Greenhouses Cooling : Intelligent Technologie using Direct Contact Heat Exchangers and Challenges of Dessiccants

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Contents

Actual Position

- Assistant professor at the “*Industrial Engineering Department*” ***at ENIT*** since september 1999
- Researcher in “ ***R.U. Energetic of Buildings and Solar Systems***”

ENIT

- Engineering School relied to the university of Tunis (***Ministry of Education and Research***)
- 1200 Students, 160 Professors, 50 Engenieers 50 Professors Visitors
- Twenty laboratories and research units

Research Fields

WATER: TREATMENT AND DESALINATION

DESIGN, MODELING AND EXPERIMENTATION OF HEAT EXCHANGERS

AUTONOMOUS DESALINATION UNITS

RENEWABLE ENERGIES

COOLING SYSTEMS

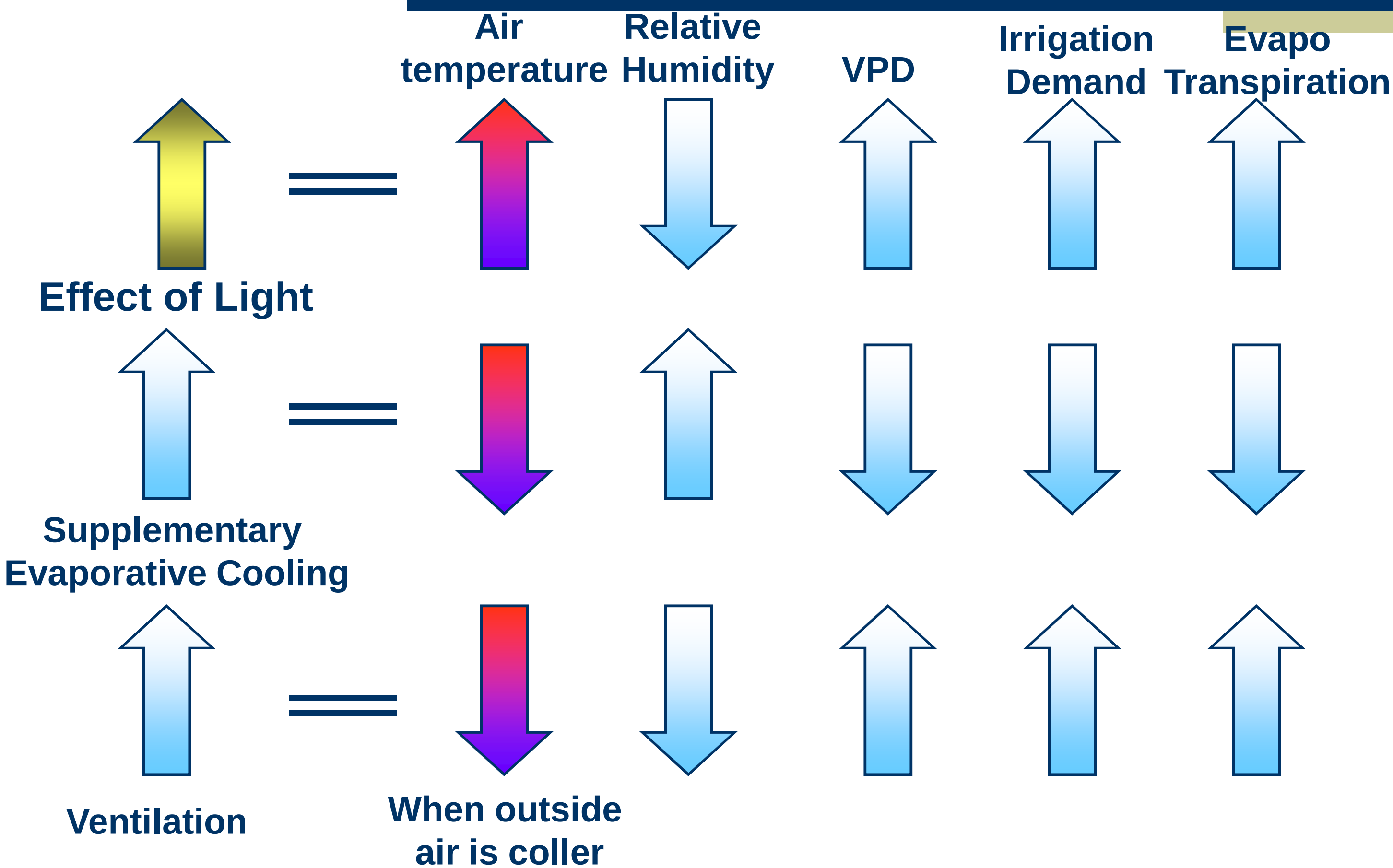
Introduction

- We build greenhouses to gather light and to trap the considerable heat contained in sunshine.

