Potential of an Ambient Air for Energy Saving Technologies through the Maisotsenko Cycle

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Outline

Evaporative Cooling

Evaporative Cooling

Mist Coolers

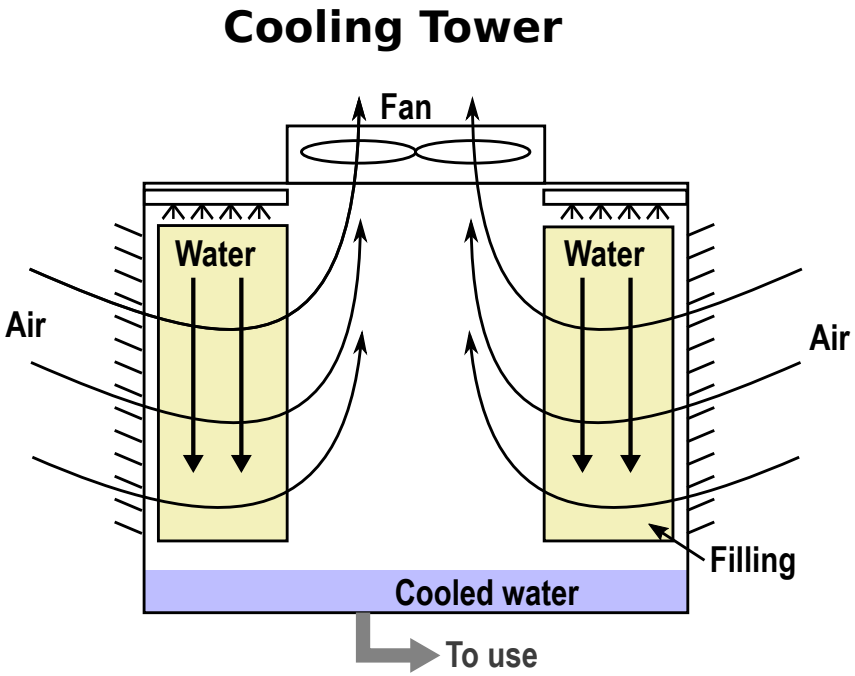
Pot-in-pot

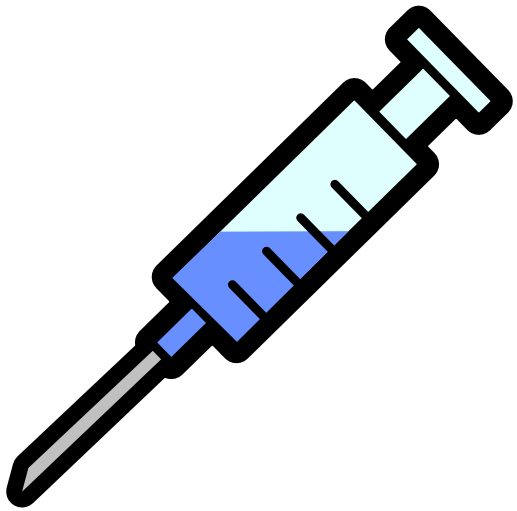
Uchimizu

Evaporation of Water

Evaporation of 1g of water uses about 2.5 kJ of heat

⇒ Water evaporation of 1 g can cool 100 g of water by 6 K.





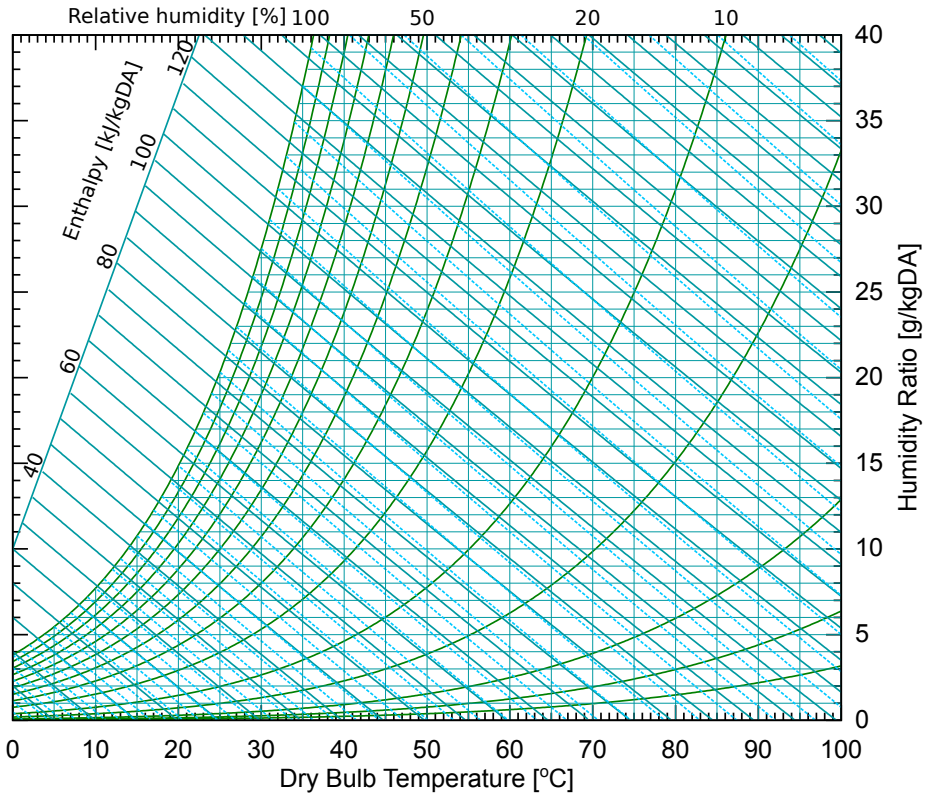
Psychrometrics

- The atmosphere contains 1-3 weight % of water vapor
- The constitution of dry air is almost constant up to 80km in altitude

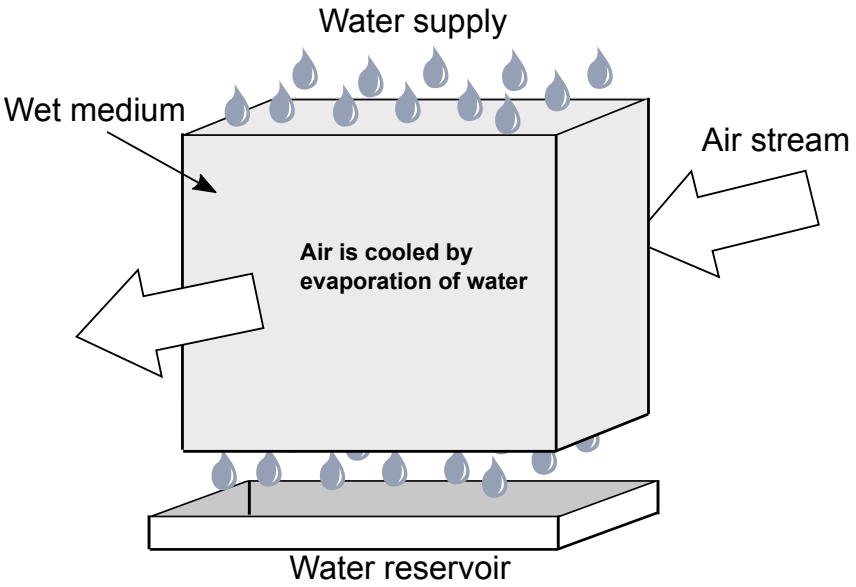
Terminology

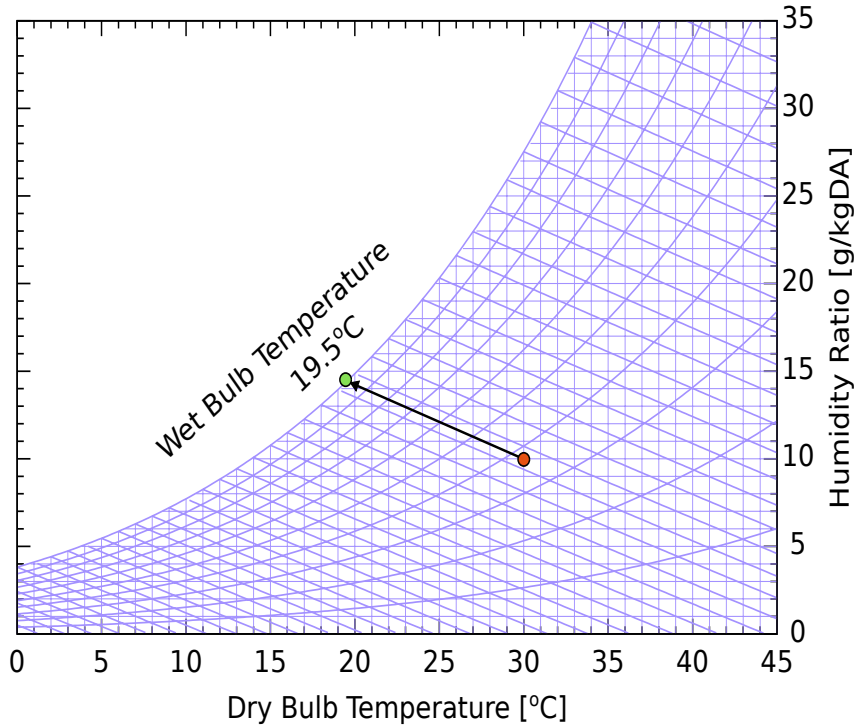
Dry air:
Air with neither water vapor nor any contaminants

Wet air:
Dry air + water vapor



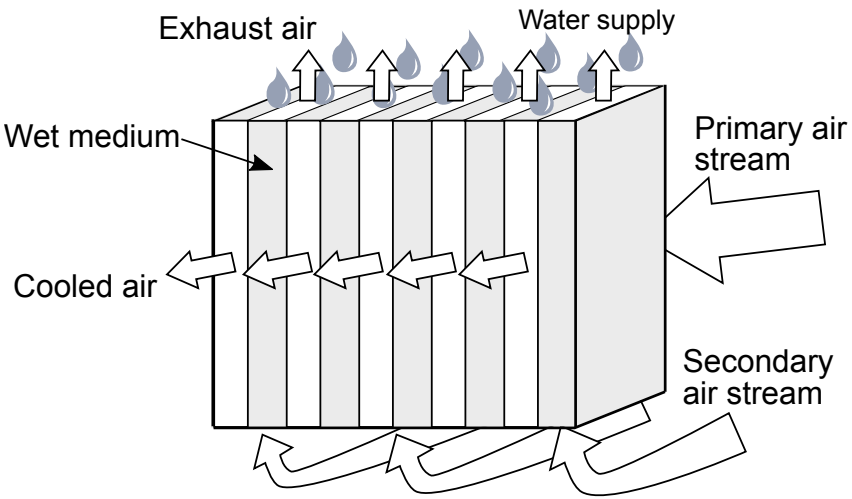
Direct Evaporative Coolers

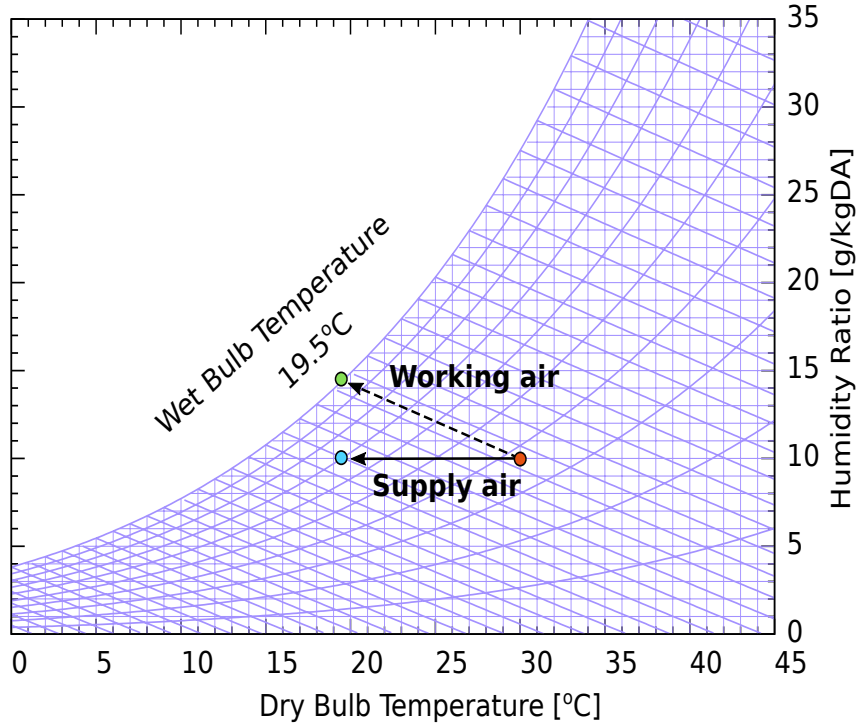




- Direct contact of air and water.
- Humidity ratio of the air increases.
- Cooling limit is defined by the wet-bulb temperature.

