Metal-organic Frameworks (MOFs) for indoor environment control

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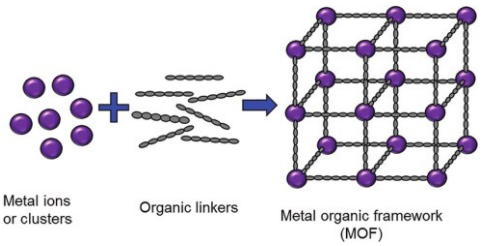
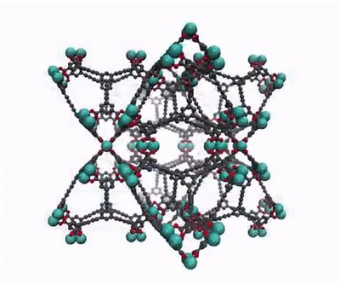
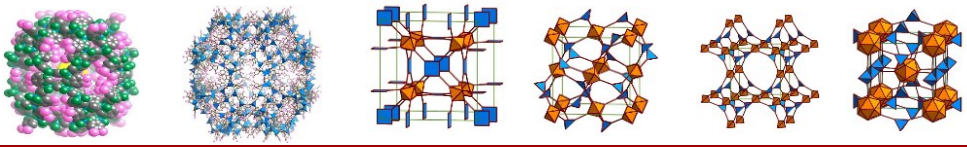
What is Metal-Organic Framework (MOF)?

- Metal-organic frameworks (MOFs) are a new class of organic-inorganic hybrid crystalline porous material.







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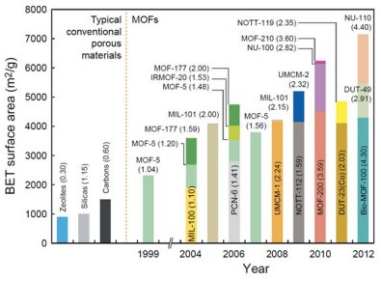
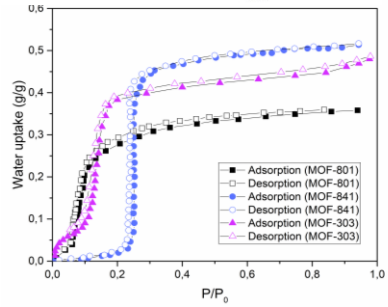
Main features of MOFs

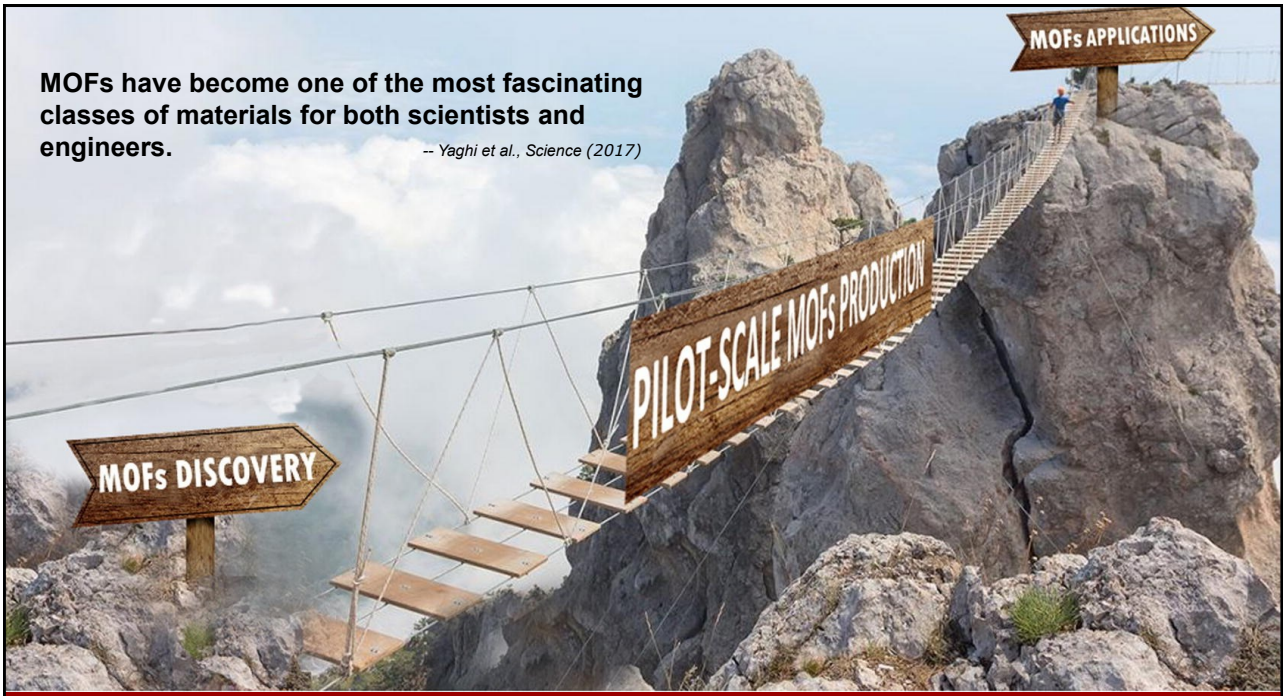
- Very high surface areas (up to 8000 m^2/g)
- Large adsorption capacity for gas (up to 2 g/g water vapour at 80% RH)
- Low regeneration temperature (around 60 ^oC)
- Structural and functional tunability
- S shape water vapor isotherms