- They are so efficient at retaining relatively low levels of solar energy, that without specialized ventilation and cooling equipment, greenhouses can quickly fry a crop during high light periods.

- Cooling strategies are required for the active management of greenhouse air temperature and humidity whenever the incoming solar radiation levels exceed the heating needs of the crop.

Greenhouse Cooling Relationship



Problematic

- Unlike heating, for which the technology is well established and straightforward, greenhouse cooling frequently presents considerable problems.

- A proper understanding of the thermal behavior of greenhouses

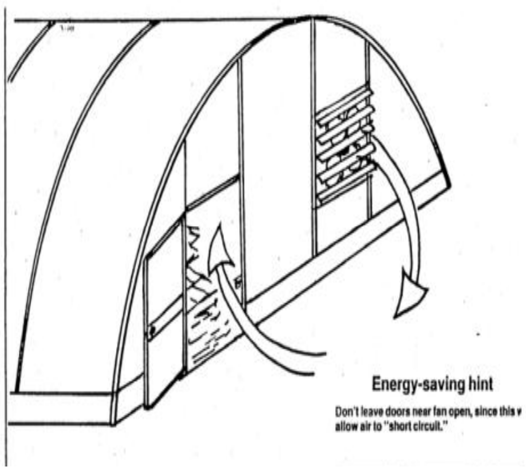
Use of cooling systems that give satisfactory performance

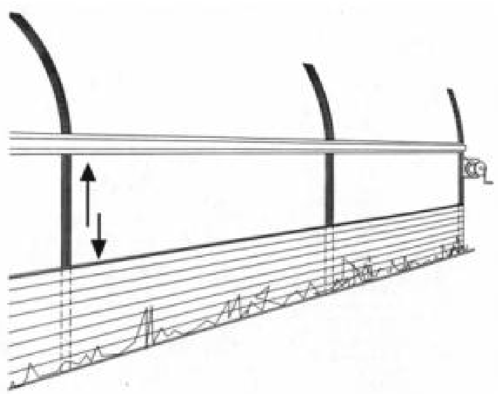
Conventional Cooling Technologies

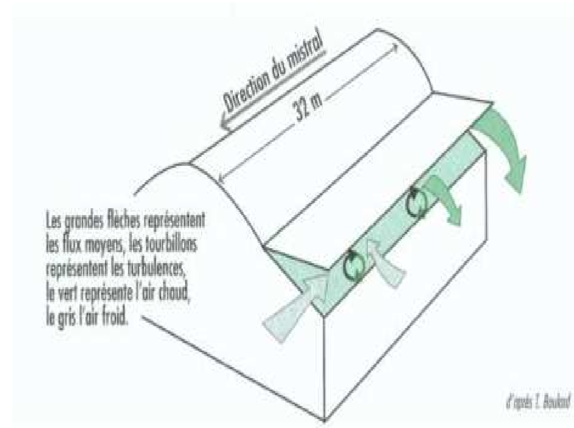
Cooling technologies for agricultural greenhouses

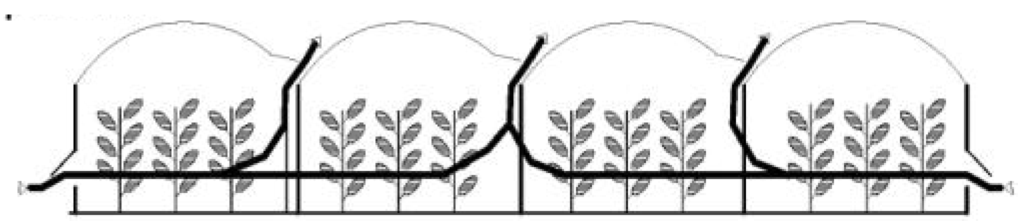
- Ventilation (natural and forced),
- Shading/reflection,
- Evaporative cooling (fan-pad, mist/fog and roof cooling)
- Composite systems (earth-to-air heat exchanger system and aquifer coupled cavity flow heat exchangers system)

Natural Ventilation









Natural Ventilation

- Natural ventilation can be used to good effect in many cases,
- Large and suitably placed ventilators are frequently all that is required,
- In combination with an exhaust fan (forced ventilation) or a partially reflective screen (shading) to prevent the entry of solar radiation that is superfluous to the plant's requirements.

