## eurammon Symposium 2017

# *Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser System*

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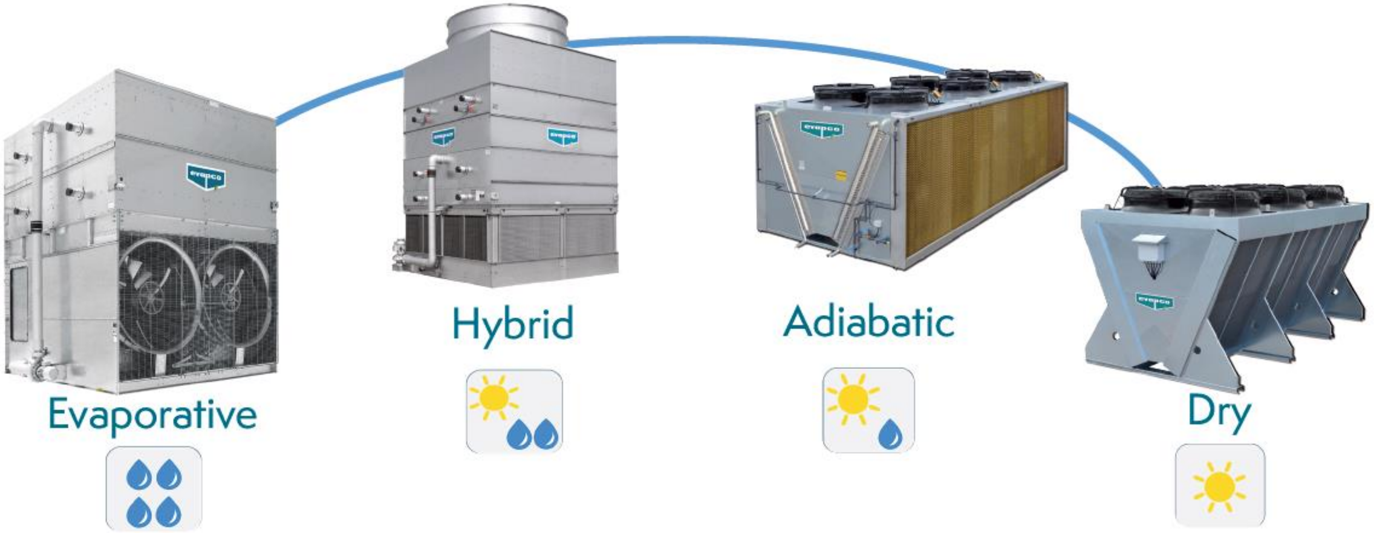
# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser



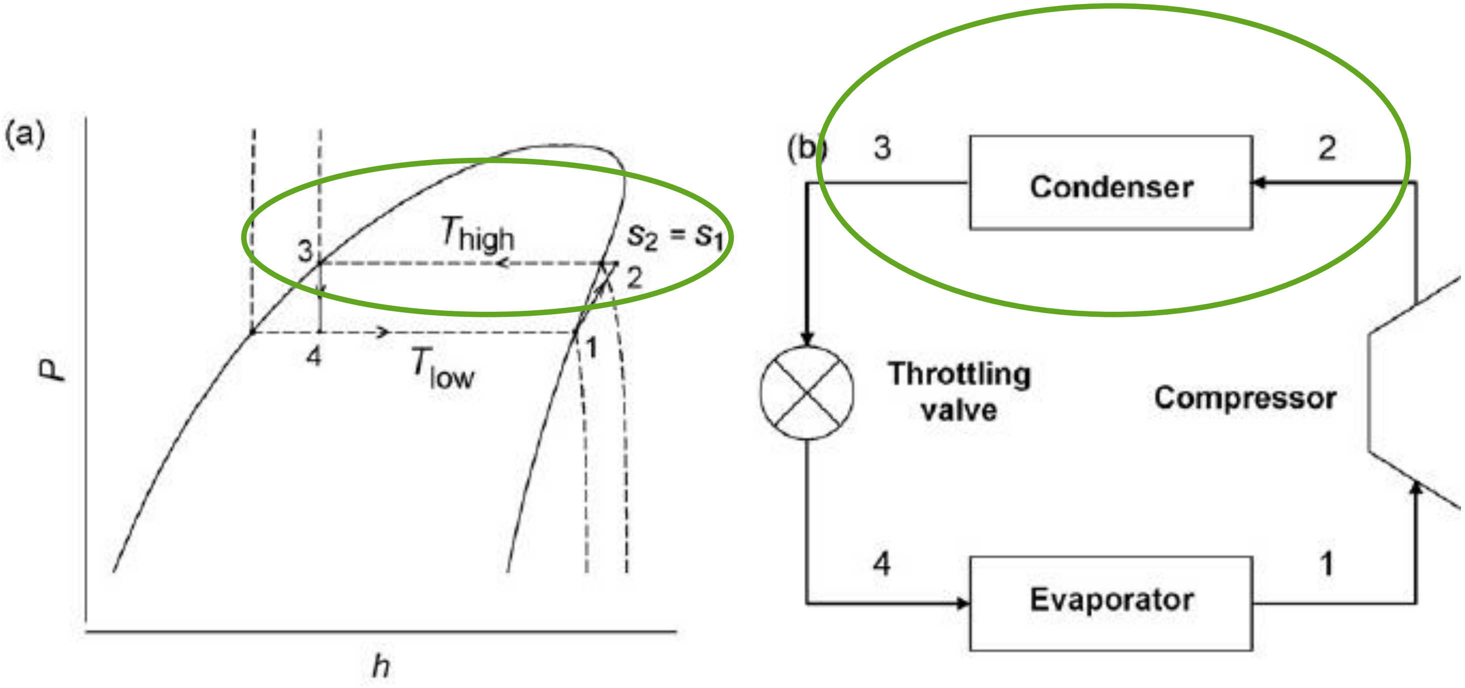
Different direct heat rejections methods