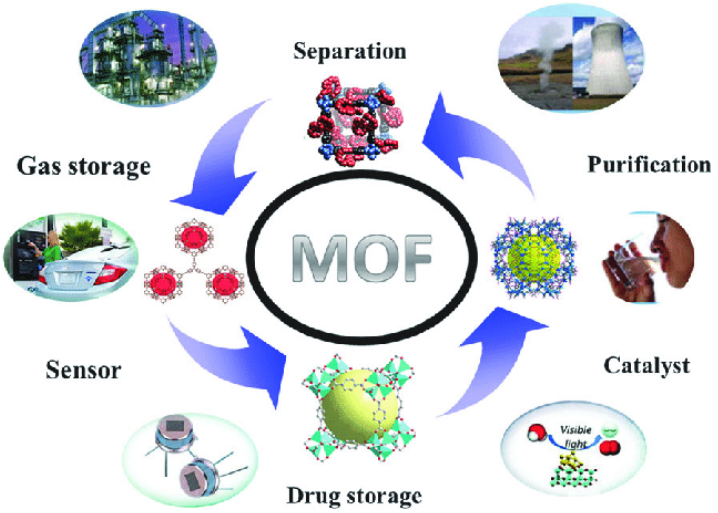


MOFs have become one of the most fascinating classes of materials for both scientists and engineers.

-- Yaghi et al., Science (2017)



Applications of MOFs



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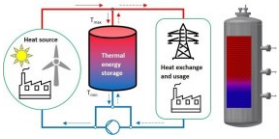
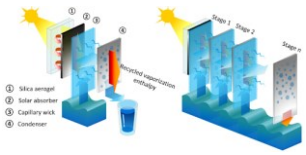
MOFs applications in built environment

Moisture regulation

Air purification



Thermal storage



Atmosphere water harvesting

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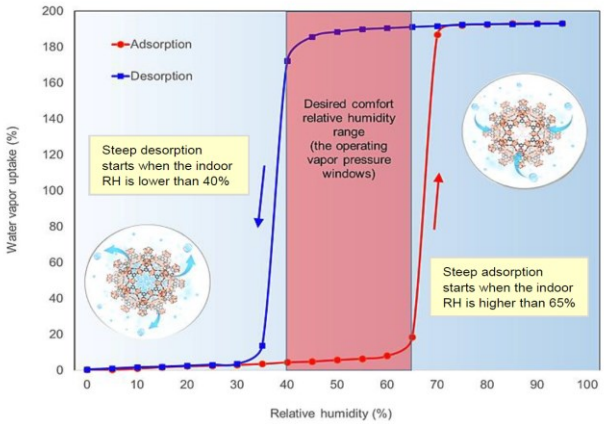
App 1. MOF based autonomous humidity control materials

- Indoor relative humidity is an important parameter to determine indoor air quality, occupants' thermal comfort and building energy consumption. As recommended by ASHRAE, the appropriate indoor relative humidity range for indoor environment is **between 40% and 65% RH**.