Forced Ventilation

Shading/reflection

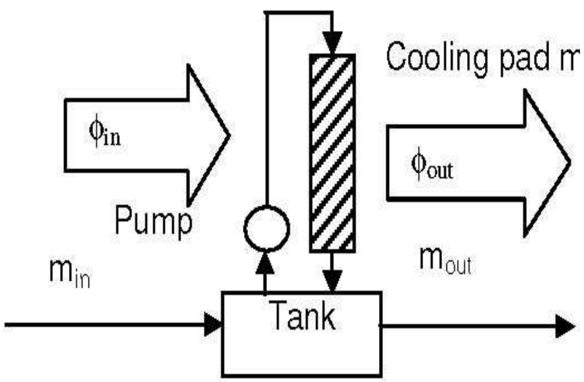
- The entry of direct solar radiation through the covers into the greenhouse enclosure is the primary source of maximum heat gain.

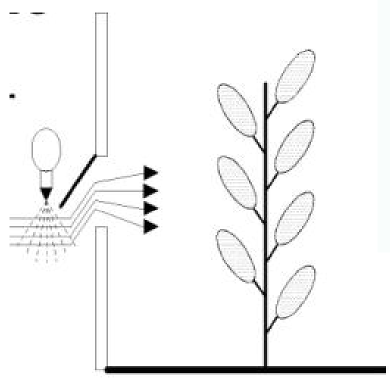
- The entry of unwanted radiation (or light) can be controlled by the use of shading or reflection.

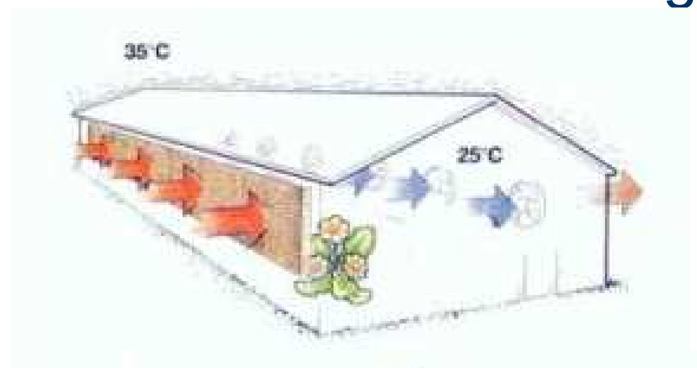
- Shading can be done by various methods : paints, external shade cloths, louvers or slatted blinds, use of nets (of various colors), partially reflective shade screens and water film over the roof and liquid foams between the greenhouse walls.

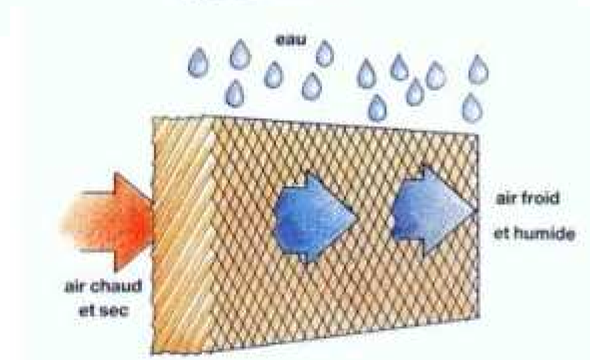
Evaporative cooling

- Using fan-pad, fog/mist inside a greenhouse and roof cooling systems.









Comments

- When summers are not severe and the maximum ambient temperature remains less than 33°C, ventilation and shading techniques can work well.

- In the extreme environmental locations, where ambient temperatures in summer generally exceeds 40°C, evaporative cooling is the most efficient means of greenhouse cooling, which can lower the inside air temperature significantly below the ambient air.

Comments

☹ Evaporative cooling relies on the dryness of the ambient air, It can not achieve temperatures lower than the ambient wet-bulb temperature

☹ Evaporative cooling performs poorly in humid conditions because humid air has little capacity to absorb moisture.

☹ The amount of latent heat absorbed through evaporation is small.

☹ The Water Consumption in Evaporative Cooling is important

The Solutions

- Using sea water intsead of drinkable water in evaporative cooling in the case of greenhouses near the coast

- Liquid desiccation with solar regeneration is considered as a means of lowering the temperature in evaporatively cooled greenhouses