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

## Challenges:

- Application: operating hours / size
- Investment cost vs efficiency
- Specifics at Jobsite
    - Refrigerant
    - Refrigerant charge?
    - Secondary loop?
    - Location for the „plant“
    - Technical level of operators

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser



Refrigeration cycle

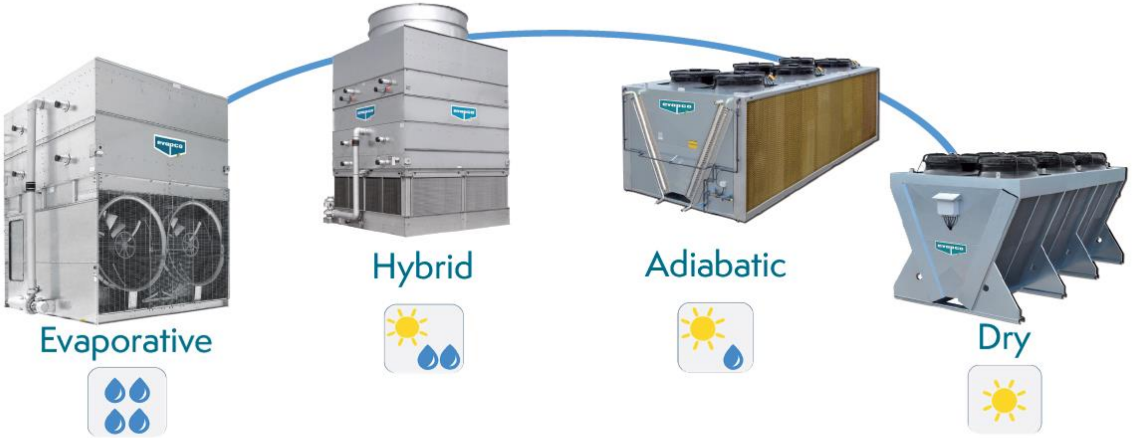
# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

The selected refrigerant can improve the system efficiency a lot, but in small applications NH3 is still competing strongly with other refrigerants.

Criteria:
- hot gas temperature (eg. limitation via oil)
- min. and max. condensing temperature
- pressure drop and refrigerant charge

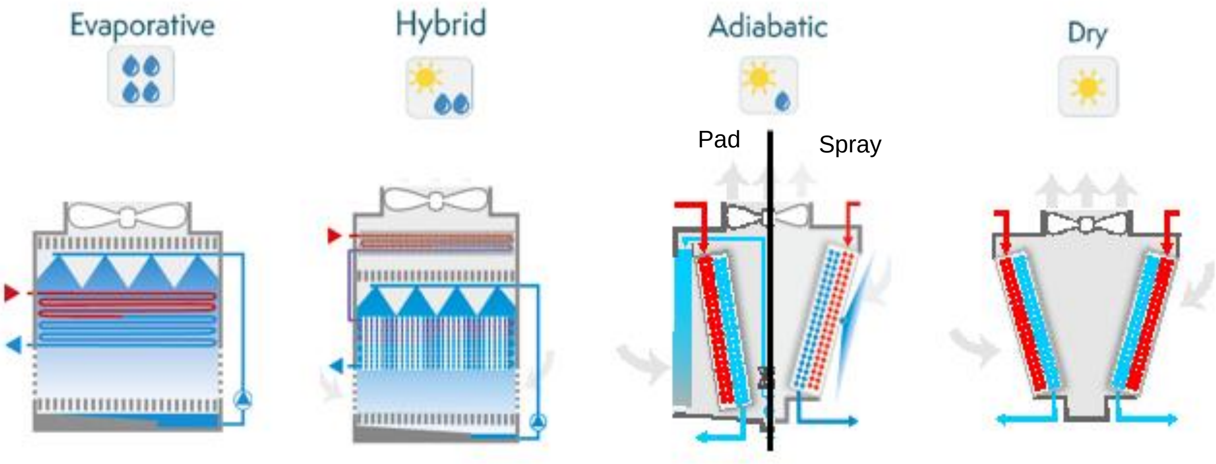
The type of heat rejection method will have impact on:
- Investment cost
- System efficiency
- Operating cost