The ideal materials for autonomous regulation of indoor RH should meet the following criteria:

- The material should have an S-shape isotherm and exhibit a steep uptake isotherm at a specific relative humidity depending on the targeted application.
- High water vapor uptake within the operating vapor pressure window;
- Low regeneration temperature and high reproducible cycling performance;
- High hygrothermal stability, non-toxicity and non-corrosion.



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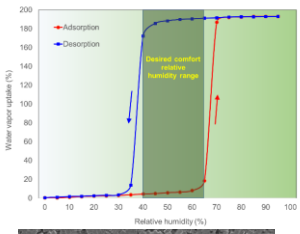
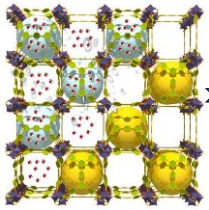
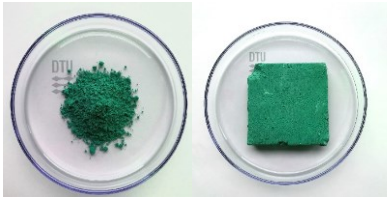
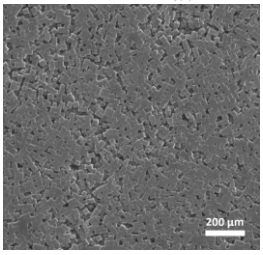
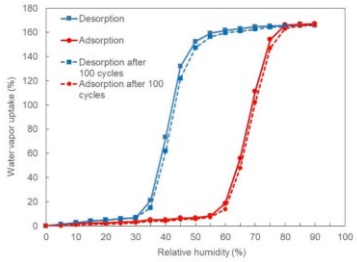










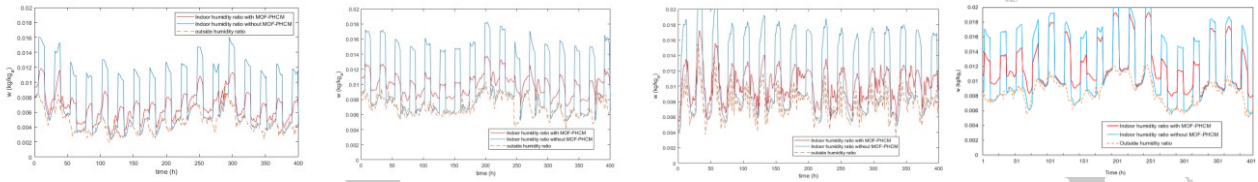
MBV of MOF-PHCM is 20.50 $g \cdot m^{-2} \cdot RH^{-1}$ at 8 hours in the experimental conditions, which is almost **45** times higher than that of laminated wood and **36** times higher than gypsum

M. QIN et al, Precise humidity control materials for autonomous regulation of indoor moisture, Building and Environment, Vol. 169, 2020.

App 1. MOF based autonomous humidity control materials

Test and simulations in different climates

- Salt Lake City (semi-arid climate),
- Phoenix (hot desert climate),
- Paris (temperate climate)
- Madrid (moderate Mediterranean climate),
- Shanghai (humid subtropical climate).



M. QIN et al, Precise humidity control materials for autonomous regulation of indoor moisture, Building and Environment, Vol. 169, 2020.