The Seawater Greenhouse Process

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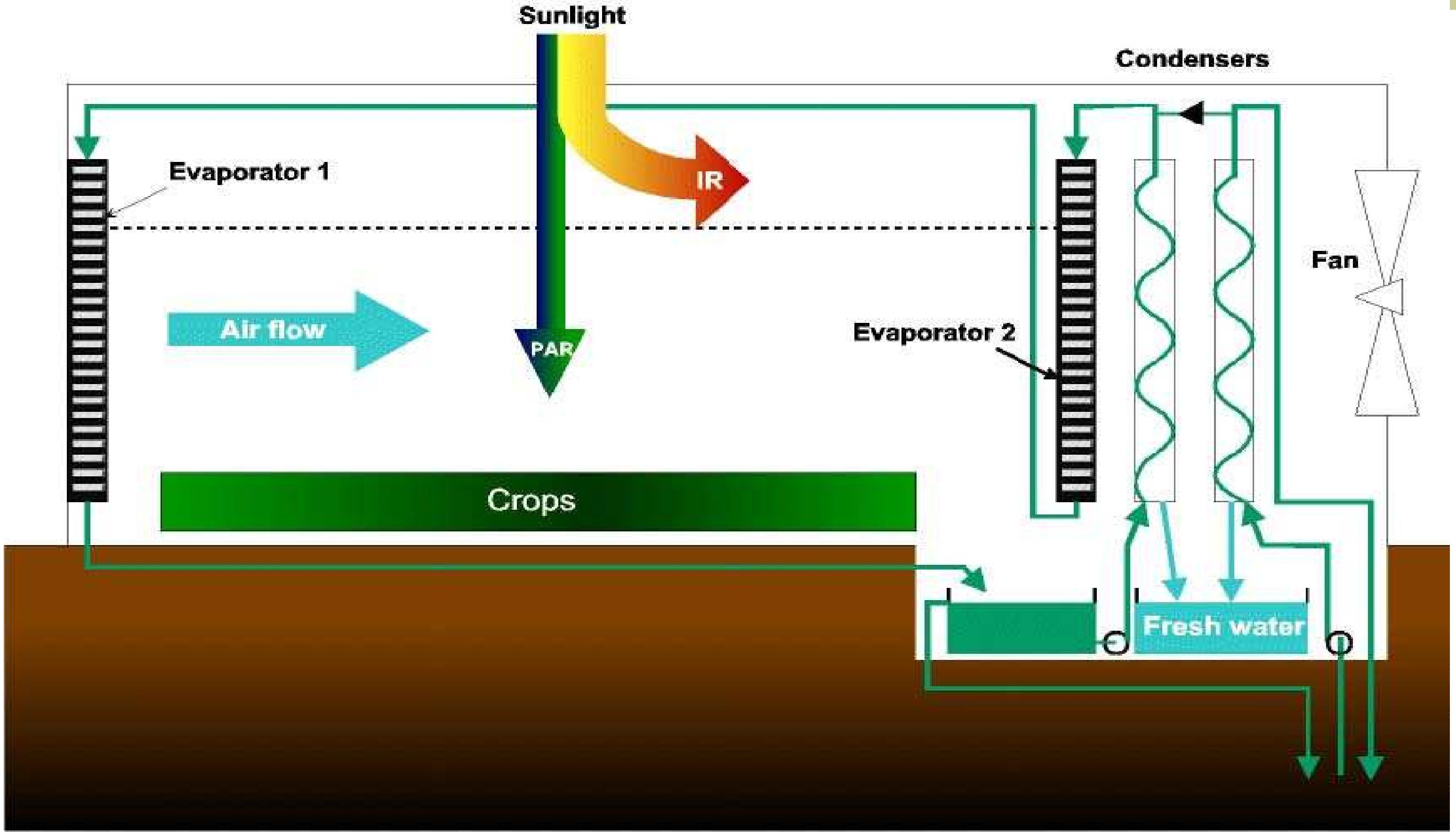