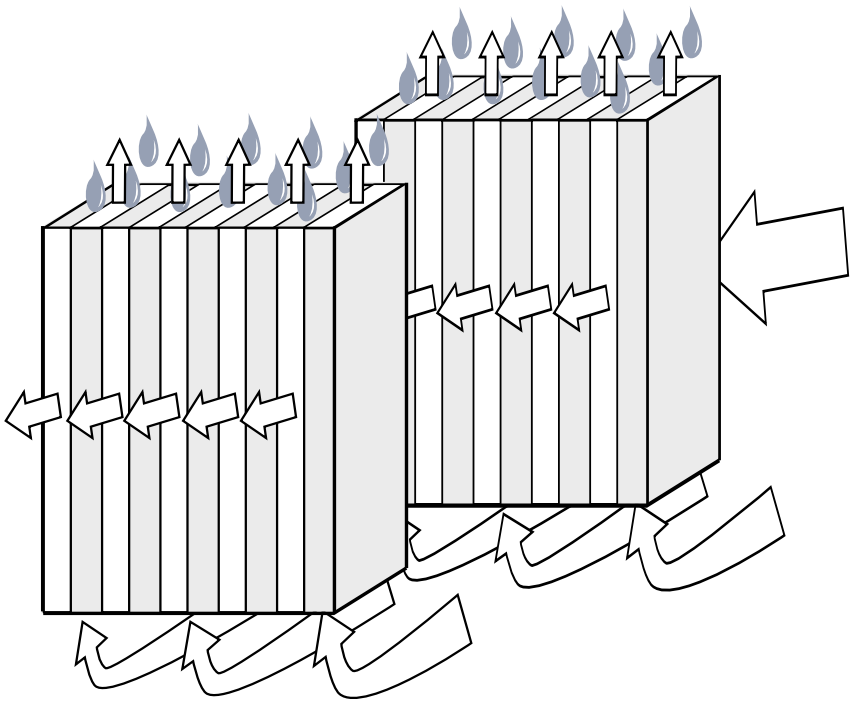
Indirect Evaporative Coolers

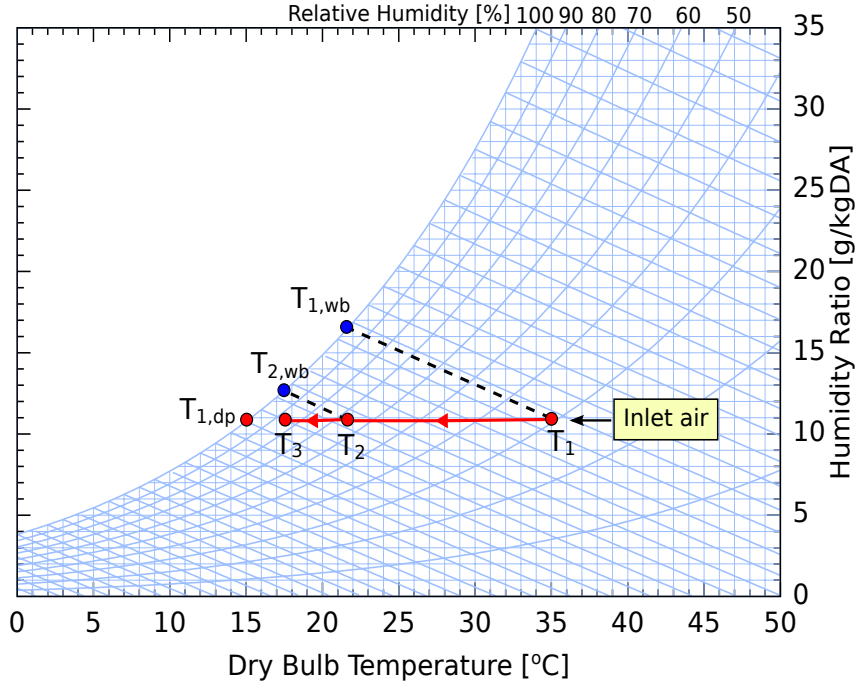




- Different air path for supply air and working air.
- Humidity ratio of the supply air does not increase.
- Cooling limit is defined by the wet-bulb temperature.

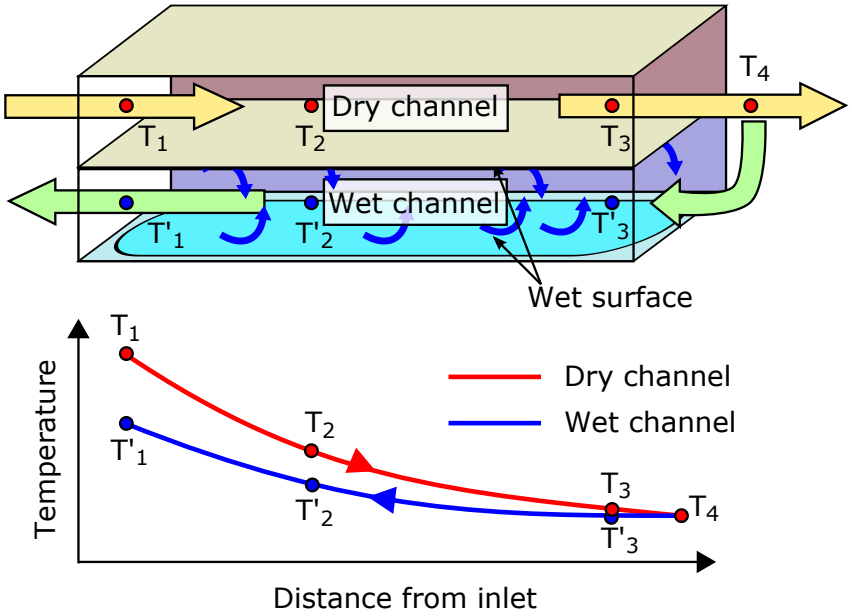
A Multistage Evaporative Cooler

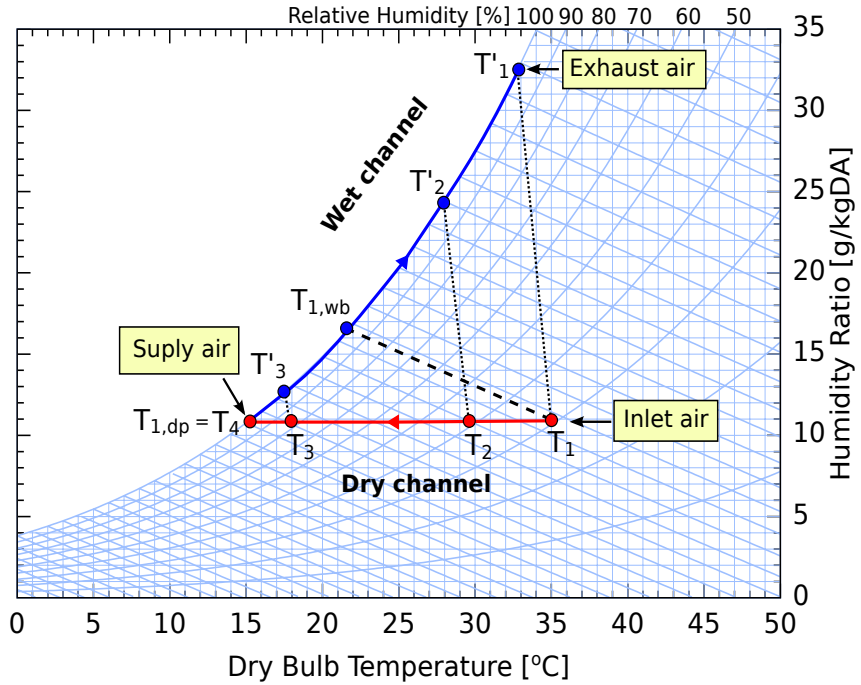




- The cooled air from an indirect evaporative cooler is further cooled by the secondary indirect evaporative cooler.
- The air temperature theoretically reaches the dew point of the inlet air by infinite stages of cooling.

The M-Cycle Evaporative Cooler





- Consists of of **Dry Channel** and **Wet Channel**, and a part of air flow through the dry channel enters the wet channel.
- The humidity ratio in the dry channel does not change, while it increases up to the saturation humidity in the wet channel.
- Theoretically, the inlet air can be cooled to **dew point temperature** at the exit of the dry channel.

The Maisotsenko Cycle (M-Cycle)

Prof. Dr. Valeriy S. Maisotsenko

Professor Emeritus,

Chief Scientist, Seeley International Americas, Coolerado

The M-Cycle is a thermodynamic concept invented by Prof. V.S. Maisotsenko.

I²CNER Seminar Series, 24th, June, 2015

https://www.youtube.com/watch?v=uWMK7ytqmnE

Performance of the M-Cycle

Enthalpy balance and temperature effectiveness

Enthalpy balance

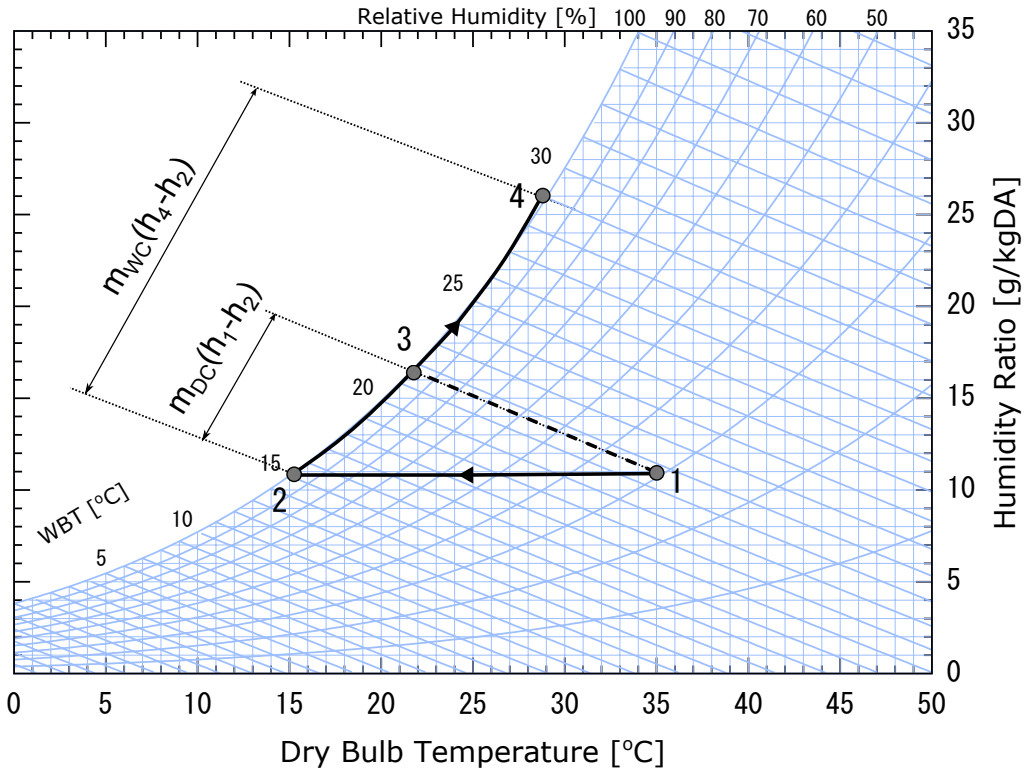
$$\dot{m}_{\mathrm{DC}}\left(h_1 - h_2\right) = \dot{m}_{\mathrm{WC}}\left(h_4 - h_2\right)$$