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

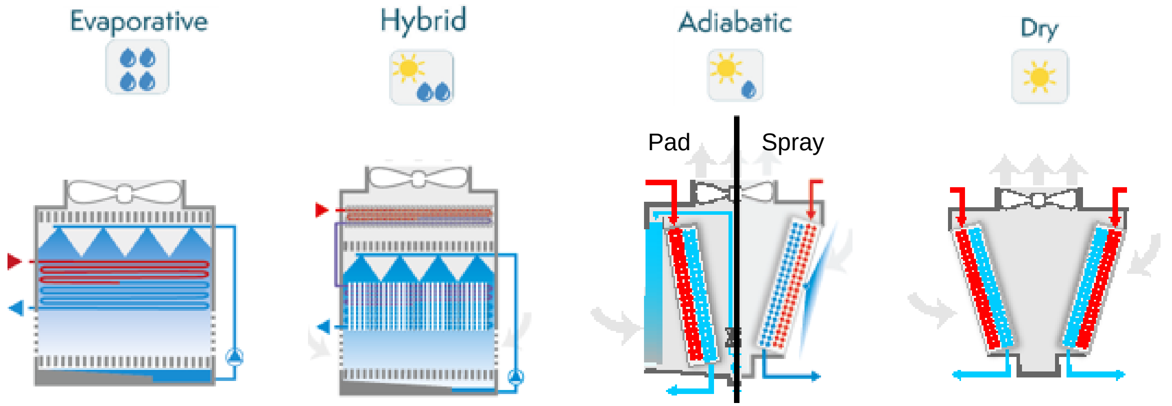


**Which one is the best?**

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser



# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

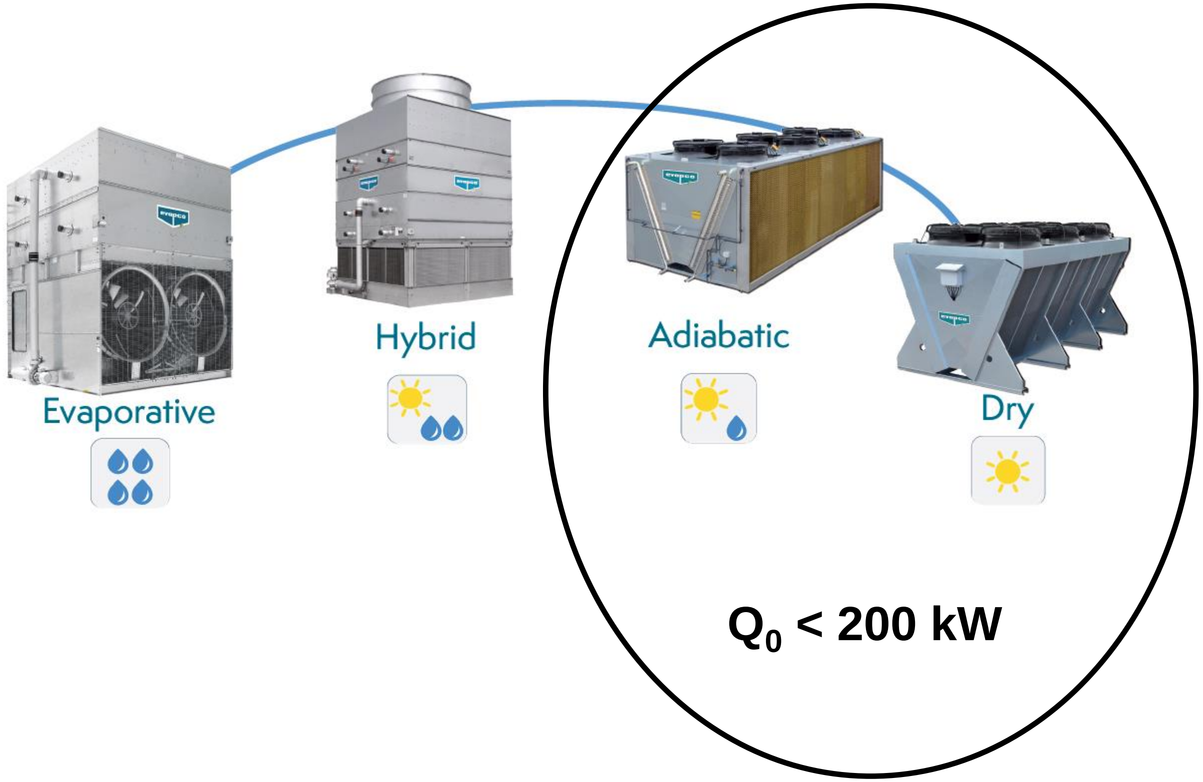


| | Evaporative | Hybrid | Adiabatic | Dry |
|---|---|---|---|---|
| Low Water Consumption | | ▨ | ▨ | 🟦 |
| Low Energy Consumption | 🟦 | 🟦 | ▨ | |
| Small Footprint | 🟦 | 🟦 | | |
| Easy Installation & Maintenance | | | 🟦 | 🟦 |
| Lowest Possible Condensing Temperature | 🟦 | 🟦 | ▨ | |