Liquid Desiccant Dehumidification systems

Definitions

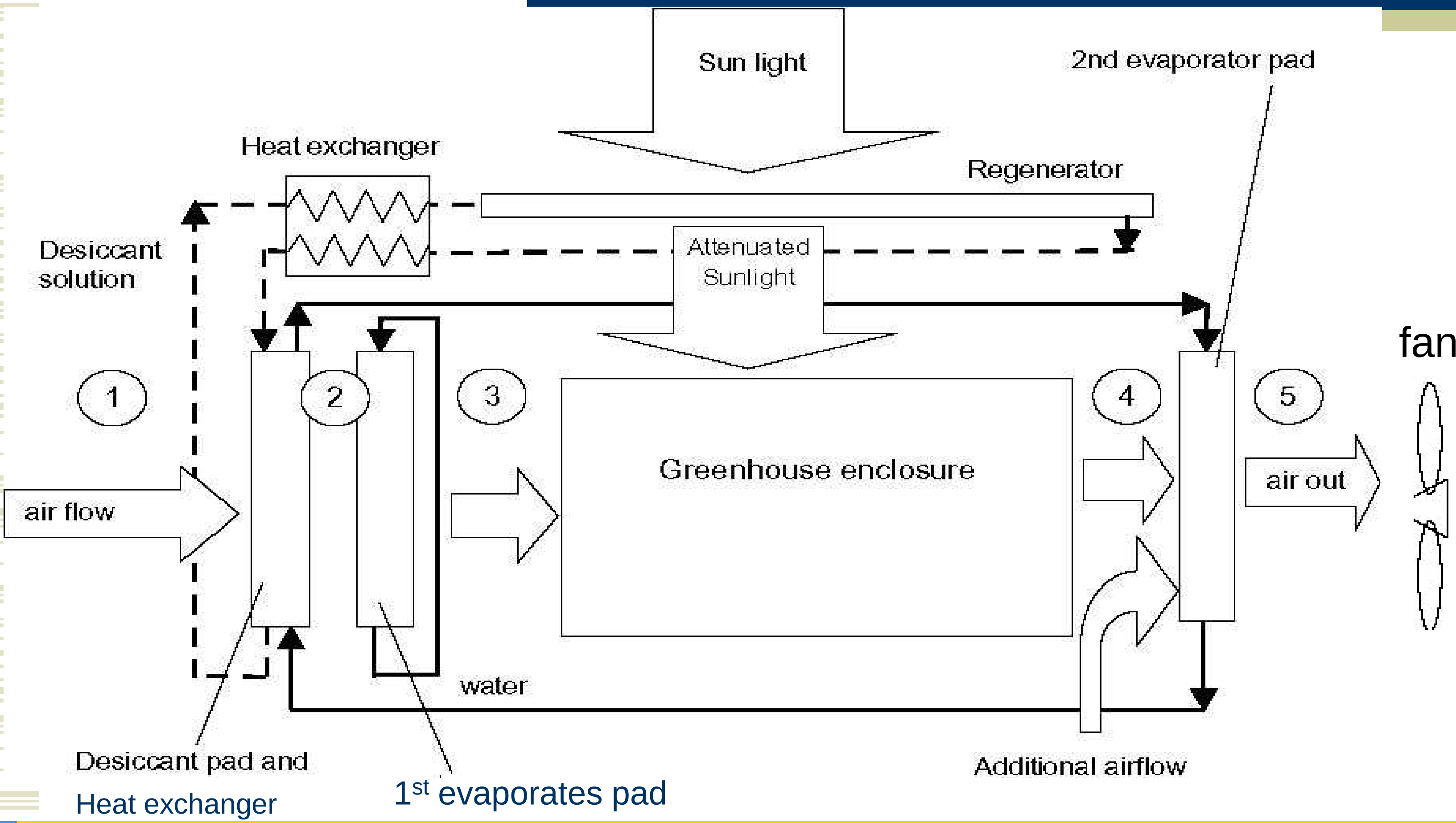
- Dehumidification :

- Process of removal of water vapor from moist air
- It can be acheived by either cooling or increasing the pressure of air or by absorption/adsorption of moisture by a solid or liquid material (desiccant)

- Desiccants :

- Materials that have high affinity for water vapor
- The removal of moisture from air depends on the difference in water vapor pressure held by the desiccant and that of water vapor in air
- If no cooling is provided in the dehumidifier, this heat is transferd to the desiccant and the air

Desiccant Systems for Cooling Greenhouses



Advantages

- In the proposed cycle, the air is dried prior to entering the evaporative cooler.
- This lowers the wet-bulb temperature of the air.
- The cooling is assisted by using the regenerator to partially shade the greenhouse.
- The heat of desiccation is transferred and rejected at the outlet of the greenhouse.

Advantages

- Compared to option (Simple fan ventilation), the Desiccant system lowers summers maximum temperatures by 5 °C.

- This will extend the optimum season for :
  - ✓ lettuce cultivation from 3 to 6 months of the year
  - ✓ for tomato and cucumber, from 7 months to the whole year.

Liquid desiccant dehumidification systems components

The Desiccant Pad

- It can be of the conventional type,
- Desiccant pad is different in construction from the evaporative one : it performs the opposite function (removing moisture from air, rather than adding moisture to the air),
- The desiccant pad is continuously irrigated with liquid desiccant.
- Like the evaporator, the pad is porous allowing air to pass through it.

Heat Exchanger

- Evaporation tends to cool air, desiccation tends to heat it,

⇨ The system requires a means of removing the heat of desiccation,

- Heat exchanger, either downstream of the desiccant pad or embedded within it.

- The heat exchanger is supplied with water at the wet-bulb temperature (from a cooling tower, a second evaporative cooling pad situated at the exit of the greenhouse.