Supply air ratio

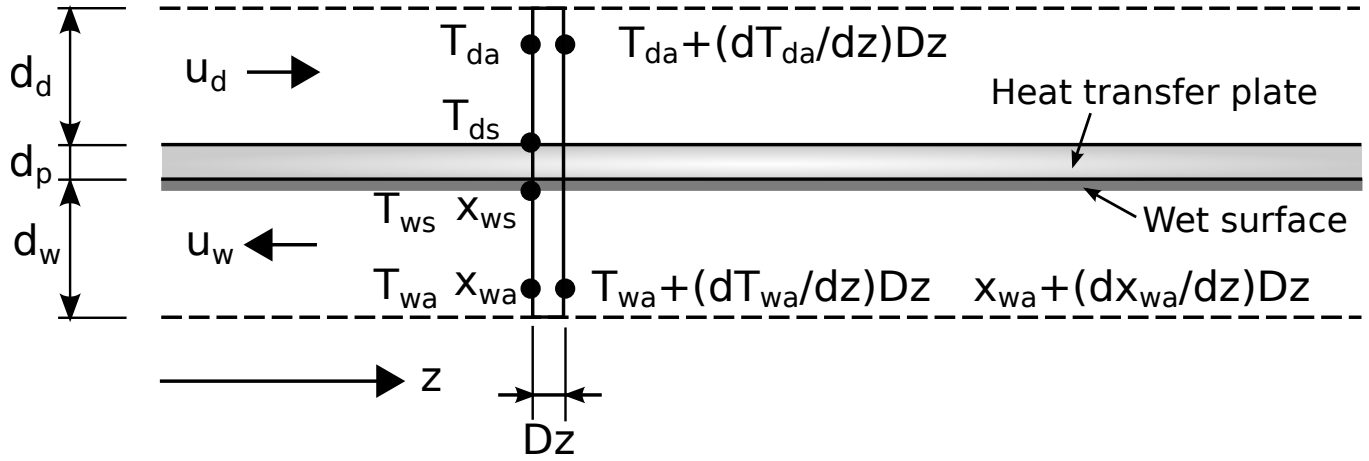
$$\gamma = \frac{\dot{m}_{\mathrm{DC}} - \dot{m}_{\mathrm{WC}}}{\dot{m}_{\mathrm{DC}}} = \frac{h_4 - h_1}{h_4 - h_2}$$

Dewpoint effectiveness

$$\eta = \frac{T_1 - T_2}{T_1 - T_{dp}}$$



Simulation Model



Dry channel

$$\frac{\mathrm{d}T_{\mathrm{da}}}{\mathrm{d}\zeta} = \frac{Nu_{\mathrm{d}}}{Re_{\mathrm{d}}Pr} A_{\mathrm{d}}(T_{\mathrm{ds}} - T_{\mathrm{da}})$$

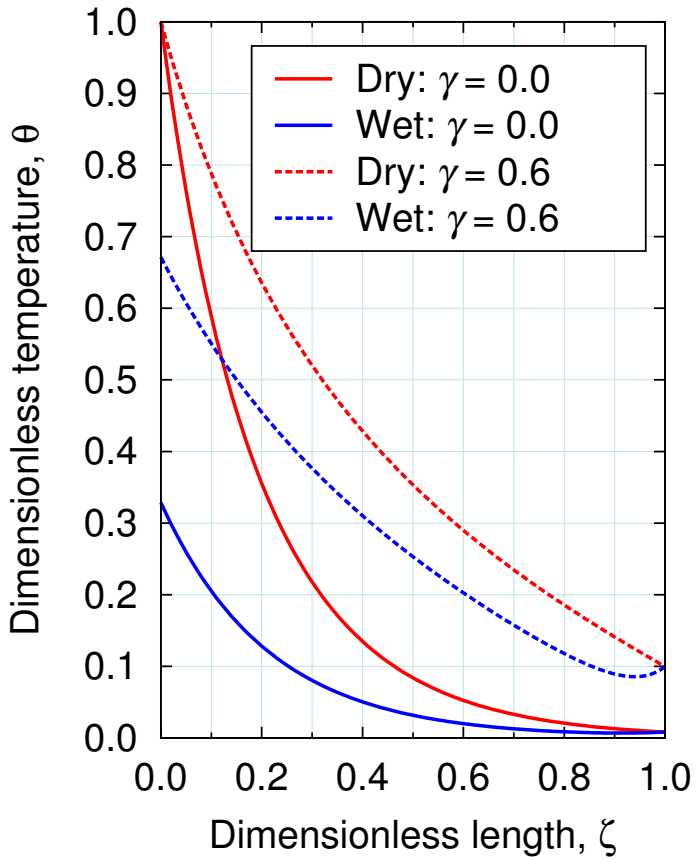
Wet channel

$$\frac{\mathrm{d}T_{\mathrm{wa}}}{\mathrm{d}\zeta} = \frac{Nu_{\mathrm{w}}}{Re_{\mathrm{w}}Pr} A_{\mathrm{w}}(T_{\mathrm{wa}} - T_{\mathrm{ws}})$$

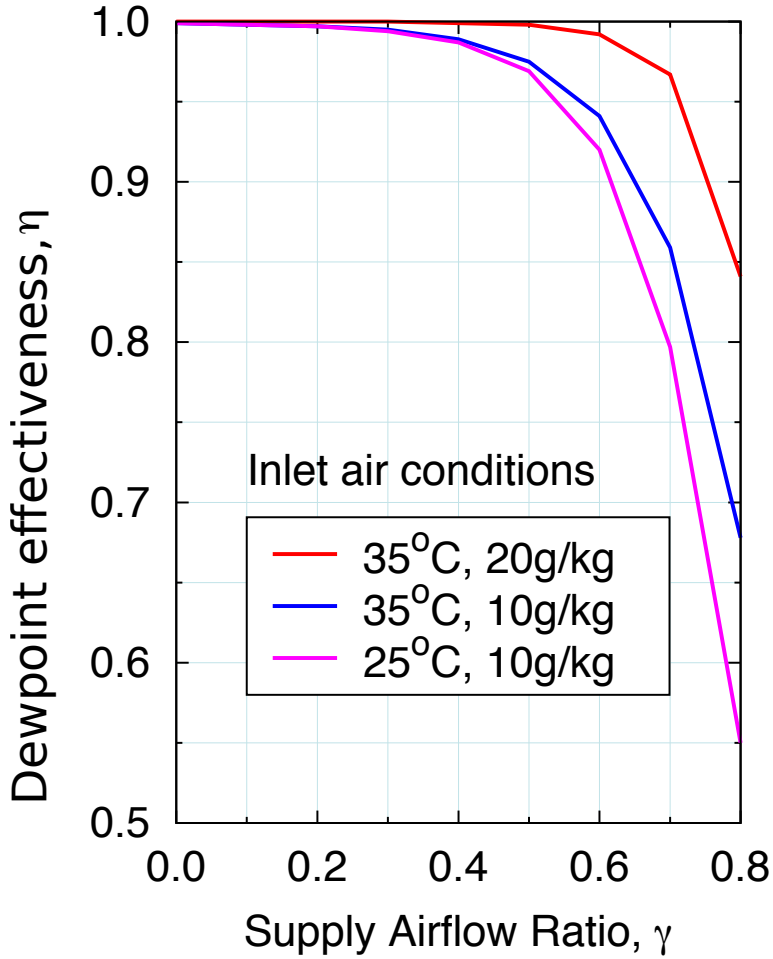
$$\frac{\mathrm{d}x_{\mathrm{wa}}}{\mathrm{d}\zeta} = -\frac{Sh}{Re_{\mathrm{w}}Sc} A_{\mathrm{w}}(x_{\mathrm{ws}} - x_{\mathrm{wa}})$$

$$(\zeta = z/L, \quad A = L/d)$$

Characteristics of the M-Cycle



Temperature distribution in the air path



Relationship between the dewpoint effectiveness and the supply air ratio.

Commercialized Products

C60

M30

M50

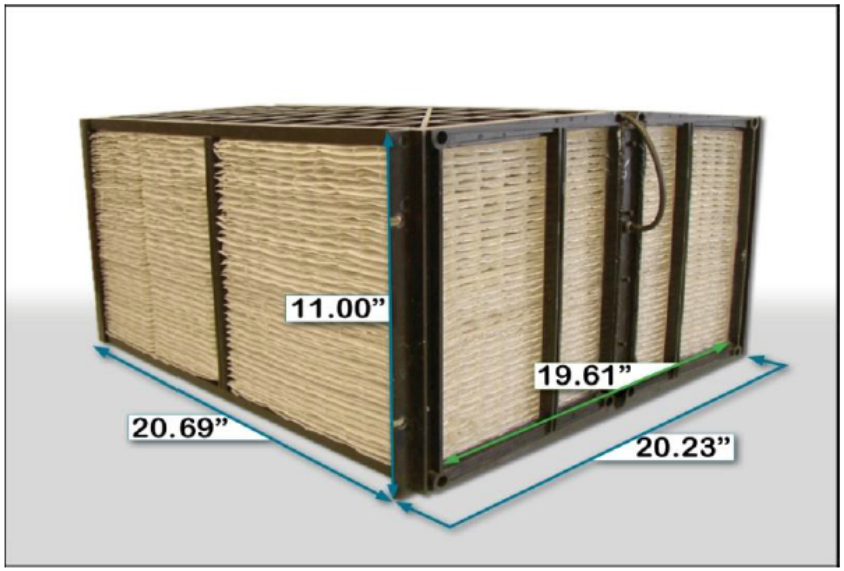
Hybrid H80

Coolerado ERV

Coolerado
Solar Air Conditioner

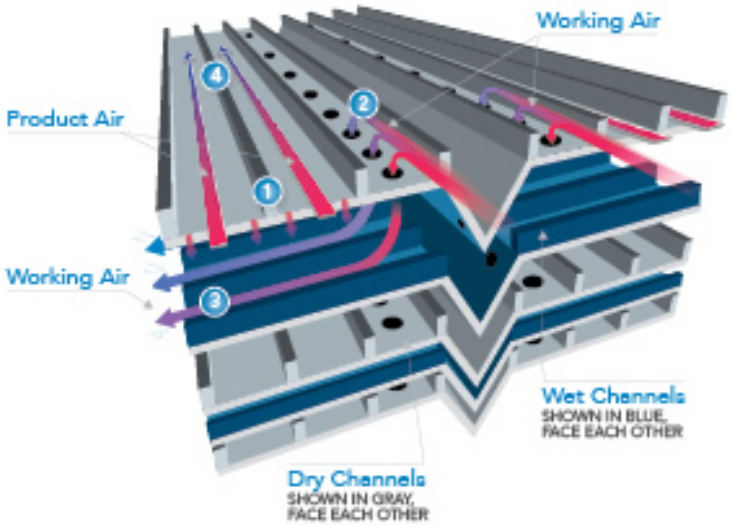
by Coolerado Corp., US

M-Cycle Heat and Mass Exchanger



A lot of problems are already overcome.

