Issues for Discussion

• High Saturation Efficiency Evap Coolers
  – What comfort standards apply?
  – Under what climate conditions can they provide comfort?
  – What is their energy and peak load reduction potential?
  – How much water do they use?
  – Is their use to augment vapor compression cooling in extreme hot-dry climates warranted?

• Evaporative Condensers
  – How do they perform relative to conventional air conditioners?
  – How much water do they use?
EC Performance Ratings

• Test Standards
  – Direct & two stage: ANSI/ASHRAE 133-2001
  – Indirect: ANSI/ASHRAE 143-2001

• CEC Title 20 Evaporative Cooler Standards
  – Tested in accordance with ASHRAE standards
  – Conditions: 80°F indoor dry bulb (relief)
  91°F outdoor dry bulb
  69°F outdoor wet bulb
  – Ratings: Saturation effectiveness
  Total power
  Airflow rate
  Evaporative cooler efficiency ratio (ECER)
ECER = 1.08 * (Tin – (Tdb – ε * (Tdb – Twb)) * Q / W
ASHRAE Standard 55-2004

• Which method applies to EC’s?
  – Section 5.2
    • Graphical method using “comfort zone”
    • Accounts for operative dry bulb temperature and relative humidity
  – Section 5.3
    • Optional method for naturally conditioned spaces
    • Assumes occupant use of windows to maintain comfort
    • No “mechanical cooling system (e.g. refrigerated air conditioning, radiant cooling, or desiccant cooling)”
Prototype Evaporative Cooler

- Saturation efficiency > 1
- Single variable speed blower
- Double pass plastic indirect heat exchanger
- Rigid cellulose evaporative media
- Airflow varies with thermostat temperature offset
- Controls regulate purge cycles as a function of cycles of concentration
Prototype Evaporative Cooler

Diagram showing the flow of air through the evaporative cooler, with labels for hot intake air, humid exhaust air, cool supply air, fresh air, indirect cooling module, direct cooling module, exhaust air, conditioned air, air turn around area, and water reservoir.
Borrego Springs Field Test

- Two 2000 ft\(^2\) houses ("Arrow" & "Wagon")
- Identical floor plans
- Different wall systems
  - Arrow: structural insulated panels (SIP)
  - Wagon: concrete-foam-concrete sandwich panel
Location
Climate

<table>
<thead>
<tr>
<th>Normal High</th>
<th>July</th>
<th>December</th>
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<tbody>
<tr>
<td>Normal Low</td>
<td>109°F</td>
<td>70°F</td>
</tr>
<tr>
<td>2006 Range of Highs</td>
<td>105-121°F</td>
<td>60-81°F</td>
</tr>
<tr>
<td>2006 Range of Lows</td>
<td>75-97°F</td>
<td>23-46°F</td>
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</tbody>
</table>
Mechanical Equipment

• ‘Wagon’
  – Minimal ducting
  – Forced air/radiant backup cooling

• ‘Arrow’
  – Full ducting shared with forced/air heating cooling
  – Motorized dampers to prevent back-drafting
"Mild" Day

- Temperature (deg F)
- Power (kW) / Fractional RH
- Indoor Temp
- Outdoor Temp
- Outdoor Wet Bulb Temp
- Supply Air Temp
- Indoor RH
- Power

Graph showing temperature and power over time.
“Mild” Day

Dry Bulb, Deg. F
Humidity Ratio

0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002

30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120

100 90 80 70 60 50 40 30
“Warm” Day

The graph shows the temperature and power distribution over the course of a day, from 0:00 to 21:00. The temperature is measured in degrees Fahrenheit (deg F) and the power in kilowatts (kW). The graph includes lines for various parameters such as Indoor Temp, Outdoor Temp, Outdoor Wet Bulb Temp, Supply Air Temp, Indoor RH, and Power. The data points are visible as curves on the graph, indicating changes in temperature and power throughout the day.
"Warm" Day
“Hot” Day

The diagram above illustrates the temperature (deg F) and power (kW) variations over time during a "hot" day. The data is categorized and represented as follows:

- **Indoor Temp**
- **Outdoor Temp**
- **Outdoor Wet Bulb Temp**
- **Supply Air Temp**
- **Indoor RH**
- **Power**

The graph shows a rising trend in temperature throughout the day, peaking around midday, followed by a slight decline in the evening. The power consumption also exhibits fluctuations, with peaks corresponding to the temperature spikes. The fractional RH values are also indicated, showing a general decreasing trend with temperature.
“Hot” Day

Dry Bulb, Deg. F

Humidity Ratio

-0.002
-0.004
-0.006
-0.008
-0.010
-0.012
-0.014
-0.016
-0.018
-0.020

30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120

100 90 80 70 60 50 40 30

10

20
# Energy & Water Use

**May 23 - July 3, 2007**

<table>
<thead>
<tr>
<th>Outdoor Conditions</th>
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<tbody>
<tr>
<td>Max Outdoor Temp</td>
<td>113.8°F</td>
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<tr>
<td>Avg Outdoor Temp</td>
<td>88.2°F</td>
</tr>
<tr>
<td>Avg Outdoor Wet Bulb</td>
<td>59.1°F</td>
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</table>