The Regenerator

- Because this solution is continuously absorbing water from the air, it is necessary to remove this water at the same rate (regeneration).
- The heat input needed to do this is quite large; consequently a low- cost source of heat is needed.
- The main options are solar energy or waste process heat (e.g. from a power generation plant).
- Solar regeneration of liquid desiccants is feasible and has been practically demonstrated using both open and covered solar panels

Functioning Problems

- Open regeneration of lithium chloride solution on the roof : liquid dissicants are hazardous : caution
- Evaporative Cooling systems, consume substantial amounts of water (more than required for irrigation of the greenhouse).
- Solution : using seawater in place of freshwater in a greenhouse providing both cooling and desalination.
- Challenge : optimum design of the regenerators and their integration in the greenhouse

Integrated desalination and agriculural system

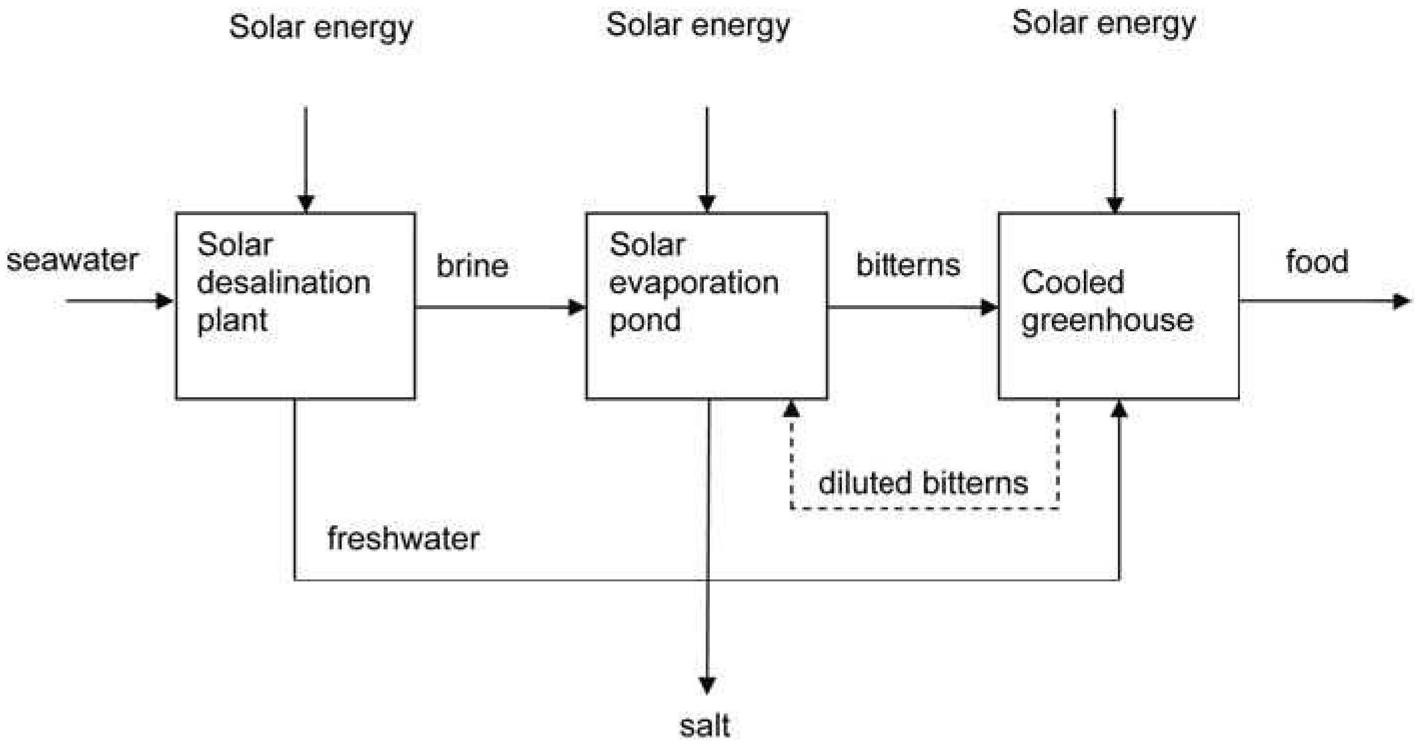
Principle

Using form of brine and bitterns, which is generally regarded as waste.

