Univerza v Ljubljani
Fakulteta za strojništvo
LOTZ

IDES-EDU modul **Energy production**

Lecture #7 **Evaporative cooling**

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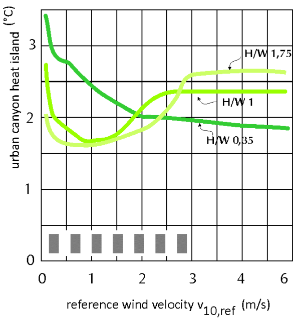
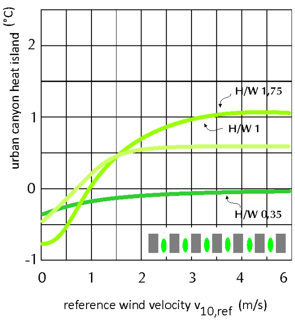
## About evaporative cooling

- One of the most used bionics principle in building service systems are evaporative cooling. This is a process of water evaporation driven by internal energy of surrounding air. The result is heat transfer from air into water droplets, causing the decrease of air temperature.
- That's why the grass fields, water layers or fountains and especially the trees, mitigate urban climate heat island.




Urban canyon heat island is shown in settlements (albedo 0,35) having different ration (H/W). Trees planted in urban canyons have big influence on outdoor environment. Natural evaporative cooling provided by trees is reason for that !

- Air is a mixture of gases and water vapour. Amount of water vapour is dependant on temperature of the air. If air is saturated, than content maximal amount of water vapour at this temperature. Partial pressure of water vapour in total air pressure is called saturation pressure ($p_{sat}$).

- In indoor air is not saturated. Therefore the water vapour pressure is lower that saturated and equal to $p_i$. Relative humidity of air is defined by:

$$\varphi = \frac{p_i}{p_{sat}} \cdot 100 \ [\%]$$

- Air humidity can be express as absolute humidity x. This is mass of water vapour in unit mass of dry air:

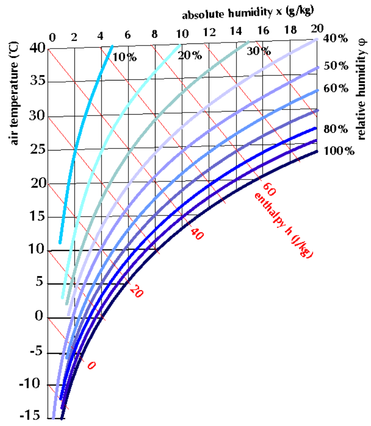
$$x = \left[\frac{kg}{kg}\right]$$

Physics behind evaporative cooling

- Water vapour in the air could change phase to water or ice. Such processes are related to latent heat transfer. Therefore heat transfer to and from the air can't be analyze just with it temperatures. New thermodynamic properties of moist air must be used – it's called enthalpy.

- Thermodynamic state of air can be shown on Mollier T-x or psychometric chart shown on the figure.

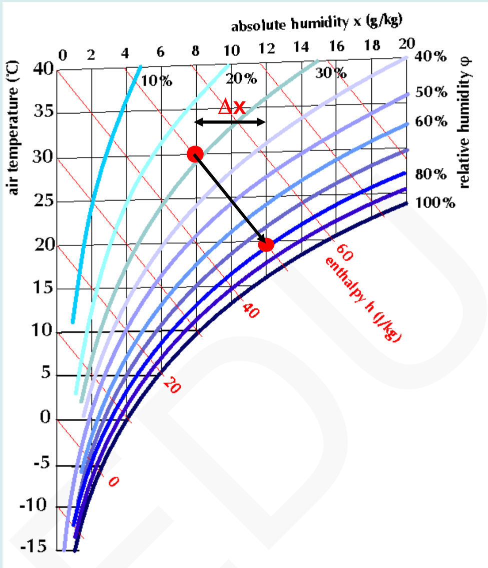
- Evaporative cooling is thermodynamic process of adding water (in form of small droplets or fog) into the air, meanwhile enthalpy of the air remain constant (h = cont).



## Physics behind evaporative cooling

EXAMPLE:

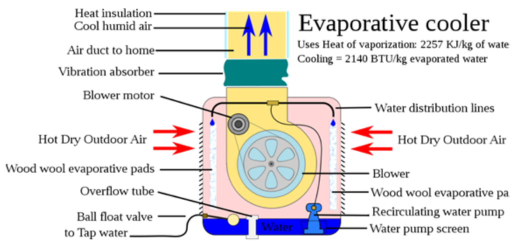
- If 4 grams of water evaporates into the 1 kg of surrounding air near the fountain having temperature $t_1$ 29°C and relative humidity $\varphi_1$ 30%, what will be the temperature of the air ?




- Answer: $t_2$ 19°C

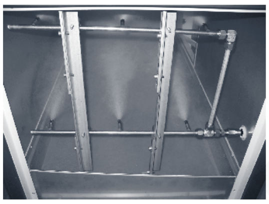
## Artificial evaporative cooling

- Beside using plants or water areas, air can be cooled by evaporation in mechanical devices. Two of such air misting appliances are shown.



## Artificial evaporative cooling

- Humidifier can be integrated into air handling unit as additional device. Nozzles for water spry or ultrasound nozzles are used to create mist or fog.
- Evaporation efficiency of humidifier can be modelling regarding to length of the chamber (between 1 m and 1,8 m) and air velocity (between 2 and 4 m/s). Evaporators can reach efficiency up to 95% (almost saturated air exit the humidifier)



Evaporation unit in AHU with nozzles for spraying water droplet into the air stream.

