression ratio = lower power consumption than other membrane dehumidification systems
  - Membrane dehumidification with sensible cooling and latent cooling in 2050 assuming static emissions intensity and building efficiency.
- Active Membrane Energy Exchanger:
  - Combines dual module vacuum dehumidification with sensible cooling
  - Process intensification
  - Enhances membrane performance
  - Improves cooling system coefficient of performance (COP)

4 Modeling and Experimental Methods
- System-level models developed in Engineering Equation Solver based on first and second laws
- Key building load information from EnergyPlus
- Computational fluid dynamics simulations in ANSYS and STAR-CCM+
- Fabricated several membrane materials, including Pebax + GO and PVA + TEG
- Scanning electron microscopy imaging
- ASTM permeance tests
- ISO permeance tests
- Solubility characterization
- Demonstrated 3 iterations of membrane module prototypes
- Built a complete test bench for steady-state performance analysis

5 Results
- Thermodynamic System Models
  - Up to 50% energy savings during extreme conditions and 20% annual savings
  - Cooling integration design can increase cooling COP and use waste heat for additional savings
  - Greatest potential in humid climates and buildings with high latent loads (e.g., restaurants)

6 Conclusions
- Vacuum-driven, vapor-selective membranes are a promising technology for efficient separate latent cooling
- The AMX system can theoretically provide up to 20% annual savings owing to low water vapor compression ratios, improved cooling COP, and waste heat use
- The AMX also enhances membrane performance owing to increased permeate at lower temperatures

References