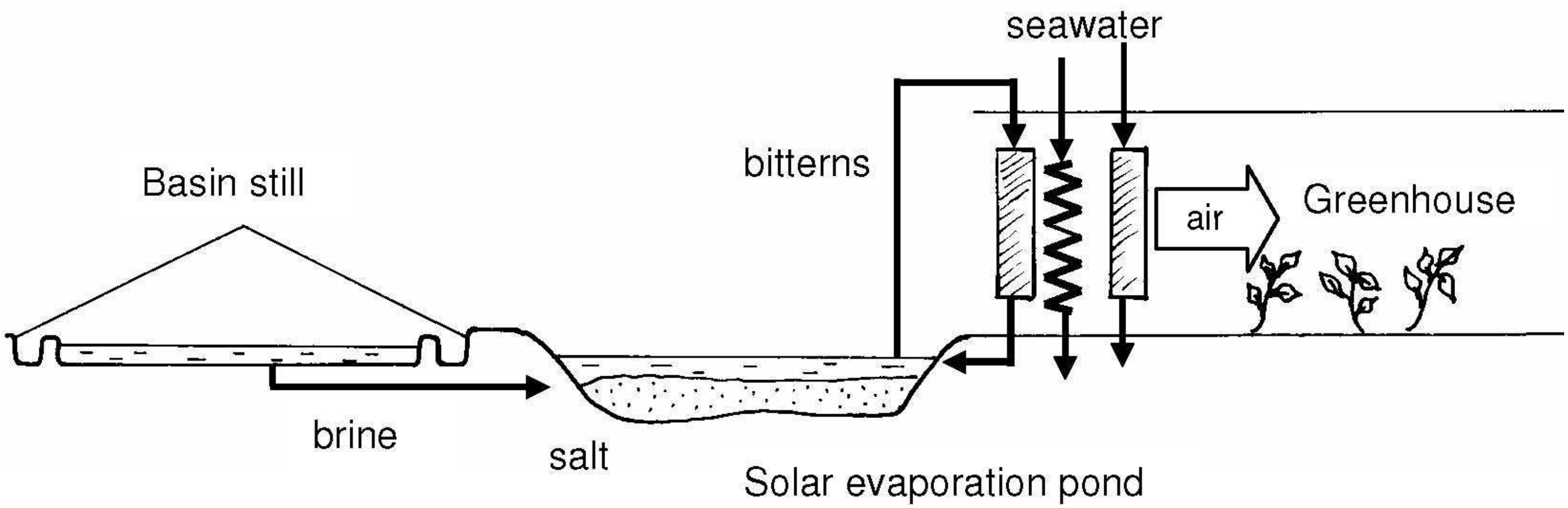
Exploiting the hygroscopic salts in bitterns by products such as magnesium, calcium and sodium chloride as desiccant solutions in a greenhouse cooling system.

Integrated desalination and agricultural system, comprising a solar desalination plant supplying freshwater (for irrigation) and bitterns (for cooling) to greenhouses, enabling efficient water use and local crop production in hot climates

Integrated desalination and agricultural system



Integrated desalination and agriculural system



A concept for integrated desalination, salt production and greenhouse cooling. Davies and Harries (2005)

Desiccants

Regarding the choice of liquid desiccant solution, we note that there are several substances that could be used. Indeed this is an important selection, as the properties of the desiccant will influence the design and performance of the whole cooling system.

Cooling Performance

- This is a primary consideration and can be quantified as the lowering of temperature in the greenhouse relative to the ambient conditions.

- The property having the greatest affect on cooling performance is hygroscopicity, conveniently measured in terms of the equilibrium relative humidity (ERH) of air brought into contact with the desiccant solution.

- The ERH of pure water is 100% while that of an ideal desiccant is theoretically 0%.

- Lower ERH will tend to improve cooling.

Human Safety

- A leak of desiccant → skin burns or intoxication by accidental ingestion.

- Such incidents could occur if the solution is mishandled during construction, maintenance or decommissioning.

- Desiccant could contaminates the soil of the greenhouse,

- The desiccant pad, and possibly the solar regenerator, is open to atmosphere,

Environmental Impact and Energy Consumption

- *Environmental impact*

✓we cannot rule out escape of the desiccant into the natural environment.

✓This could have an adverse effect on aquatic or terrestrial organisms, plant or animal.

✓ Ecotoxicity of the liquid desiccant must be considered.

- *Energy consumption*

✓Electrical energy is needed to drive pumps and fans that circulate the liquid desiccant and the air.

✓The properties of the desiccant affecting energy consumption are:
(1) density,
(2) (water absorption capacity),
(3) Viscosity

Cost and Reliability

- *Cost*

✓ The cost of greenhouses varies tremendously, from about 15 USD/m^2 for a basic polytunnel type to more than ten times

✓ It is estimated that approximately 1–2 L of desiccant solution will be needed per 1 m^2 of greenhouse floor area, based on the volume needed to fill the system.

