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Expected energy and economic benefits, and environmental impacts for liquid-to-air membrane energy exchangers (LAMEEs) in HVAC systems: A review

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HIGHLIGHTS

- LAMEEs can be used for air dehumidification and energy recovery in HVAC systems.
- The economic benefits and environmental impacts of LAMEEs are reviewed.
- LAMEEs can effectively improve indoor air quality.
- Several topics are suggested for future research.

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ABSTRACT

A review of the literature on liquid desiccant-to-air permeable-membrane energy exchangers will indicate opportunities for future research and application of this new technology in HVAC systems. HVAC systems are responsible for a large fraction of energy consumption and some airborne emissions other than CO_2. Liquid-to-air membrane energy exchangers (LAMEEs) can be used in run-around membrane energy exchanger (RAMEE) systems for passive energy recovery and can be used as a dehumidifier/regenerator for active air dehumidification in HVAC systems. LAMEEs have been under research and development for over a decade. This paper reviews the applications of LAMEEs for ventilation energy recovery and air dehumidification in buildings and automotive air-conditioners.

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Nomenclature

Acronyms

ACH	Air Changes Per Hour
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
AUD	Australian Dollar
COP	Coefficient of Performance
ECOP	Electrical Coefficient of Performance
HVAC	Heating, Ventilation, and Air Conditioning
NTU	Number of Heat Transfer Units
PP	Polypropylene
PTFE	Polytetrafluoroethylene
RH	Relative Humidity
TCOP	Thermal Coefficient of Performance
tCO_2e	Tons of Carbon Dioxide Equivalent
VAV	Variable-Air-Volume

Symbol

Cr^*	Ratio between solution and air heat capacity rates

Chemical symbols

CO	Carbon monoxide
CO_2	Carbon dioxide
CH_4	Methane
$CaCl_2$	Calcium chloride
H_2S	Hydrogen sulfide
K_2CO_3	Potassium carbonate
$KMnO_4$	Potassium permanganate
LiBr	Lithium bromide
LiCl	Lithium chloride
$LiNO_3$	Lithium nitrate
$MgCl_2$	Magnesium chloride
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
O_3	Ozone
PM	Particulates
SO_x	Sulfur oxides
SO_2	Sulfur dioxide
VOCs	Volatile organic compounds

1. Introduction

Between 2000 and 2011, global energy consumption increased by 32% [1,2] and the building sector is responsible for 40% of this total [3,4]. In recent years, research [5–20] has been conducted to reduce cooling and heating energy consumption in buildings. Heating, ventilation, and air-conditioning (HVAC) systems are responsible for a substantial portion of the total energy consumed in buildings; for instance, space cooling consumes 70% of the building total energy consumption in the Middle East region [21], and space heating represents 60% of the building total energy consumption in the UK [22].

Buildings account for more than 30% of global CO_2 emissions [23]. Since the industrial revolution, global warming, outdoor air quality, and climate change have become serious environmental problems, where a large percentage increase in greenhouse gases contained in our planet's atmosphere (e.g. CO_2 and CH_4, etc.) prevent low temperature re-radiation of solar gain from easily leaving the atmosphere, causing the global average air temperature to increase. Sims [24] reported the following facts: (1) the atmospheric concentration of CO_2 has increased by 31% during the last 200 years, (2) the global mean surface temperature has increased by 0.4–0.8 °C during the past century, (3) due to ice melting, sea levels have increased by an average rate of 1-2 mm/year during the past century, and (4) the number of frost days all over the world has decreased over the past century [24].

Since people spend more than 90% of their time in buildings [25], it is important to provide good and healthy indoor environment for occupants. Depending on the climate (cold, hot, humid, etc.) and building type (hospital, school, residence, etc.), outdoor ventilation air conditioning can consume up to 30–60% of the total energy consumption in buildings [26]. Wyon [4] found that poor indoor air quality may reduce the performance of the occupants in an office by up to 6–9%. Therefore, if ventilation rates are reduced below acceptable standards for the sake of energy conservation, occupant productivity losses are likely to follow.

In conventional air-conditioning systems, dehumidification of the supply air is achieved by cooling the air to a temperature below its dew point temperature to remove moisture, and then reheating the air to a comfortable temperature before it is supplied to the conditioned space. This process consumes large amounts of energy. Energy recovery is an effective method to reduce the energy consumption in building HVAC systems. Different types of energy recovery ventilators (ERV) have been investigated [27–33] and integrated with air dehumidification systems [34–37]. However, they encounter some challenges in practical applications, especially for the retrofitting of existing buildings.

2. Direct-contact liquid desiccant energy exchangers

In the last two decades, direct-contact liquid desiccant air-conditioning systems, where the supply air is dehumidified through

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