<table>
<thead>
<tr>
<th>Indoor Conditions</th>
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<tbody>
<tr>
<td>Max Indoor Temp</td>
<td>79.6°F</td>
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<tr>
<td>Avg Indoor Temp</td>
<td>76.5°F</td>
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<tr>
<td>Max Indoor RH</td>
<td>66%</td>
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<tr>
<td>Avg Indoor RH</td>
<td>45%</td>
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</tbody>
</table>

## Energy & Water

- **kWh Saved**: 17.02 per day
- **% kWh Savings**: 79%
- **Water Use**: 97.4 gal per day
- **Cooling Delivered**: 160.1 kBtu/day
- **Water Use/kBtu**: 0.61 gal/kBtu
Evaporative Cooler EER
Energy Savings vs. Indoor RH

- The graph shows the relationship between maximum acceptable indoor relative humidity (RH) and energy savings, categorized into percent energy savings.
- Two categories are represented: Wagon (diamond) and Arrow (square).
- The graph indicates that as the maximum acceptable indoor RH increases, energy savings also increase, with peaks at specific RH levels for both categories.

Percent Energy Savings vs. Maximum Acceptable Indoor RH
Evap Cooler vs. AC Energy Demand

15 minute peak loads, Summer 2006

<table>
<thead>
<tr>
<th></th>
<th>AC</th>
<th>Evap</th>
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</thead>
<tbody>
<tr>
<td>Wagon</td>
<td>3834 W</td>
<td>645 W</td>
</tr>
<tr>
<td>Arrow</td>
<td>4278 W</td>
<td>816 W</td>
</tr>
</tbody>
</table>
Evaporative Cooling Economics

• Assumptions
  – Neutral cash flow (incremental mortgage payments = energy savings)
  – 6.5%, 30 year mortgage
  – $0.14/kWh

• Results
  – At a maximum indoor RH of 60%, energy savings range from 55-58% and justify an incremental cost ranging from $4443 to $9282
  – Cash flow is more favorable when cooling load is higher
Evap Cooler Conclusions

- Evaporative cooling comfort criteria are subjective
- When used with air conditioning, energy savings can range from 40-60% while maintaining conditions that meet ASHRAE 55
- Peak load can be reduced by as much as 80%
- Houses in climates with extreme highs exceeding 105°F and coincident wet bulb temperatures exceeding 70°F should probably use vapor compression cooling
- High saturation efficiency evaporative coolers can be justified in hot climate homes equipped with conventional air conditioning
Freus Evap Condenser Performance

- 3 ton nominal outdoor unit capacity
- Nightbreeze air handler w/ Amana 5 ton indoor coil
- Evap sump water used for “floor cooling mode”
- Following results for AC mode only
Comparison to Mfg. Power Data

- Outdoor Unit Power, Eng Data (1200CFM 80°Fdb/67°Fwb Return Temperature)
- Outdoor Unit Power, Monitored 2006 (kW)
- Outdoor Unit Power, Monitored 2007 (kW)
Outdoor Unit Power Comparison

• Why is the outdoor unit power as measured in the field higher than Manufacturer’s data?
  – Non-standard condenser fan (276W, ~1500CFM) was installed. Standard condenser fan is ~100w, 1000CFM
  – Water pump power was found to be higher than expected (~90W vs 60W expected)
  – Manufacturer suspects that scale from condenser coils may have damaged the water pump, water pump inlet screen was improperly placed underneath coils allowing scale to fall into the water pump suction port
Comparison to Manufacturers Performance Data, Sensible Cooling Capacity for Freus Operation

Comparison to Mfg. Capacity Data
Sensible Cooling Capacity Comparison

- Why is the sensible cooling capacity as measured in the field higher than Manufacturer’s data?
  - Indoor fan power higher than expected, high external static pressure
  - 2006 data compares to Manufacturer’s data within measurement uncertainty
  - 2007 data shows sensible capacity degradation, manufacturer suspects that evap media is not properly wetted due to scale from water pump inhibiting water distribution
Measured Sensible EER Comparison
Freus Performance Comparison to other Borrego Air Conditioners

- Freus sensible EER is relatively flat with outdoor drybulb temperature
- Freus sensible EER approaches SEER 21 performance at high drybulb temperatures
- Freus outperforms the SEER 13 air conditioner
- Caveats (2006 data)
  - Freus indoor fan has a higher power draw (~560W, ~400CFM/ton) than the SEER 21 unit (2 ton mode - ~125W, 3 ton mode ~360W, ~400CFM/ton) due to duct system & extra heating coil
  - Freus had higher condenser fan power and water pump power than expected
  - After reviewing field data and making a site visit Manufacturer is replacing the outdoor unit, new unit will have standard condenser fan and properly located pump inlet screen, swap to be completed 7/10/07. Monitoring will continue through summer ‘07