▨ Good
🟦 Very good

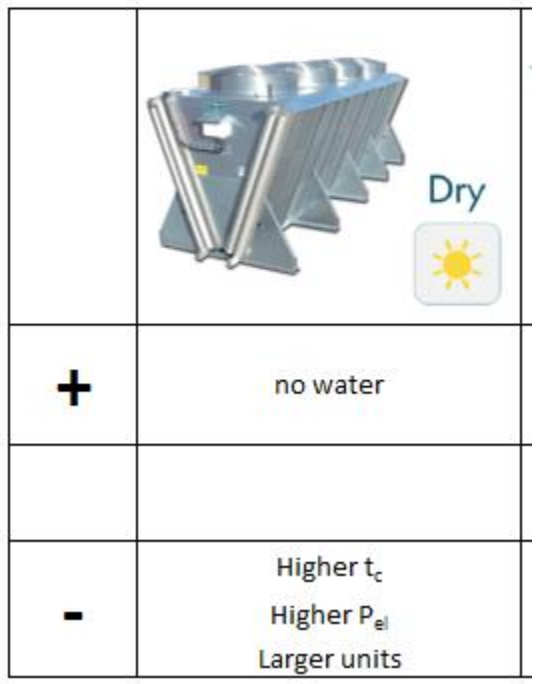
Features of different solutions

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser



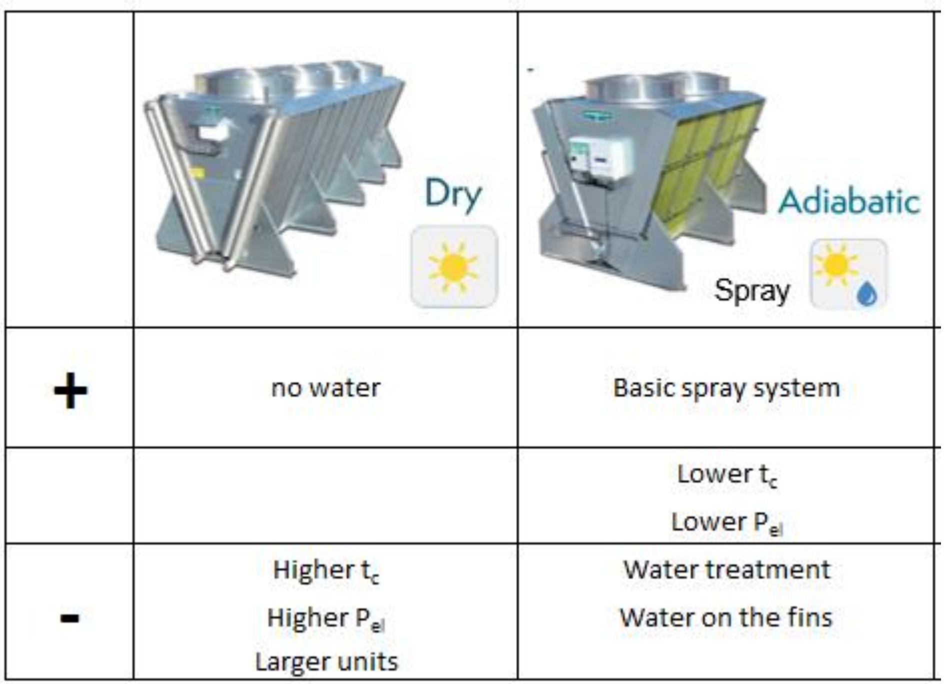
$Q_0 < 200$ kW

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser



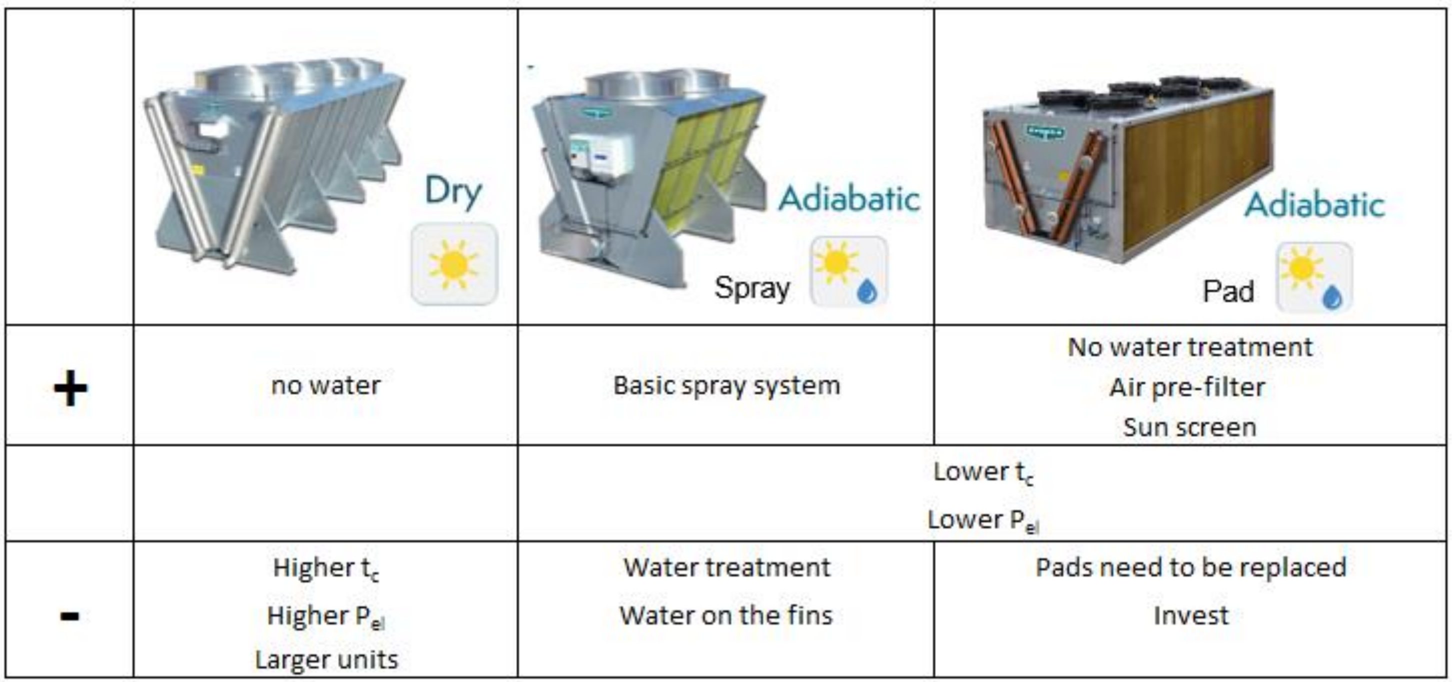
| | Dry ☀ |
|---|---|
| + | no water |
| | |
| - | Higher $t_c$<br>Higher $P_{el}$<br>Larger units |