- Pressure drop
- Durability
- Hygiene



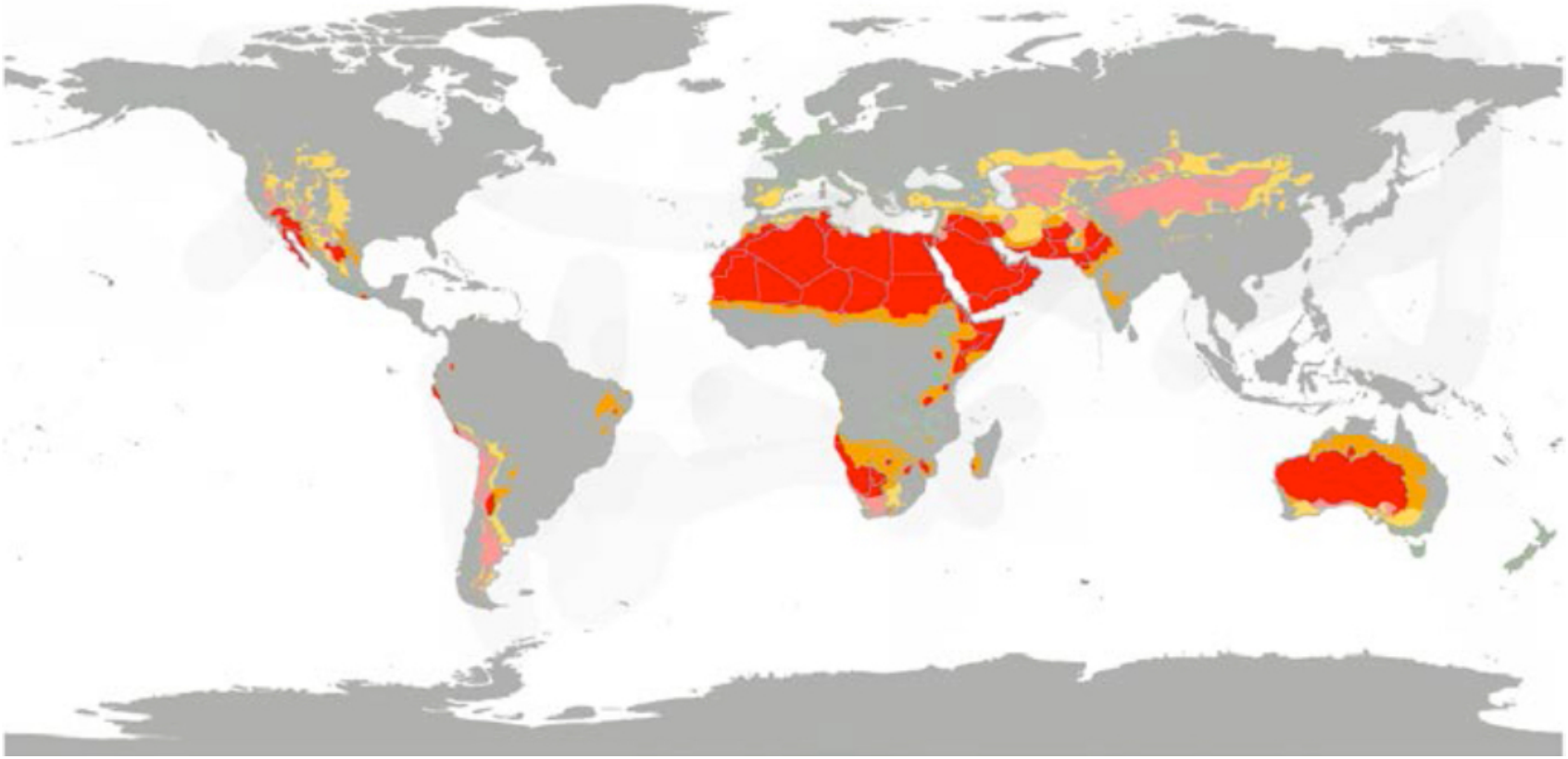
1. Product air and working air enter the dry side of the HMX.
2. Cooled working air is fractioned off into wet channels throughout the exchanger.
3. Heat from the product air is transferred into the working air through evaporation and is rejected as exhaust.
4. The product air travels the length of the dry channels, while transferring its heat to the working air in the wet channels above and below. As a result, the product air cools down and remains dry as it enters the building.

Ref: Coolerado web site, `http://www.coolerado.com`

Applications of the M-Cycle Technology

Possibility of the M-Cycle Application

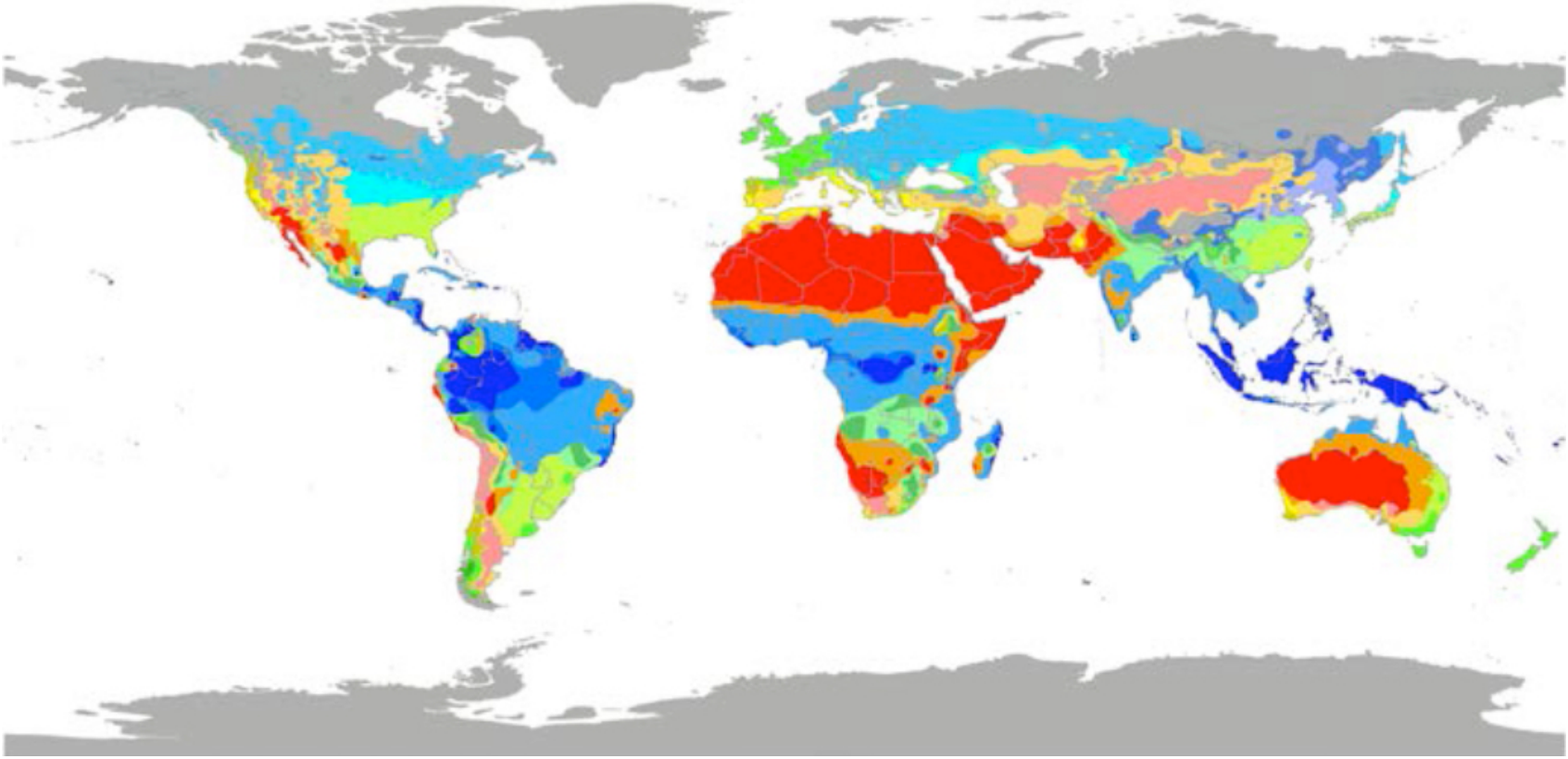
Effective in dry region（7-10% of world population）



Ref.: Buyadgie et al., 14th International Conference on Sustainable Energy Technologies (SET2015), 25-26 Aug. 2015

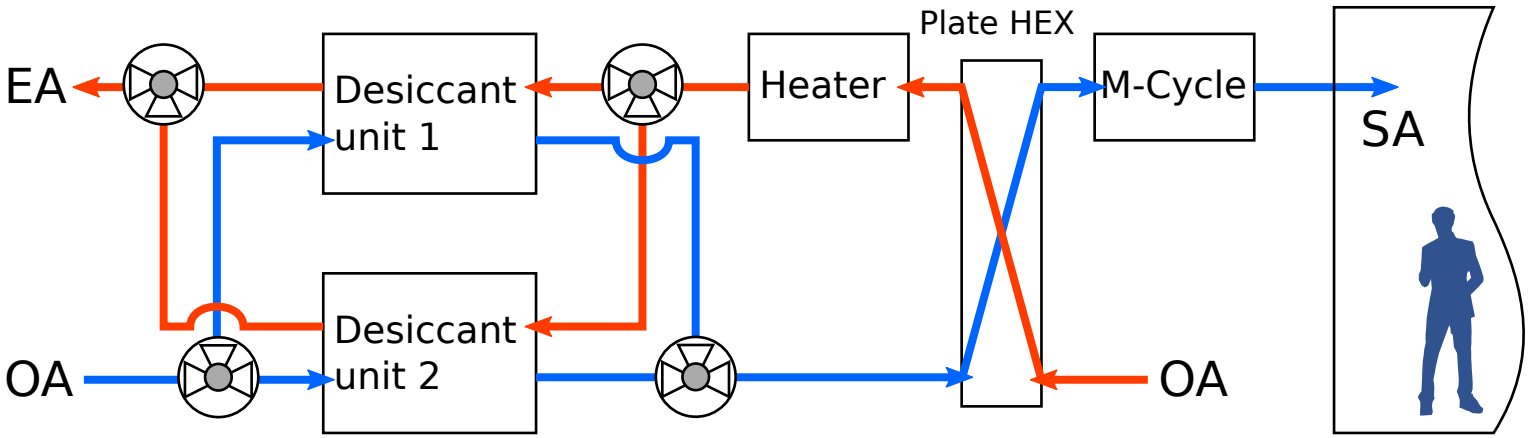
Possibility of the M-Cycle Application

Covers 90% of world population with dehumidification

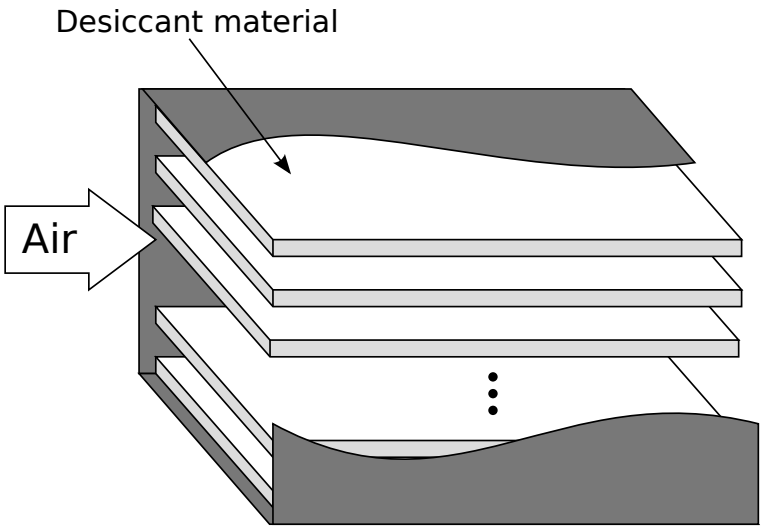


Ref.: Buyadgie et al., 14th International Conference on Sustainable Energy Technologies (SET2015), 25-26 Aug. 2015