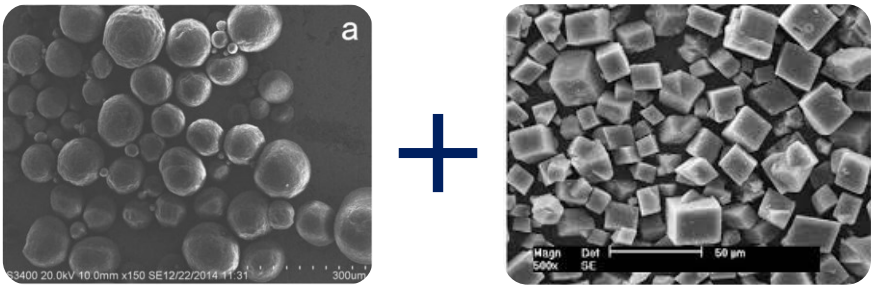
App 1. MOF based autonomous humidity control materials

- MOF-PHCM can autonomously control indoor relative humidity within the thermal comfort range and reduce building energy consumption in most climates without any additional energy input.
- MOF-PHCM can be easily regenerated by either night ventilation (e.g. in hot desert, semi-arid, Mediterranean climates) or heating system powered by low-grade energy (e.g. in humid climates).

M. QIN et al, Precise humidity control materials for autonomous regulation of indoor moisture, Building and Environment, Vol. 169, 2020.

App 2. Metal-Organic Framework /Microencapsulated Phase Change Material Composites

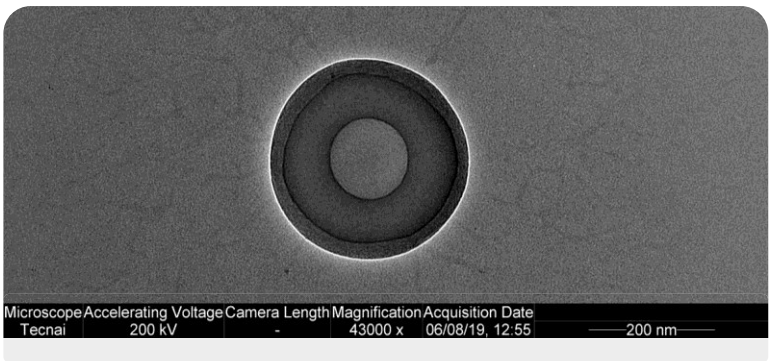
Phase Change Humidity Control Material (PCHCM) can moderate both the indoor temperature and moisture.



M QIN et al., Phase change humidity control material and its impact on building energy consumption. Energy and Buildings 174 (2018) 254-261.

App 2. Metal-Organic Framework /Microencapsulated Phase Change Material Composites

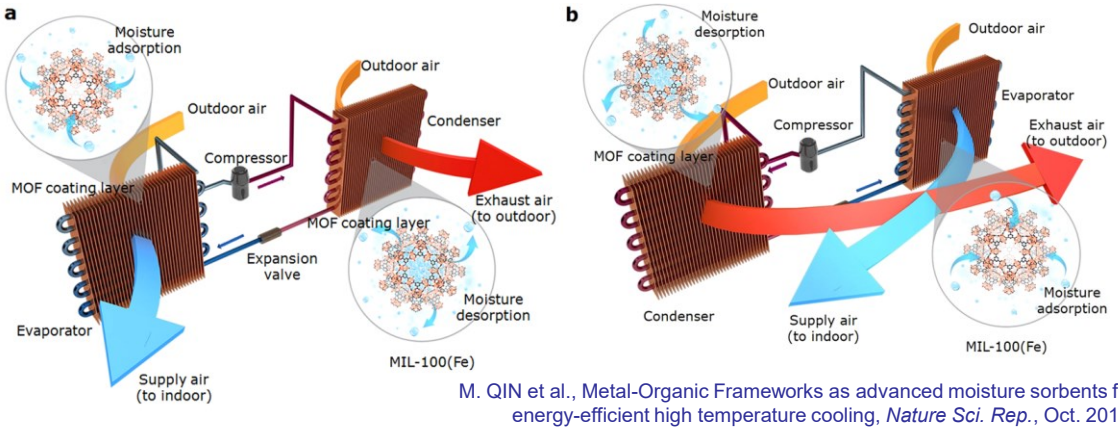
Double shell MOF/PCM composites can moderate both the indoor temperature and moisture. （2020）



M QIN et al., Preparation and Characterization of Metal-Organic Framework /Microencapsulated Phase Change Material Composites for Indoor Hygrothermal Control. Journal of Building Engineering, 2020.