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser



| | | |
|---|---|---|
| | Dry | Adiabatic<br>Spray |
| + | no water | Basic spray system |
| | | Lower $t_c$<br>Lower $P_{el}$ |
| - | Higher $t_c$<br>Higher $P_{el}$<br>Larger units | Water treatment<br>Water on the fins |

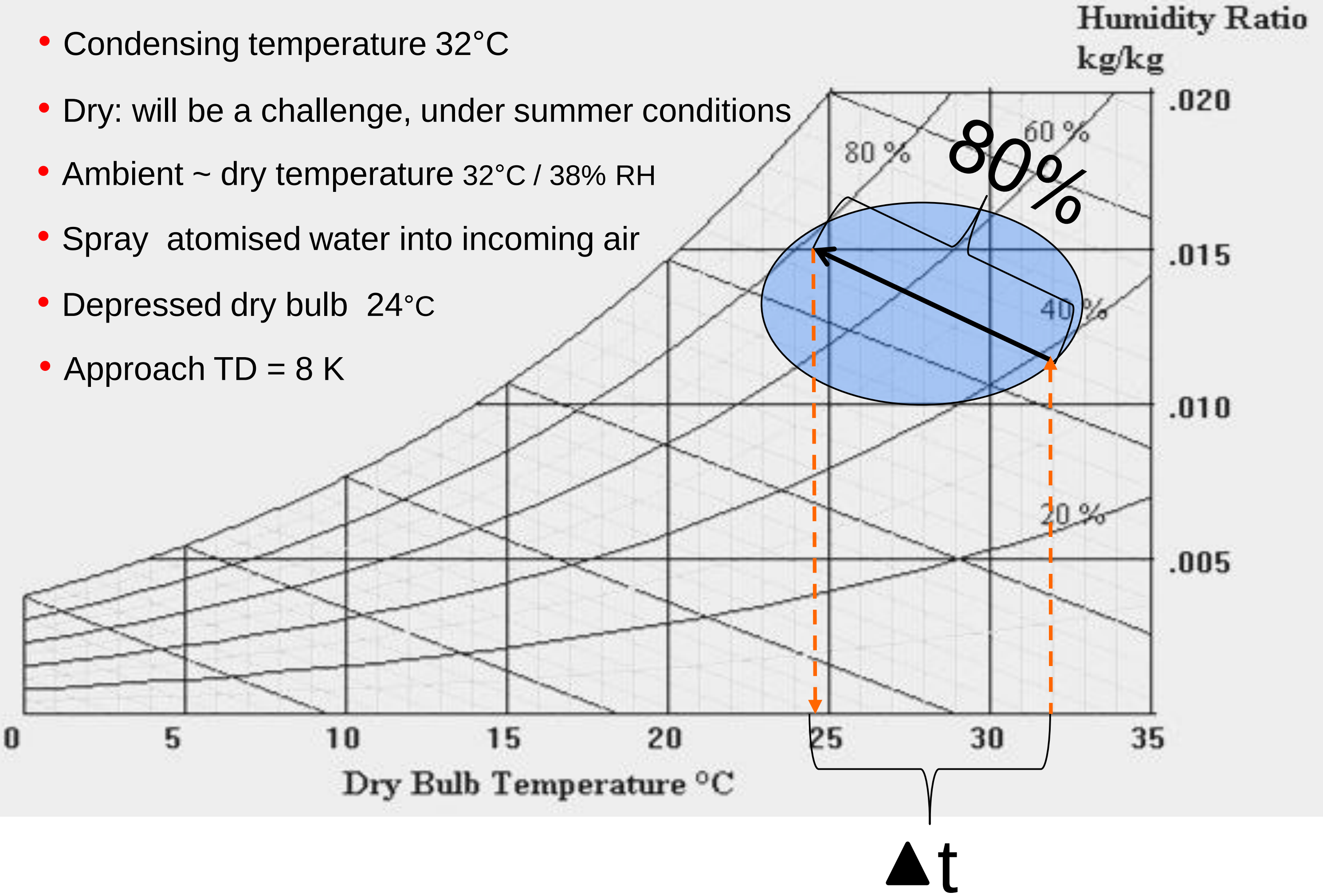
# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser



| | Dry | Adiabatic<br>Spray | Adiabatic<br>Pad |
|---|---|---|---|
| + | no water | Basic spray system | No water treatment<br>Air pre-filter<br>Sun screen |
| | | Lower $t_c$<br>Lower $P_{el}$ | |
| - | Higher $t_c$<br>Higher $P_{el}$<br>Larger units | Water treatment<br>Water on the fins | Pads need to be replaced<br>Invest |