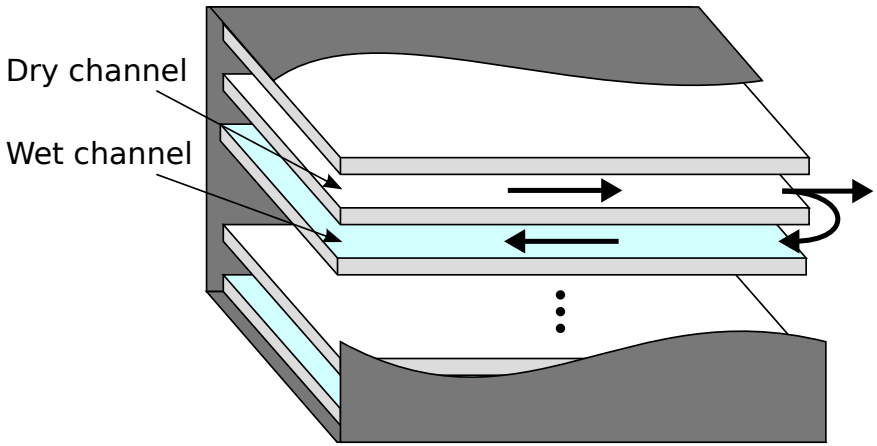
Desiccant Air Conditioning with the M-Cycle