- Unfortunately during evaporative cooling humidity of air increase. This can cause unpleasant indoor living condition. Therefore other techniques must be implemented in such cases !

## Physics behind evaporative cooling

EXAMPLE:

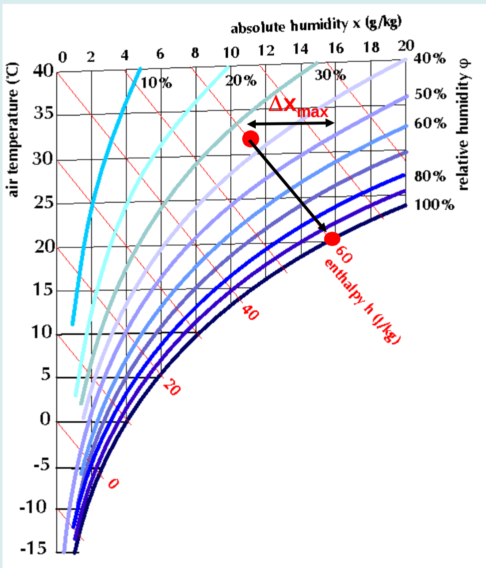
- How much water is needed per 1 kg of air with temperature $t_1$ 33°C and relative humidity $\varphi_1$ 38%, if humidifier efficiency $\eta_{humid}$ is 65% ?

$$\eta_{humid} = \frac{\Delta x}{\Delta x_{max}} \cdot 100 \ [\%]$$

From chart can be seen that $\Delta X_{max}$ is equal 5 g/kg ->

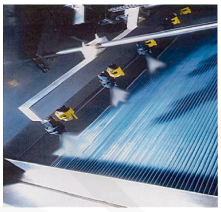
$$\Delta x = \frac{\eta_{humid} \cdot \Delta x_{max}}{100} \ [\%]$$

- Answer: $\Delta x$ is 3,25 g/kg



## Artificial evaporative cooling

- Instead of humidifying of the fresh air, exhaust air living the building is humidified. Another type of humidifier is used in this case – plate heat exchanger. It is the same element that is used for heat recovery in winter time.

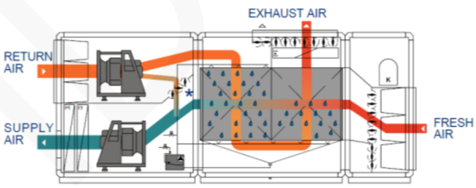


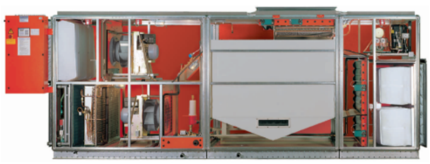
- During the summer heat transfer in heat exchanger is enhance because simultaneous heat and mass transfer. Evaporation cooling is more intense because water flows in thin layers all over heat exchanger plates.

- Because exhaust air is humidified instead of fresh, supply air, the presents of water droplets potentially caring microorganisms in supply air is eliminated as well.

## Artificial evaporative cooling

- Air handling unit with integrated evaporative cooling is shown on figure (Menerga)

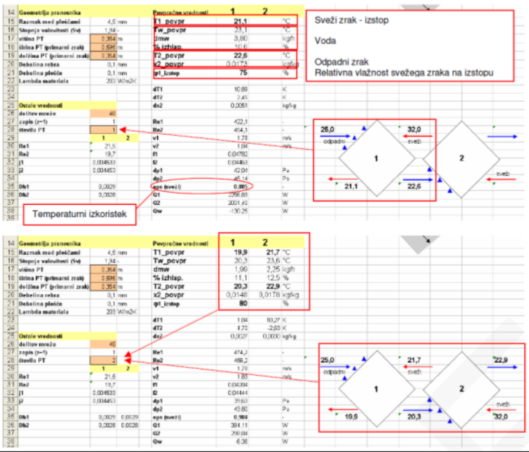


- Efficiency of evaporative cooling depends mostly on local climate (stete of supply air), size of heat exchanger and humidifier efficiency. Special computer tool must be used for hour-to-hour analyzes.

## Modelling of evaporative cooling

- Instead of humidifying of the fresh air, exhaust air living the building is humidified. Another type of humidifier is used in this case – plate heat exchanger. It is the same element that is used for heat recovery in winter time.




Example of custom made computer tool for evaporative cooling modelling.

One or two consecutive heat exchanger in AHU can be analyzed.

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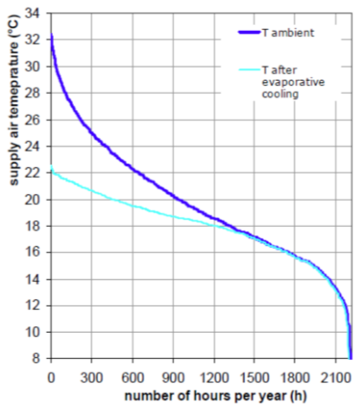
## Efficiency of evaporative cooling

- Overall efficiency of evaporative cooling technique is presented on chart for location with mild summer.
- It can be concluded that evaporative cooling is most efficient when needed most – during hottest period of the year. This is perfect for "peak shaving" of electricity use.
- Therefore evaporative cooling should be used every time if climate conditions are suitable.
- This technique of energy conservation is already mandatory in some countries – in Slovenia for example.



## Self evaluation

- Explane how content of water vapour in the are can be defined !
- Present process of evaporative cooling in T-x diagram !
- In which cases evaporative cooling is most efficient ?

## Literature/References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