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

- Condensing temperature 32°C
- Dry: will be a challenge, under summer conditions
- Ambient ~ dry temperature 32°C / 38% RH
- Spray  atomised water into incoming air
- Depressed dry bulb  24°C
- Approach TD = 8 K



# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

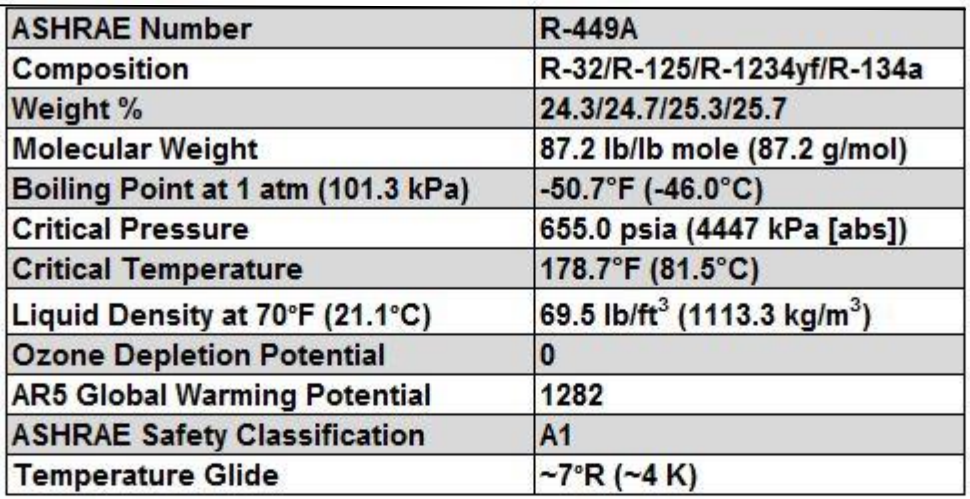
Example: „whole egg – production“in Northern Europe

+/- 7000 h/year
+/- 165 kW @ - 8°C

## R449A – Plant

## R717 – Plant

**R449A**



| ASHRAE Number | R-449A |
|---|---|
| Composition | R-32/R-125/R-1234yf/R-134a |
| Weight % | 24.3/24.7/25.3/25.7 |
| Molecular Weight | 87.2 lb/lb mole (87.2 g/mol) |
| Boiling Point at 1 atm (101.3 kPa) | -50.7°F (-46.0°C) |
| Critical Pressure | 655.0 psia (4447 kPa [abs]) |
| Critical Temperature | 178.7°F (81.5°C) |
| Liquid Density at 70°F (21.1°C) | 69.5 lb/ft$^3$ (1113.3 kg/m$^3$) |
| Ozone Depletion Potential | 0 |
| AR5 Global Warming Potential | 1282 |
| ASHRAE Safety Classification | A1 |
| Temperature Glide | ~7°R (~4 K) |

R449A: example Replacement refrigerant for R134A

https://www.chemours.com/Refrigerants/en_US/products/Opteon/Stationary_Refrigeration/products/Opteon_XP40.html

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

Example: „whole egg – production“
+/- 7000 h/year
+/- 165 kW @ - 8°C

| | **R449A- Plant** | **R717 – Plant** |
|---|---|---|
| **Capacity in total** | 164,4 kW | 174 kW |
| Screw compressor | 3x semi-hermetic screw | 3x open screw |
| $t_0$ | -8°C | -8°C |
| $t_c$ | +43 ... + 20°C | +32 ... + 20°C |
| Shaft power (each compressor) | 24,4 kW | 14,97 kW |
| Motor (each compressor) | 37,3 kW | 18,50 kW |
| COP | 2,25 ... 4,41 | 3,88 ... 5,4 |
| Condensing capacity | 237,6 kW | 198,6 kW |
| + Oil cooler | 10,95 kW (internal) | 20,4 kW |

Used for pre-heating of the warm water and for heating in Winter

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

Example: „whole egg – production“

## Main components

| R449A – Plant | R717 - Plant |
|---|---|
| 3 x compressor | 3 x compressor |
| 1 x oil separator | 1 x oil seperator |
| 1 x air cooled condenser (dry) | 1 x air cooled condenser (adiabatic) |
| 1 x receiver | 1 x HP-floatvalve @ the condenser |
| 1 x electronic expansion valve | 1 x separator |
| 1 x tube bundle evaporator | 1 x plate & shell heat exchanger (gravity) |
| => Secondary loop with PG 33% | 1 x oil cooler |
| | 1 x air cooled emergency oil cooler |
| | => Secondary loop with PG 33% |
| **Invest cost +/- 60.000 € *)**)** | **Invest cost +/- 145.000 € *)**)** |