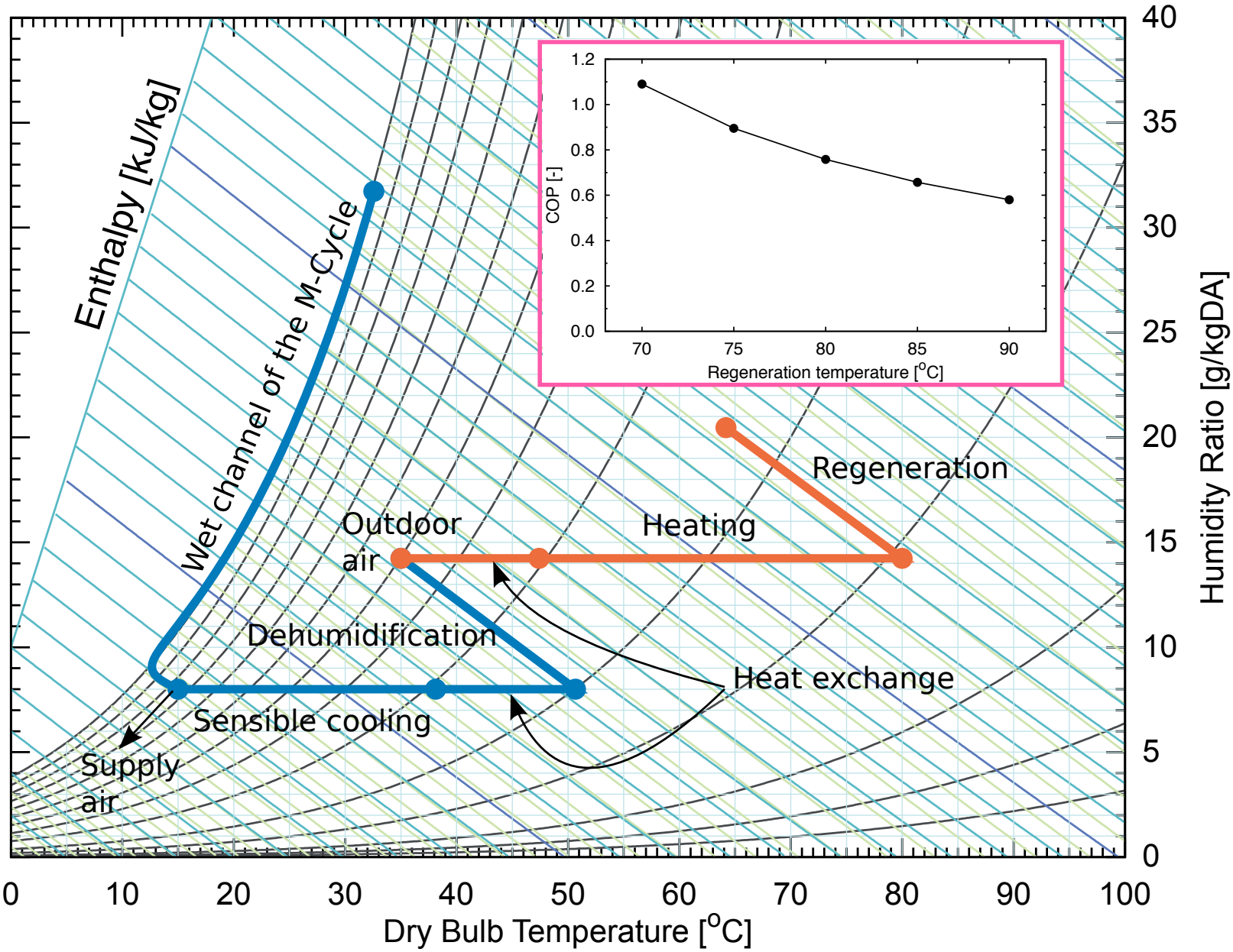
Desiccant unit



M-cycle evaporative cooler



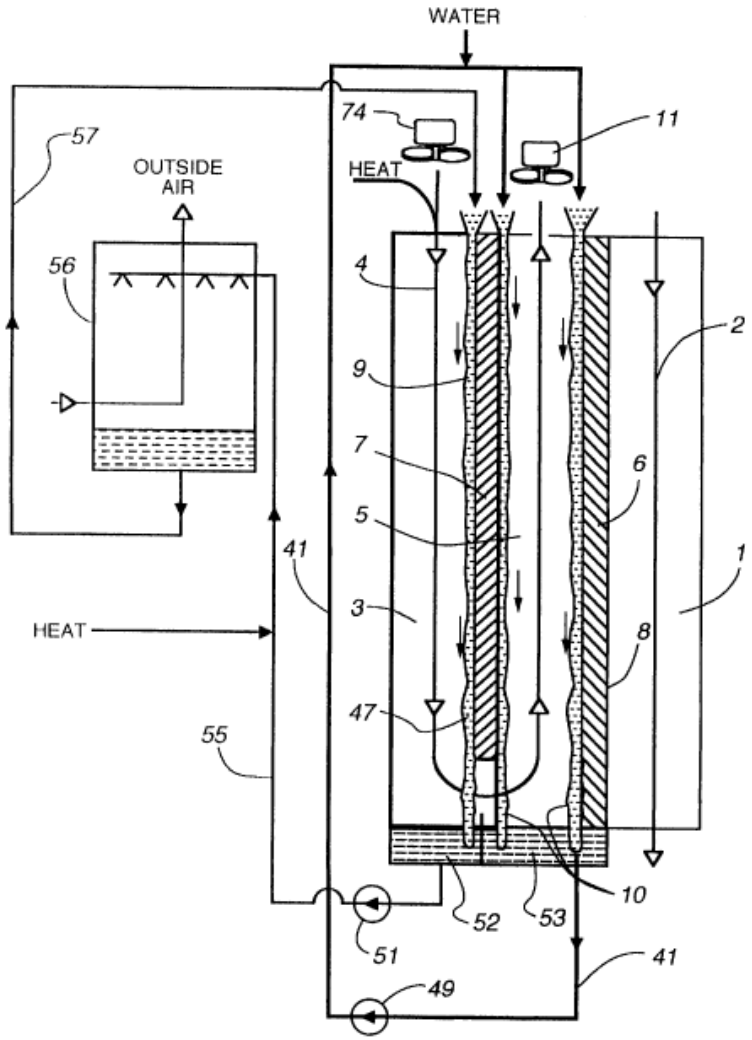
Desiccant Air Conditioning Process



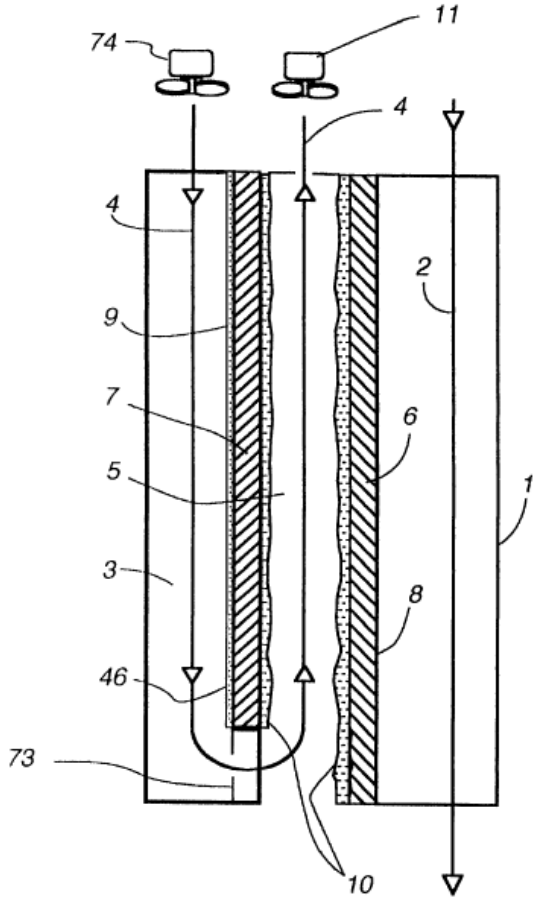
Concept of a new M-Cycle with Desiccant

Combined M-Cycle and Desiccant

Liquid desiccant

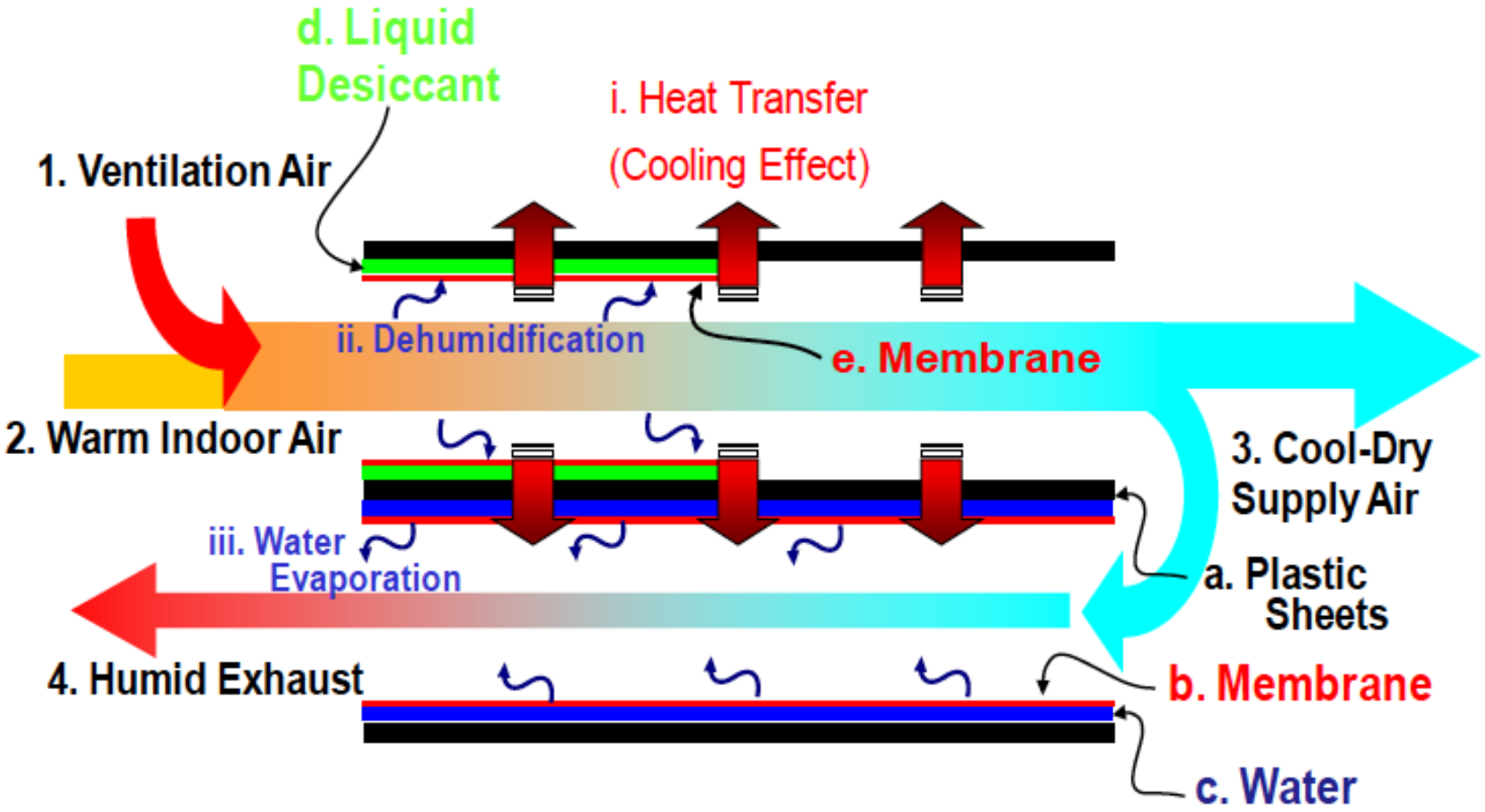


Solid desiccant



US Patent No. 6,497,107

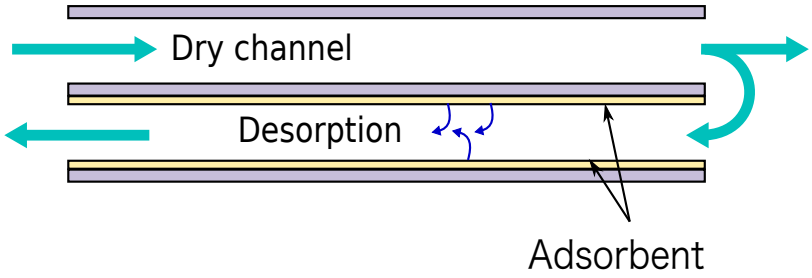
Research in NREL, USA

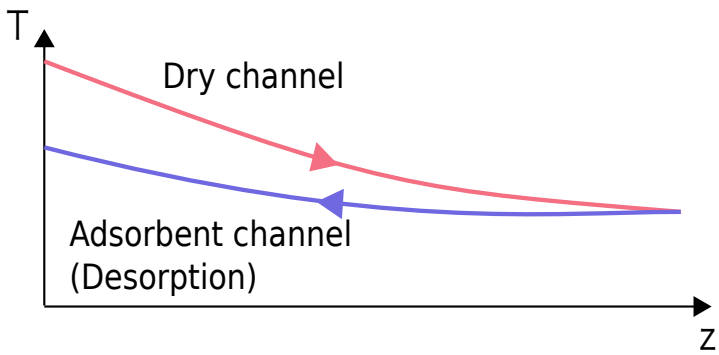


Kozubal et al., Desiccant Enhanced Evaporative Air-Conditioning (DEVap): Evaluation of a New Concept in Ultra Efficient Air Conditioning, NREL

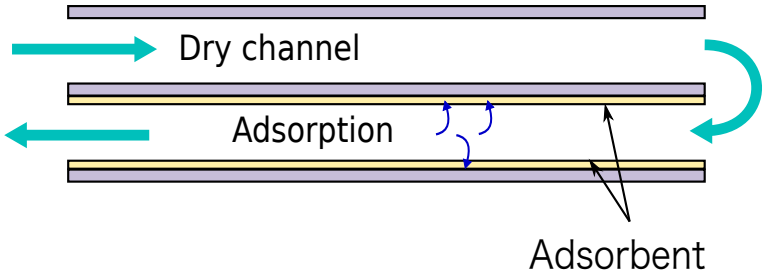
M-Cycle with Adsorbent Channel

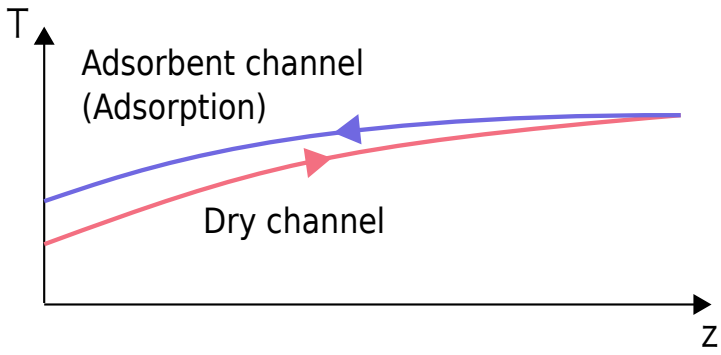
① Desorption mode





② Adsorption mode



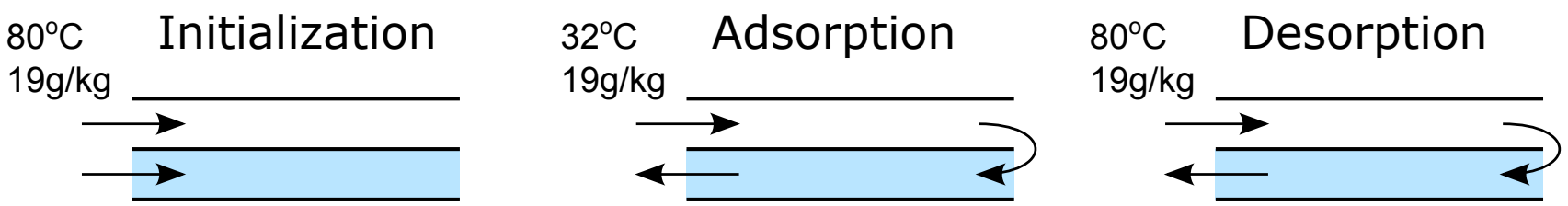


Miyazaki and Koyama, National Heat Transfer Symposium of Japan, 2015

Prediction by Simulation

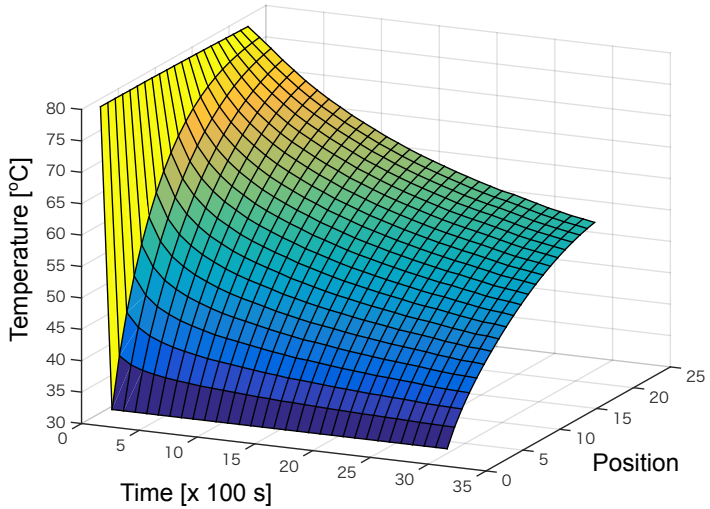
Boundary conditions

Mode	Initialization	Adsorption	Desorption
Time	3000s	3000s	3000s
Flow	Parallel	Conter	Counter
Inlet Air	80°C, 19g/kg	32°C, 19g/kg	80°C, 19g/kg