✓other properties affecting the cost of the system may include toxicity and corrosivity.

✓ A more aggressive substance may demand more costly components in order to reduce the likelihood of leaks and corrosion.

- *Reliability*

A more corrosive liquid desiccant would tend to attack components in the system causing failures and shortening the life of the product.

Desiccants Properties

Preliminary assessment of how the properties of the liquid desiccant influence the attributes of the greenhouse system as a whole. ■ indicates a strong influence, □ indicates a weak influence Davies et al (2006)

Desiccant properties: / Target system attributes:	Hygroscopicity	Cost	Abundance in nature	Density	Viscosity	Heat capacity	Thermal conductivity	Diffusivity of water	Heat of dilution	Water absorption capacity	Human toxicity	Ecotoxicity	Corrosivity
Cooling performance	■					□	□	□	□				
Human safety											■		
Low environmental impact			■								■	■	
Low energy usage				■	□					□			
Low cost		■									□	□	□
Reliability											□	□	■

Desiccants Properties

- Calculations based on five locations (Tunis, Jiddah, Abu Dhabi, Mumbai and Bangkok) show that the liquid desiccant should have ERH $\leq$ 50% to give improved cooling compared to both direct and indirect evaporative systems. (Davies et al 2006)

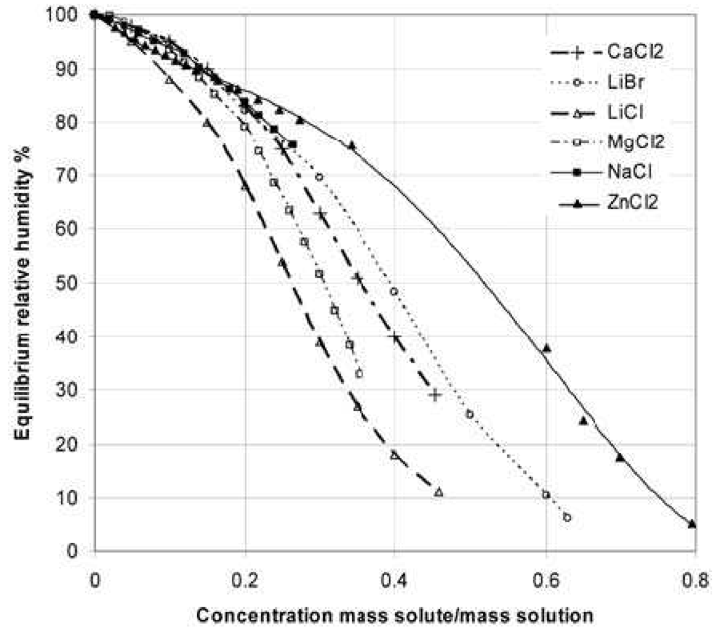
- Magnesium chloride is the most abundant salt in seawater bitterns and both magnesium and calcium chloride stand out as being of low toxicity.

- At 25°C, a saturated solution of magnesium chloride can only reduce the humidity of air to 33%, compared to 29% for calcium chloride and 11% for lithium chloride

Used diseccants

- Aqueous solutions of salts

- calcium chloride,
- lithium bromide,
- lithium chloride,
- magnesium chloride,
- sodium chloride and
- zinc chloride.



Equilibrium relative humidities (ERH) of solutions of six salts as a function of mass concentration up to saturation. Temperature = 25°C.

Conclusions

Conclusions

- The use of liquid desiccants derived from seawater brine or bitterns in a greenhouse cooling system shoul be considered.

- The second most abundant salt in seawater, magnesium chloride, is considerably more hygroscopic.

- A magnesium chloride solution of mass concentration 0.31 would have an equilibrium relative humidity of 50%, giving an improved cooling effect, compared to both direct and indirect evaporative cooling systems.

Conclusions

- One m^3 of such solution could be obtained by concentrating approximately 80 m^3 of seawater.
- Typically, the desiccant system would deliver air 5–7ºC cooler than direct evaporative cooling and 2–4ºC cooler than indirect evaporative cooling.
- Though less hygroscopic than the more conventional liquid desiccants consisting of lithium or zinc salts, magnesium chloride is significantly less toxic both to humans and the environment.

Conclusions

- The development and capital costs of the desiccant pad, the solar regenerator and the second evaporator pad are likely to be the main obstacles in implementing the proposed system.
- Where waste heat is available from industrial processes or cogeneration sites, this may provide a lower cost means of regeneration than solar energy.
- However, the solar concept benefits from a very wide geographical applicability and, if it is generally accepted, this will tend to offset the initial development costs.

Thank You for your Attention

« One drop of water is enough to create a world »

Gaston Bachelard

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