*) Both, without: secondary loop, control, external piping and insulation

**) Budget price via TEKO, www.teko-gmbh.com

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

## Example: „whole egg – production“

### Main components

| R449A – Plant | R717 - Plant |
|---|---|
| 3 x compressor | 3 x compressor |
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| **1 x air cooled condenser (dry)** | **1 x air cooled condenser (adiabatic)** |
| 1 x receiver | 1 x HP-floatvalve @ the condenser |
| 1 x electronic expansion valve | 1 x separator |
| 1 x tube bundle evaporator | 1 x plate & shell heat exchanger (gravity) |
| => Secondary loop with PG 33% | 1 x oil cooler |
|  | **1 x air cooled emergency oil cooler** |
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| **Invest cost +/- 60.000 € *)**)** | **Invest cost +/- 145.000 € *)**)** |

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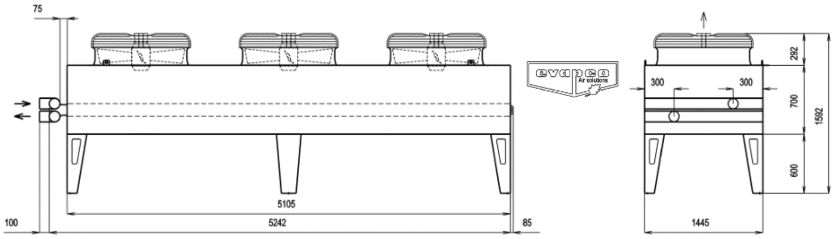
# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

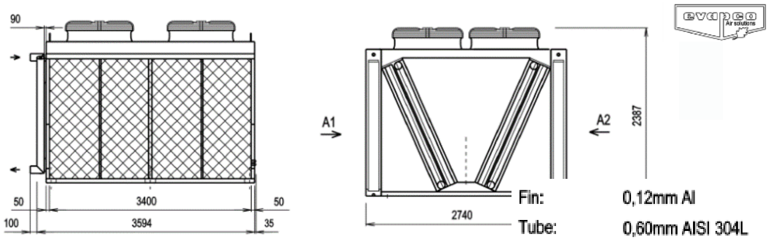
Example: „whole egg – production“

| **R449A – Plant** | **R717 - Plant** |
|---|---|
| 1 x air cooled condenser | 1 x adiabatic condenser |



Fin: 0,10mm Al

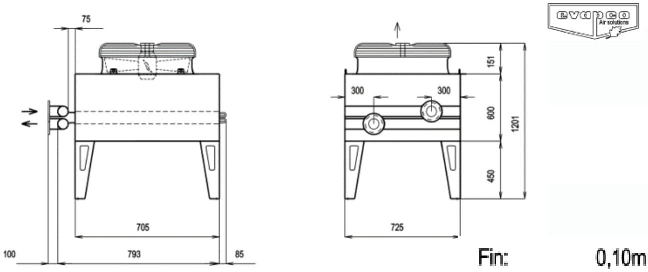
Tube: 0,28mm Cu



Fin: 0,12mm Al

Tube: 0,60mm AISI 304L

1 x emergency oil cooler (air cooled)



Fin: 0,10mm Al

Tube: 0,28mm Cu

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

## Example: „whole egg – production“ : R449A - Plant

| Month | Day | Hour | Ambient Temp. (°C) | Condenser | | | | Compressor | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Installed Capacity (kW) | Required Heat Rejection (kW) | Power Consumption | | Pe each (kW) | No. of running Compressors | Power Consumption (kWh) |
| | | | | | | Actual (kW) | Actual (kWh) | | | |
| 1 | 1 | 1 | -2.7 | 694 | 199 | 0.17 | 0.10 | 16,17 | 2,3 | 22 |
| 1 | 1 | 2 | -3.3 | 720 | 199 | 0.15 | 0.09 | 16,17 | 2,3 | 22 |
| 1 | 1 | 3 | -3.8 | 720 | 199 | 0.15 | 0.09 | 16,17 | 2,3 | 22 |
| 1 | 1 | 4 | -3.5 | 720 | 199 | 0.15 | 0.09 | 16,17 | 2,3 | 22 |
| 1 | 1 | 5 | -3.2 | 720 | 199 | 0.15 | 0.09 | 16,17 | 2,3 | 22 |
| ... | | | | ... | | | | ... | | |
| 12 | 31 | 20 | -0.2 | 642 | 199 | 0.20 | 0.20 | 16,17 | 2,3 | 37 |
| 12 | 31 | 21 | -0.2 | 642 | 199 | 0.20 | 0.12 | 16,17 | 2,3 | 22 |
| 12 | 31 | 22 | -0.3 | 642 | 199 | 0.20 | 0.12 | 16,17 | 2,3 | 22 |
| 12 | 31 | 23 | -0.9 | 642 | 199 | 0.20 | 0.12 | 16,17 | 2,3 | 22 |
| 12 | 31 | 24 | -1.8 | 668 | 199 | 0.18 | 0.11 | 16,17 | 2,3 | 22 |
| | | | 9.3 | | | kWh | **5755.53** | | kWh | **298881** |

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

## Notes:

- Condenser unit oversized to allow operation at reduced fan speed to improve power consumption
- Chiller capacity:
  - Each 54,8 kW @ **43°C** condensing
  - Each 71,4 kW @ **20°C** condensing

  - 71,4 x 3 = 214,2 kW (165 kW required)
  - Compressor operates at reduced RPM to improve COP