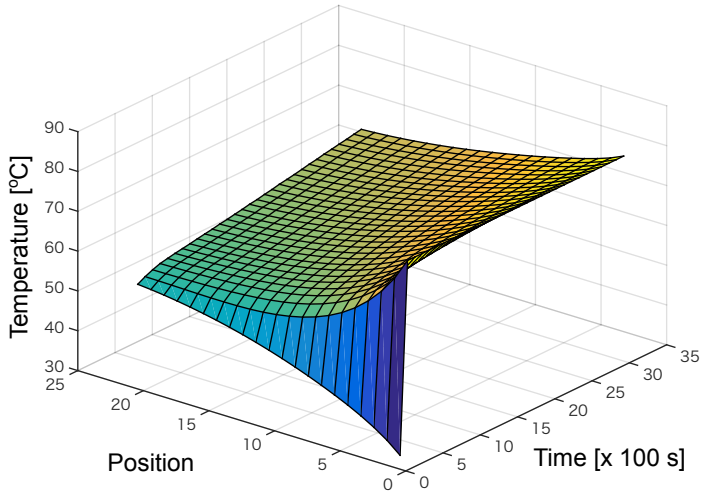


Temperature Profiles

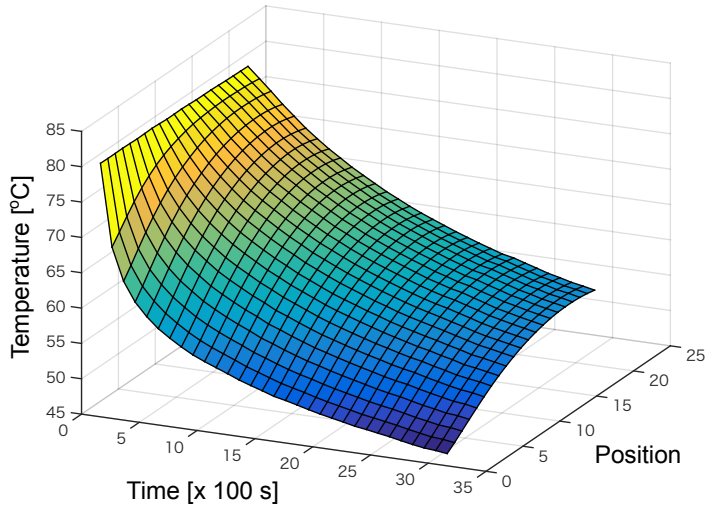
Adsorption mode: Dry channel



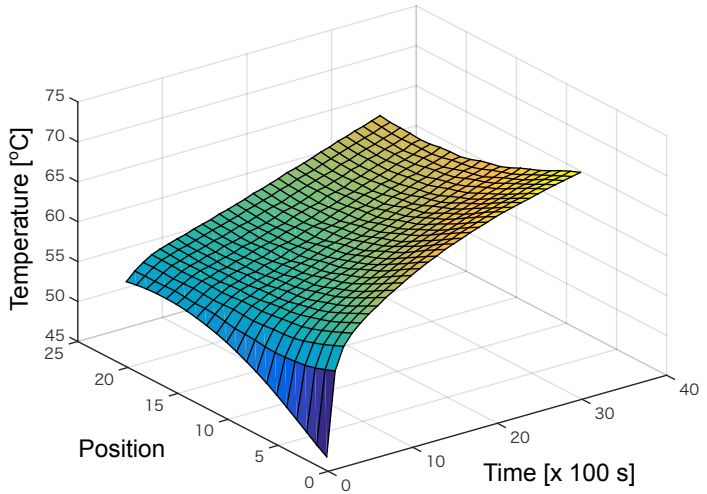
Desorption mode: Dry channel



Adsorption mode: Adsorbent channel

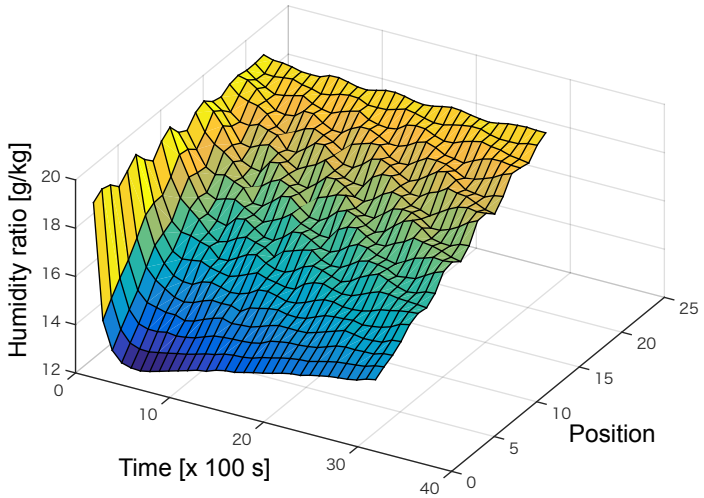


Desorption mode: Adsorbent channel

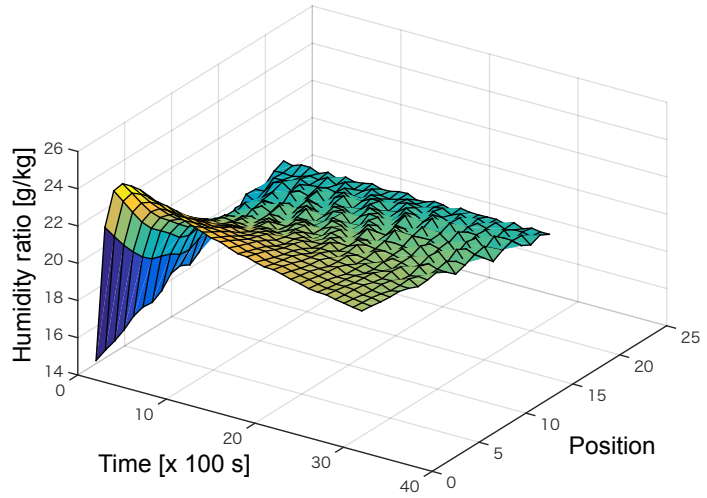


Moisture Change in Adsorbent Channeol

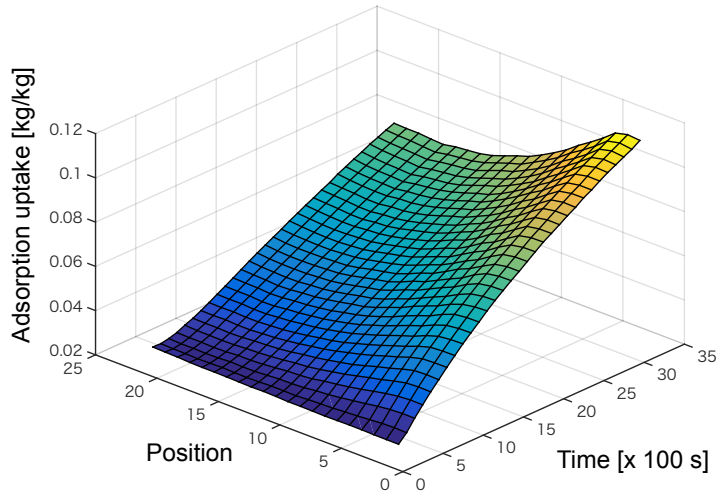
Humidity ratio (Adsorption mode)



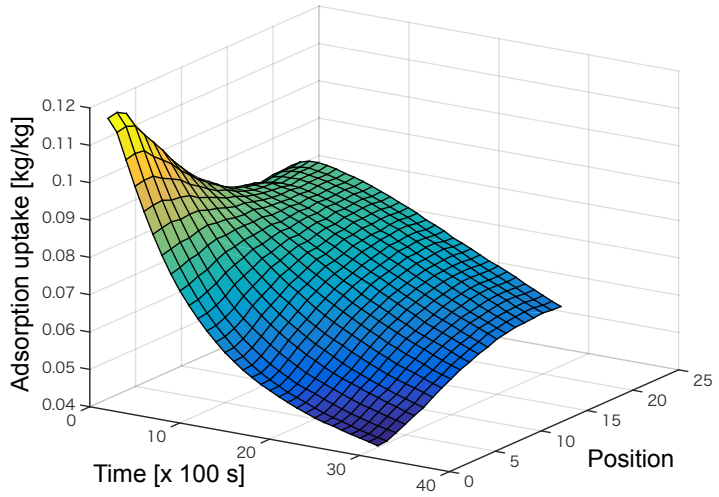
Humidity ratio (Desorption mode)



Adsorption uptake (Adsorption mode)

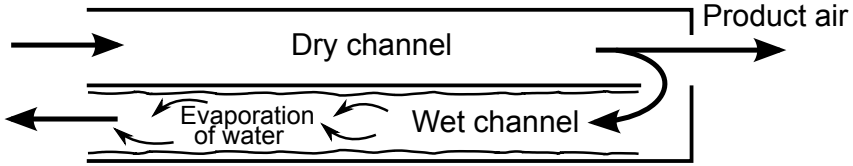


Adsorption uptake (Desorption mode)

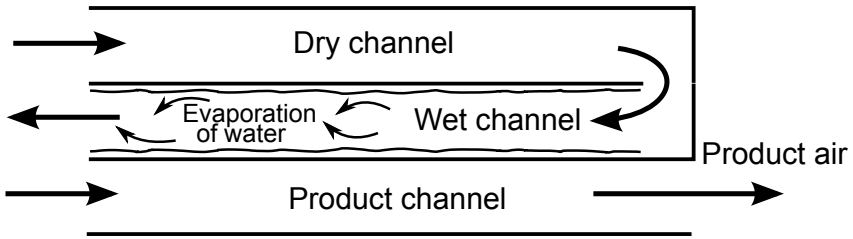


M-Cycle with three air path

Two channel-structure



Three channel-structure



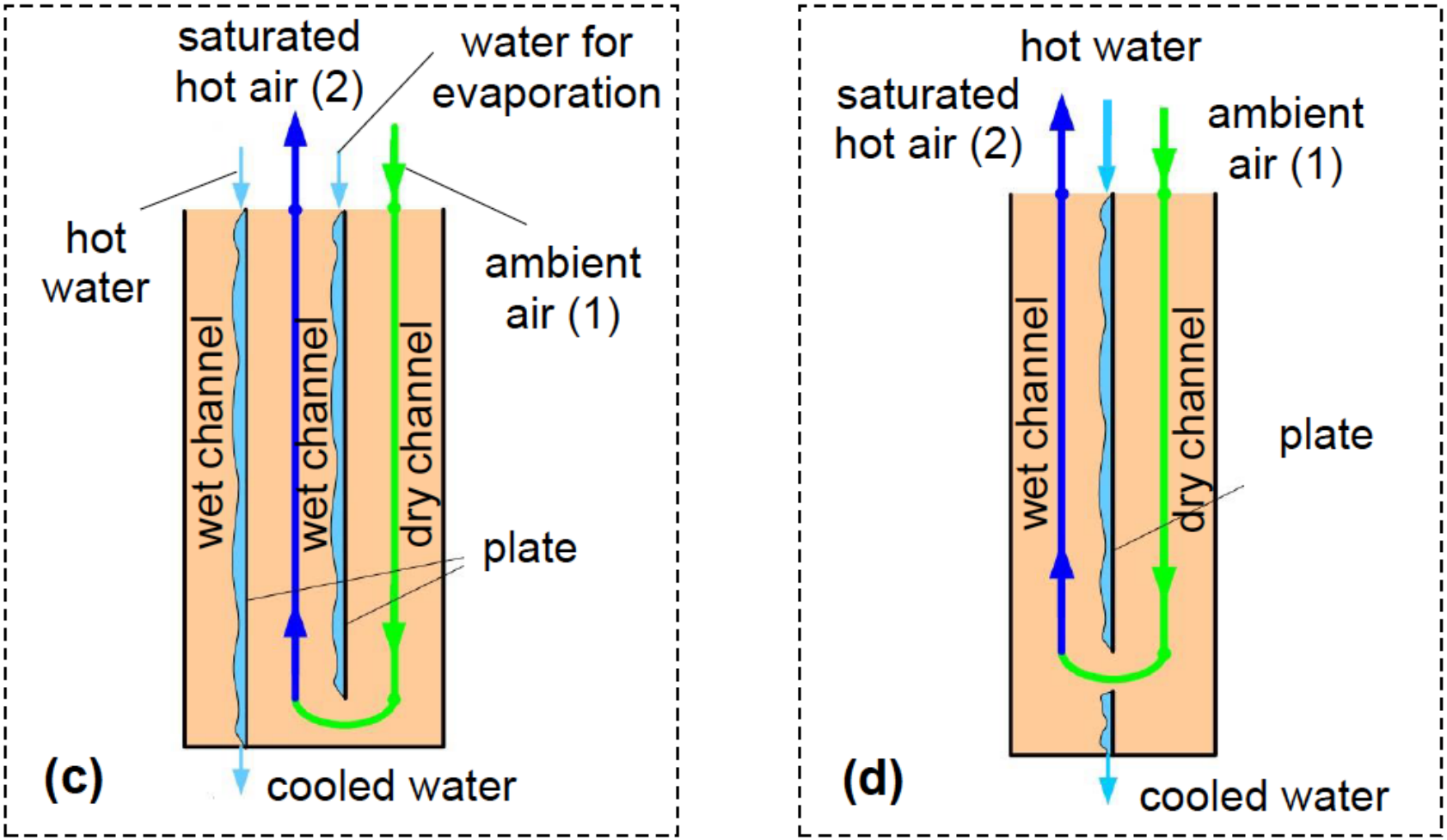
Any fluid can be cooled!

⇓

Expanded the application field.

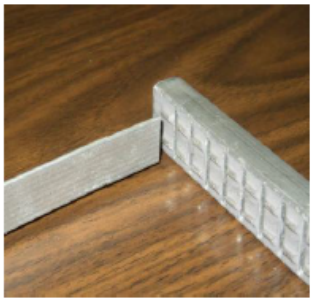
- Cooling tower
- Condenser
- Waste heat recovery

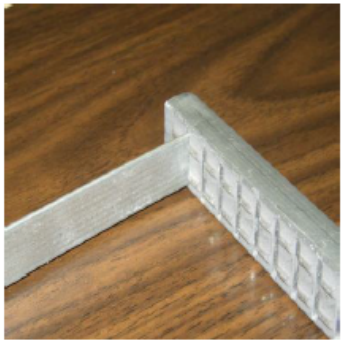
M-Cycle Cooling Tower

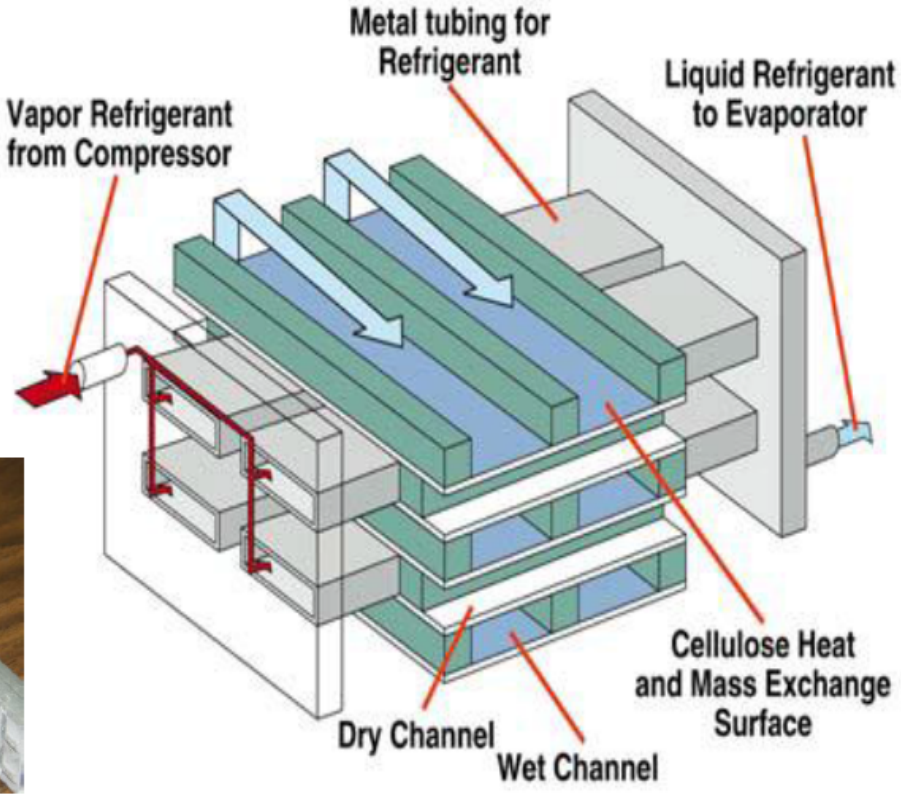


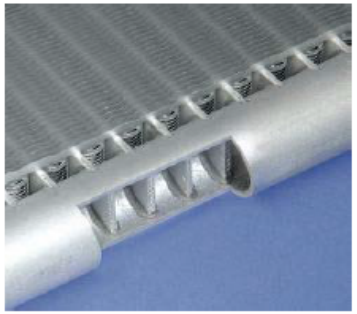
Reproduced from: Khalatov et al., Int J Energy Clean Environ 2011;12:141–57

