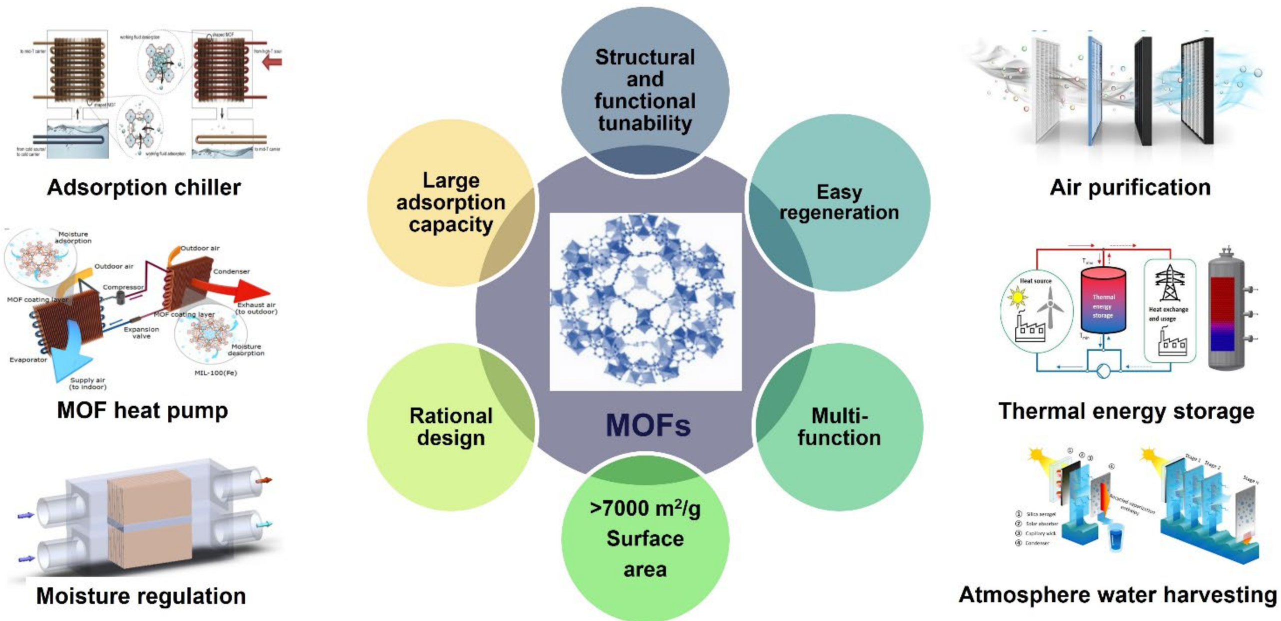
Smart materials for energy-efficient heating, cooling and IAQ control in residential buildings

EBC ANNEX 92

The fast-growing use of heating, ventilation and air-conditioning (HVAC) systems in buildings worldwide has become one of the main drivers of global energy demand. An estimated 3.3 billion room air-conditioners will be installed globally between now and 2050. Many new air-conditioning units are energy inefficient and will significantly burden electricity grids and our climate. Using air conditioners for cooling and dehumidification already accounts for more than 30% of the total building electricity consumption. When combined with the atmospheric impact of refrigerants, the energy consumption associated with cooling represents one of the largest end-use risks to our climate. The basic technology of mechanical cooling hasn't changed much since it was invented 100 years ago. Drastic transformation of cooling/heating technology by using new functional materials and new physical-chemical processes can significantly reduce HVAC systems' energy demand, improving indoor air quality (IAQ) and minimizing the negative impacts on the environment and climate.

Numerous novel functional materials have been developed by chemists and material scientists in recent decades. Many of them have exceptional sorption performances and hygrothermal properties, such as metal-organic frameworks (MOFs), polymer hydrogels, etc. They can be integrated into either building structures or HVAC systems to passively/actively control the indoor hygrothermal conditions and IAQ, and reduce the energy demand for air-conditioning and ventilation. MOFs are a recently developed class of crystalline micro or meso-porous materials. The organic-inorganic hybrid characteristics lead to a unique steep uptake of water vapor. Their exceptional chemical and structural diversity allow them to tune on demand the hydrophilic/hydrophobic balance and is associated in most cases with an easy release at low relative pressures and moderate temperatures (50-80°C), together with high working capacities (up to 2g of water vapor per g of MOF) under these conditions while their cyclability under long term testing for heat reallocation or dehumidification has also been established. This makes MOFs highly attractive, promising materials for energy-efficient applications in adsorption devices for humidity control (evaporation and condensation processes) and heat reallocation (heating and cooling) by utilizing water as benign adsorptive and low-grade renewable or waste heat. Emerging MOF-based process applications covered are dehumidification, heat pumps/chillers, air conditioning, air cleaners, thermal energy storage, water harvesting, etc.