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

## Example: „whole egg – production“ : R717 - Plant

| Month | Day | Hour | Ambient temp.(°C) | Air inlet Condenser | Installed Condenser Capacity (kW) | Required Plant Capacity (kW) | Water Flow (Liter) | Power consumption Condenser (kW) | Hours in wet operation | Power Consumption (kWh) | Total Water Usage (Liter) | Power Consumption Chiller (kWh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | -2.7 | -2.7 | 816 | 188 | 0 | 0.07 | 0 | 0.04 | 0 | 18 |
| 1 | 1 | 2 | -3.3 | -3.3 | 848 | 188 | 0 | 0.06 | 0 | 0.03 | 0 | 18 |
| 1 | 1 | 3 | -3.8 | -3.8 | 848 | 188 | 0 | 0.06 | 0 | 0.03 | 0 | 18 |
| 1 | 1 | 4 | -3.5 | -3.5 | 848 | 188 | 0 | 0.06 | 0 | 0.03 | 0 | 18 |
| 1 | 1 | 5 | -3.2 | -3.2 | 848 | 188 | 0 | 0.06 | 0 | 0.03 | 0 | 18 |
| | | … | | | | | … | | | | … | |
| 12 | 31 | 20 | -0.2 | -0.2 | 753 | 188 | 0 | 0.08 | 0 | 0.08 | 0 | 30 |
| 12 | 31 | 21 | -0.2 | -0.2 | 753 | 188 | 0 | 0.08 | 0 | 0.05 | 0 | 18 |
| 12 | 31 | 22 | -0.3 | -0.3 | 753 | 188 | 0 | 0.08 | 0 | 0.05 | 0 | 18 |
| 12 | 31 | 23 | -0.9 | -0.9 | 753 | 188 | 0 | 0.08 | 0 | 0.05 | 0 | 18 |
| 12 | 31 | 24 | -1.8 | -1.8 | 785 | 188 | 0 | 0.08 | 0 | 0.05 | 0 | 18 |
| | | | **9,3** | | | | | | **244.33** | **10547.90** | **309326** | **226668** |
| | | | | | | | | | | kWh | | kWh |

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

## Notes:

- Condenser oversized to allow for operation at reduced speed to improve power consumption
- Chiller capacity:
  - Each 58 kW @ **32°C** condensing
  - Each 62,3 kW @ **20°C** condensing

  - 62,3 x 3 = 186,9 kW (165 kW required)
  - Compressor operates at reduced RPM to improve COP

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

Example: „whole egg – production“

## Operating costs

### R449A - Plant

| | Consumption* | Unit price | Operating costs |
|---|---|---|---|
| **Condenser** | 5756 kWh | 16 Ct/kWh | 921 € |
| **Water** | 0m³ | 3,5 EUR/m³ | 0 € |
| **Chiller** | 298881 kWh | 16 Ct/kWh | 47.821 € |
| **Annual operating costs** | | | 48.742 €/year |

### R717 - Plant

| Consumption* | Unit price | Operating costs |
|---|---|---|
| 10548 kWh | 16 CT/kWh | 1.688 € |
| 309m³ | 3,5 EUR/m³ | 1.083 € |
| 226668 kWh | 16 Ct/kWh | 36.267 € |
| | | 39.037 €/year |

* theoretical calculated consumption, under consideration of the ambient temperatures

# Energy Efficiency and Life Cycle Costs of a NH$_3$ Evaporative Condenser

Example: „whole egg – production“

| **R449A - Plant** | | **R717 - Plant** | |
|---|---|---|---|
| First costs | +/- 60.000 € | First costs | +/- 145.000 € |
| Operating costs: | +/- 49.000 € | Operating cots | +/- 39.000 € |

Maintenance costs:

R449A compact chiller: 2 times/year
Air cooled condenser: 1 time/year

R717 compact chiller: 2 times/year
Air cooled oil cooler: 1 time/year
Adiabatic condenser: 1 time/year

*) theoretical calculated consumption, under consideration of the ambient temperature

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

Example: „whole egg – production“

**R449A - Plant**

First costs +/- 60.000 €

Operating costs: +/- 49.000 €

Maintenance costs

Additionial costs:

**R717 - Plant**

First costs +/- 145.000 €

Operating cots +/- 39.000 €

The pad needs to be replaced from time to time.

⇒ +/- 500 €/year
(3x2500 = 7500/15)

*) theoretical calculated consumption, under consideration of the ambient temperature

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

Example: „whole egg – production“

| **R449A - Plant** | |
|---|---|
| First costs | +/- 60.000 € |
| Operating costs: | +/- 49.000 € |
| Maintenance costs | |

| **R717 - Plant** | |
|---|---|
| First costs | +/- 145.000 € |
| Operating cots | +/- 39.000 € |

Additionial costs:

+/- 500 €/year

**Simplefied payback period: < 9 years !!!**

**+ profit from using of the oil cooler capacity**

*) theoretical calculated consumption, under consideration of the ambient temperature

# Energy Efficiency and Life Cycle Costs of a $NH_3$ Evaporative Condenser

Conclusion:

- The better energy and life cycle costs of plants with NH3 Evaporative condenser are for larger one‘s known and accepted.
- For smaller applications, NH3 needs to overcome the high cost against lower operating cost.

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