M-Cycle Condenser



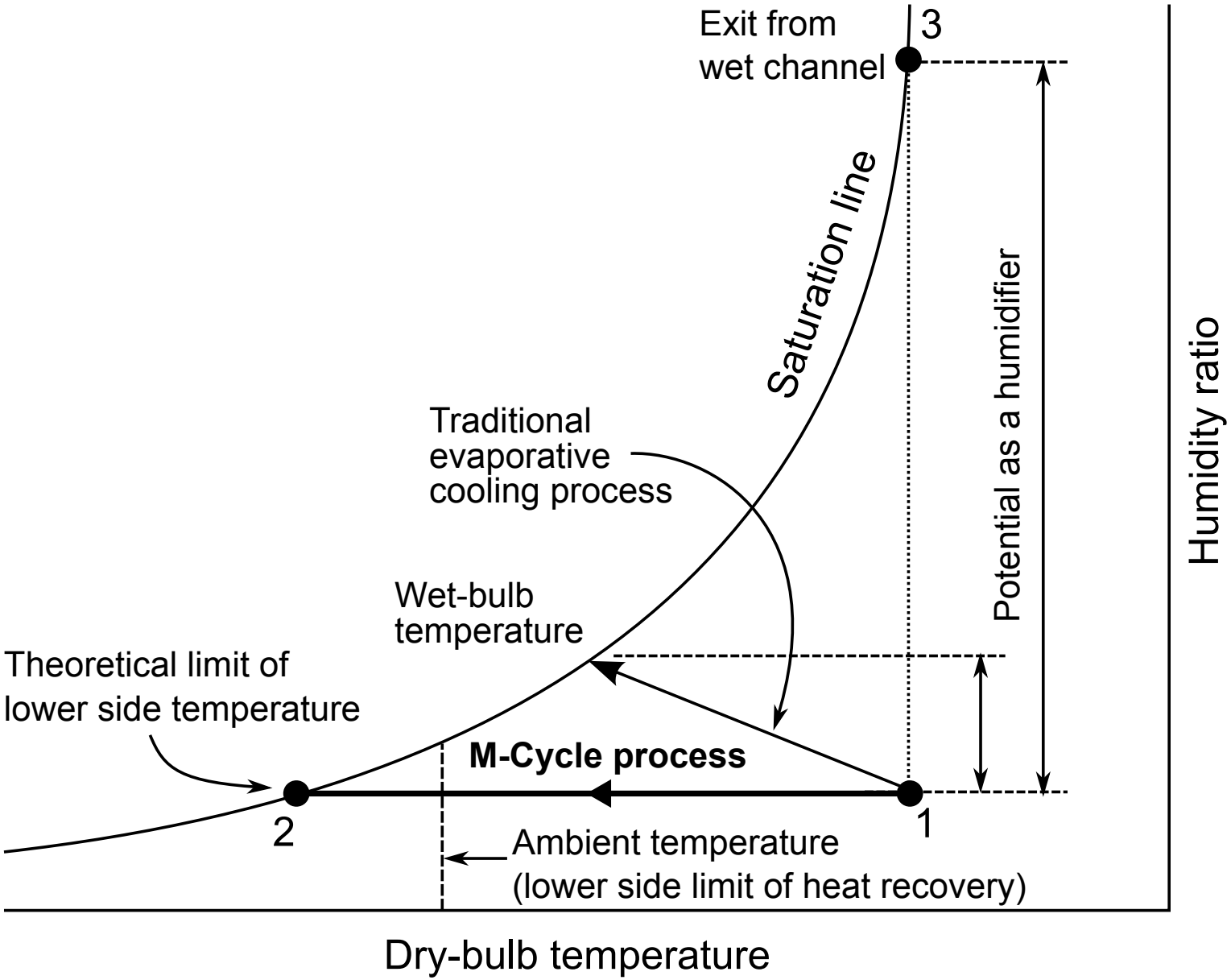






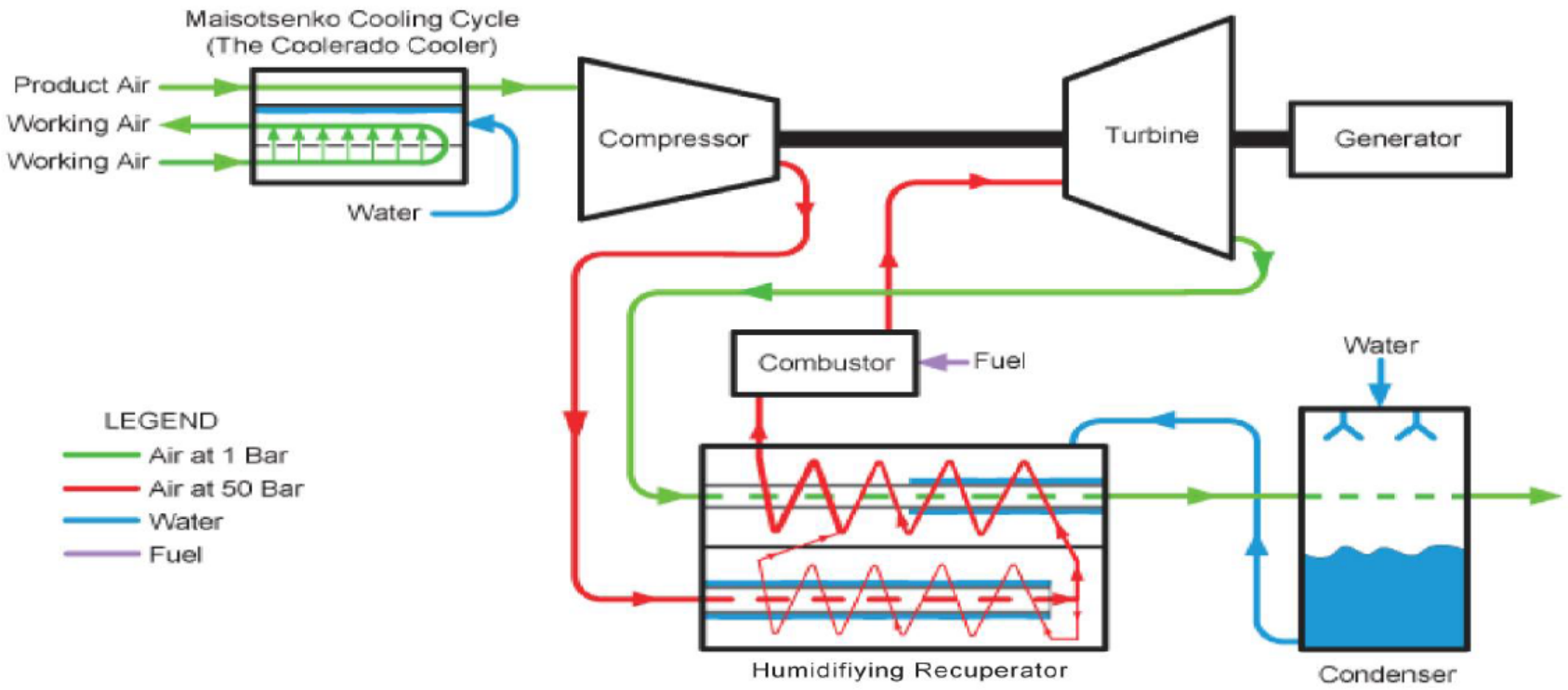
Reproduced from: Gillan et al., Int J Energy Clean Environ 2011;12:251-258

Potential of Heat and Mass Exchanger



Improvement of Gas Turbine Efficiency

Cooling of inlet air and addition of water vapor



from Prof. Maisotsenko presentation slide

Power Generation by Density Difference

The Exergy Tower of Maisotsenko (EXTOM)

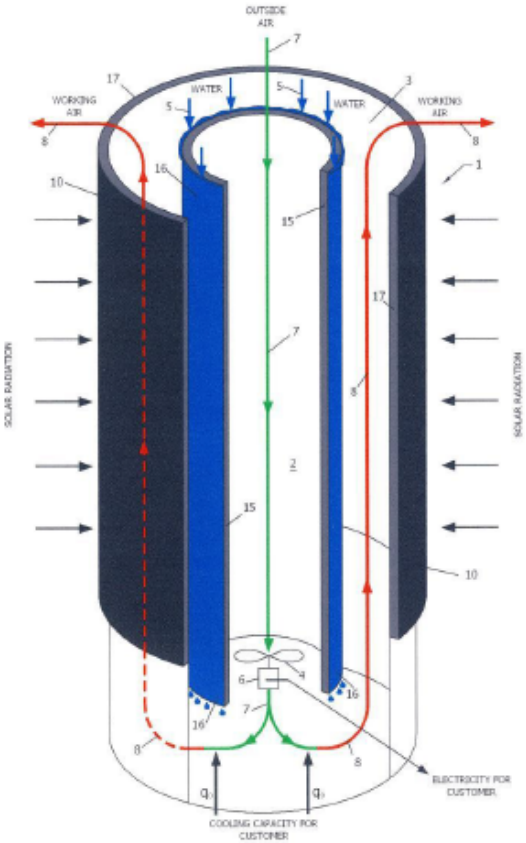


Figure 1

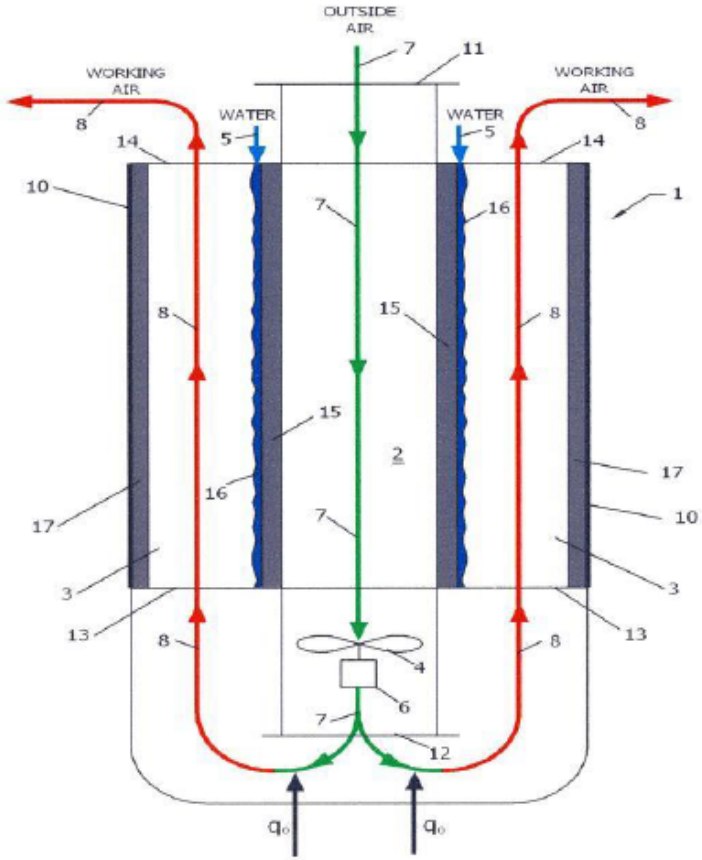


Figure 2

from Prof. Maisotsenko presentation slide

Remarks

- Maisotsenko Cycle is a new thermodynamic concept and it is realized as a air cooler in the USA.
- To use it in Japan (humid climate), combination with desiccant system (dehumidification) is necessary.
- There are a lot of possibilities in application of the M-Cycle to other fields, such as cooling towers, condensers, and power cycles.

Thank you for your kind attention!

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