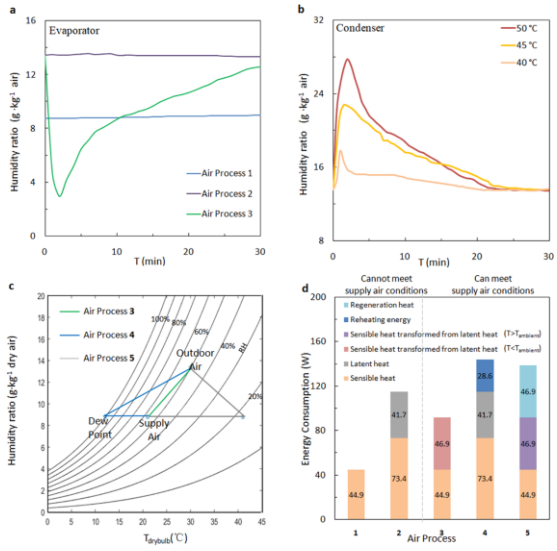
App 3. MOF coated heat exchangers

- Traditional vapour-compression air-conditioning has a low coefficient of performance (COP) due to the refrigeration dehumidification process, which often makes necessary a great deal of subsequent re-heating.



M. QIN et al., Metal-Organic Frameworks as advanced moisture sorbents for energy-efficient high temperature cooling, *Nature Sci. Rep.*, Oct. 2018.

App 3. MOF coated heat exchangers

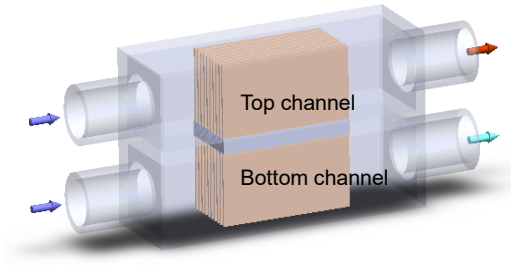


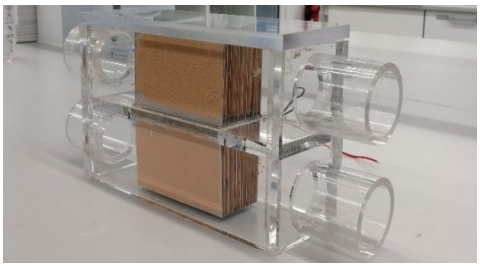
- MOFs coated heat exchangers has a good performance in removing **both latent and sensible heat loads simultaneously.**
- The system makes possible an energy-efficient working cycle with **a small temperature difference of less than 30 C** between the evaporator and the condenser
- The system **eliminates 36.1% of the working load** in refrigeration-based dehumidification by a conventional air-conditioner with reheating. The **overall COP of the system could be up to 7.9**.

M. QIN et al., Metal-Organic Frameworks as advanced moisture sorbents for energy-efficient high temperature cooling, Nature Sci. Rep., Oct. 2018.

App 4. MOF humidity pump

The concept of a humidity pump is inspired by a heat pump. A humidity pump is a device that can transport moisture through the inverse gradient of vapor concentration, i.e., the vapor can be transferred from a relatively low-humidity space to a high-humidity space. For example, in summers, the humidity pump will transfer moisture from cool and less-humid indoor condition to a hot and humid outdoor condition; vice versa, in winters.