This annex project will develop energy-efficient heating, cooling and air purification strategies by using novel smart materials, especially advanced sorbents, such as metal-organic frameworks (MOFs) and their related composites, through cross-disciplinary



Metal-organic framework (MOF) and its application for built environment control
Source: EBC Annex 92

international collaboration. The project will gather the existing scientific knowledge and data on novel sorbent materials for cooling/dehumidification, pollutant removal, heating and energy storage; study current and innovative use of these materials in air-conditioning, air purification, and thermal storage systems. It will also identify and bridge the knowledge gaps by establishing links between different disciplines. In the project, experts from building science, materials chemistry, mechanical engineering, material sciences, and environmental health will work together with other stakeholders to accelerate the development of better and more energy-efficient heating, cooling, and IAQ control systems by using advanced materials.

The Annex consists of five synergetic Subtasks.

- Subtask A - Material preparation and characterization.
- Subtask B - Applications: Cooling and dehumidification.
- Subtask C - Applications: Air purification and ventilation.
- Subtask D - Applications: Heating and energy storage.
- Subtask E - Dissemination, management and interaction.

Subtask A will conduct fundamental research on new MOF materials and will provide materials samples and characterization data for other subtasks. Subtasks B, C, and D will work largely in parallel, but their work is closely interconnected, with the results from the different tasks feeding into the work of others. This requires an iterative process of interaction with the whole group.

Objectives

The annex project aims to develop energy-efficient heating, cooling and air purification strategies by using novel smart materials, especially advanced sorbents (MOFs and hydrogels) and their related composites, through a cross-disciplinary international collaboration.

The Annex has the following specific key objectives:

- To establish a cross-disciplinary international collaboration platform to develop breakthrough cooling/heating technologies by using smart materials.
- To review, analyze, and evaluate novel sorbent materials suitable for energy-efficient heating, cooling, and air purification. Selection criteria will be set up for different applications.
- To develop or further improve the performance of the selected materials for specific applications in different climates.
- To develop suitable shaping methods of the best sorbents to adapt to the criteria of the different applications.
- To identify or further develop innovative cooling systems using new materials, which avoid conventional vapor compression refrigeration.
- To develop innovative air purification systems using new sorbent materials. Both the active system and passive approaches will be studied.
- To develop innovative heating and heat storage systems using new sorbent materials.
- To carry out laboratory tests to measure the performance of the new solid cooling, heating, and air purification systems. Numerical modeling and optimization will also be conducted.
- To develop guidelines regarding design and control strategies for novel cooling, heating and air purification systems using novel sorbent materials.
- To identify or further develop models and tools that will be needed to assist designers and managers of buildings in using the guidelines.
- To identify and investigate relevant case studies where the above-mentioned performances can be examined and optimized.

Deliverables

The project shall result in the following 4 deliverables:

- A literature list for energy efficient energy management. This deliverable will provide a comprehensive overview of all the literature that was used and highlighted during the annex.
- An overview report on methods and tools for selecting smart materials for energy-efficient cooling, dehumidification, IAQ control and thermal energy storage strategies.
  This deliverable will provide professionals and practitioners with a collection of methods and tools for IAQ management strategy.
- A collection of scientific publications at high-level journals. This deliverable will bring together scientific publications from all subtasks.
- A collection of case studies and demonstrations of energy-efficient heating, cooling and thermal energy storage using smart materials.
  This deliverable will provide both policy and industry practitioners with an overview of current practices and real-life examples of energy-efficient built environment control strategies using novel smart materials.

Target audience

- Materials and HVAC system manufacturers
- Building designers and consultants
- Researchers and professionals
- Policy makers, standardization bodies and public authorities
- Building owners, managers, and users

Project duration
2024 – 2028

Operating Agent
Prof. Menghao Qin, Technical University of Denmark (DTU), Denmark

Participating countries
Australia, Austria, Belgium, Brazil, Canada, China, Denmark, France, Germany, Korea, Norway, Portugal, Sweden, USA

Further information
www.iea-ebc.org