M. QIN et al., A novel metal-organic frameworks based humidity pump for indoor moisture control, Building and Environment, 107396, 2020

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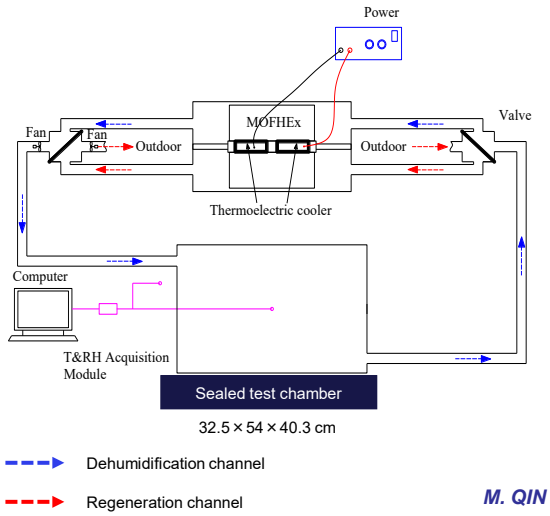
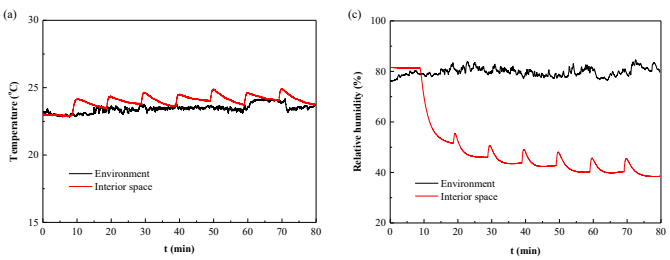
App 4. MOF humidity pump





- *MOFs* are promising desiccants to the indoor environment control;
- The humidity pump can achieve dehumidification above the dew point temperature, improving the *overall efficiency*;
- The humidity pump has a *fast response rate* to the humidity load of a localized space;
- The humidity pump has *compact and flexible structures*.

M. QIN et al., A novel metal-organic frameworks based humidity pump for indoor moisture control, Building and Environment, 107396, 2020

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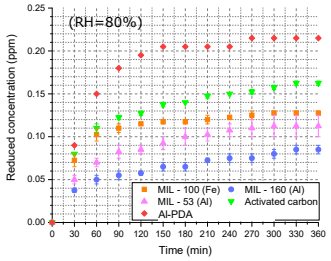
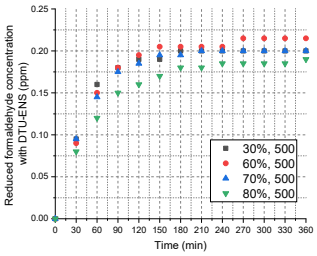
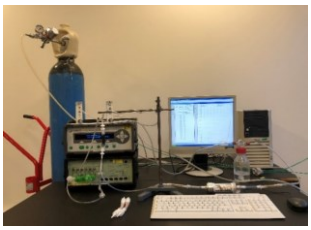
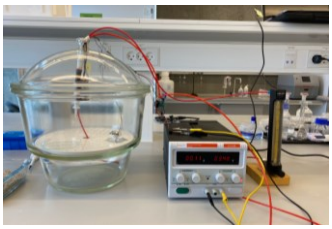
App 5. MOFs for VOC (formaldehyde) removal

The DTU test conditions:
temperature (23ºC),
Relative humidity (30%, 60%, 70%, and 80%RH).
The initial formaldehyde concentration is 0.26ppm









S. Chen, Master thesis, 2021

Conclusion

- MOFs with large adsorption capacity, the energy demand of desorption, ad/desorption kinetics, and cycling durability are good candidates for energy-efficient indoor environment control.
- Superior moisture sorption based on materials with enhanced water affinity, large surface area and high porosity can increase the water uptake to adsorb more moisture from the indoor air.
- Pyrazole-based MOFs are the best sorbents for FA adsorption from air.
- Low regeneration energy demand can be achieved by tailoring the sorption behavior of materials and incorporating functional materials,
- Fast moisture/VOC adsorption and desorption are essential for energy-efficient dehumidification/air cleaning within a short period of time.

Thank you for your attention!

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