The Path Towards Zero Energy District

Cooling Plant in Qatar

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Disclaimer:

this is an unscientific presentation, with scientific overtones
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Net-Zero Concept & Boundary Limits

• Net Zero Energy Solution, in the simplest terms, produce as much energy as it consumes.

• Net-Zero Site Energy Use: Export an equal amount of received energy measured over the course of one year.

• Net-Zero Source Energy Use: One energy unit produced on-site could offset three imported units produced off-site.

• Net-Zero Energy Emissions: Offset equal amount of produced carbon emissions through the energy source powering the building.

The present is for zero & the future is for positive
Natural Resources State of Affairs in the GCC

• GCC countries will emerge as world leaders in electricity consumption per capita expected to increase at annual rates of 2.5%.

• Power requirements in Qatar to rise to 10 GW in 2020, compared to 7.6 GW today.

• Water demand in Qatar to double from 1.1 Million m³/day in 2011 to 2.1 Million m³/day in 2020.

• A large part of this increase is attributed to the needs of a growing population and a significant 47% of energy consumption diverted into residential use.

• GCC countries put only 10.5% of their electricity to use in industry, as opposed to 37.7% globally.
Water Consumption in the GCC 2010

2010 Overall Water Per Capita Consumption Benchmark

<table>
<thead>
<tr>
<th>Country</th>
<th>Consumption (l/c/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qatar (KAHRAMAA)</td>
<td>464</td>
</tr>
<tr>
<td>Bahrain (EWA)</td>
<td>311</td>
</tr>
<tr>
<td>UAE (FEWA)</td>
<td>307</td>
</tr>
<tr>
<td>Saudi Arab</td>
<td>253</td>
</tr>
</tbody>
</table>
Total Water Production in Qatar

Average annual growth from 2006 to 2010 is 13.2%.
Top 10 Challenges in Achieving Net-Zero

1. Climatic conditions
2. Water scarcity
3. An open air experience
4. Evening matches in summer
5. Safety of athletes
6. Comfort of spectators
7. State of technology
8. Integration & flexibility
9. Infrastructure
Solar Assisted Refrigeration Solution

- Source of the Solution
- Systems of the Solution
- Current System Solution
- Alternative at a larger Scale
- Alternative at a Smaller Scale
- Alternative at the Air Side
Annual Sum of Direct Normal Irradiation [kWh/(m²a)] for the year 2002

Source: MED-CSP 2005
Tested Data: Solar radiation in Al-Khor (kW/m²), Jun. 22-29, 2008

the \textbf{source} of the solution
The Source

MEAN DAILY GLOBAL RADIATION for Doha, Ummsaid, Al-Khor 1988 and Al-Otoriya 2008 (kWh/m²)
Amazing but true, in August 1913 Maadi was the site of history-making innovation when American inventor-engineer Frank Shuman (1862-1918) chose this still-nascent nileside suburb to launch his amazing contraption—a solar panel power plant.

Here's how the *Egyptian Gazette* described this groundbreaking event in its 12 July 1913 issue.
Amazing but true: It all started here

Fig. 1.9 Detail from the north of the long parabolic-cylinder mirror collectors used in the human-Boys system. Note the hoops on which the mirror was tilted to follow the sun.
Amazing but true: It all started here

THE ELECTRICAL EXPERIMENTER

H. Gernsback Editor
H. W. Secor Associate Editor

Vol. III Whole No. 35
MARCH, 1916
Number 11

The Utilization of the Sun's Energy

It has been given to astronomers to measure the heat generated by the sun and calculate the force emanating from it. We know that the surface of our sun is subjected to a heat greater than 10,000,000 degrees Fahrenheit, and that the light, which we sometimes call the sun's embers, is about one-tenth of a mile away. The heat which the sun has given off since it started, is calculated to be the equivalent of a great building.

Every sort of light with which we illumi- nate our homes, comes from the sun's rays that spread out upon the earth's surface. Every ray of light that falls on objects and produces color, is a product originating in the sun. The sun is the greatest and most powerful source of energy in the world.
Amazing but true: It all started here
Amazing but true: It all started here

In the focus of five parabolic reflectors, each 204 feet long, a trough is placed through which water runs in a thin film.

The mirrors are carried on arc-shaped frames which can be rocked so as to face the sun at all times.
Amazing but true: It all started here

"إنني على يقين من شئين واحد: أن البشرية لن تعود إلى استخدام الطاقة الشمسية أو ترتد إلى البرية.
فإنك قلبي 1914"

[...] One thing I feel sure of, and that is that the human race must finally utilize direct sun power or revert to barbarism.

Frank Shuman 1914
Absorption Refrigeration Cycle

FAN COIL UNIT

Heat Medium

WATER FIRED CHILLER-HEATER

COOLING TOWER

* Cooling/Heating Changeover Valv supplied on Chiller-Heaters only

Legend:
- Dilute Solution
- Concentrated Solution
- Refrigerant Vapor
- Refrigerant Liquid
- Cooling Water
- Chilled Water
- Heat Medium
Absorption Chillers Advantages

- Reliable, durable and mature technology
- Significant reduction of electrical consumption,
- Reduced operating costs
- Reduced CO₂ emissions
- Non-flammable & non-toxic
- Ecologically benign
- Ozone-friendly working medium LiBr
- Vacuum and LiBr solutions charged in factory ("plug & play")
- Water as refrigerant
- Available for outdoor installations
Absorption Chillers Challenges:

- High sensitivity towards high condenser water temperature
- High make-up water rates (evaporation, blow down & drift loss)
- Relatively high chilled water temperature (7 to 8°C)
- Temperature level of the heat medium, provokes aggressive corrosion
- Large area for solar collectors
- Overall system's efficiency
- Assisting rather than driving
## Absorption Machines Comparison

<table>
<thead>
<tr>
<th></th>
<th>Double effect $\text{H}_2\text{O}/\text{LiBr}$</th>
<th>Triple effect $\text{H}_2\text{O}/\text{LiBr}$</th>
<th>Single effect $\text{NH}_3/\text{H}_2\text{O}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature lift (max)</td>
<td>25 K</td>
<td>25 K</td>
<td>55 K</td>
</tr>
<tr>
<td>Temperature of Cold</td>
<td>5-20°C</td>
<td>5-20°C</td>
<td>-20°C to 20°C</td>
</tr>
<tr>
<td>Driving temperature</td>
<td>140-180°C</td>
<td>230-270°C</td>
<td>160-180°C</td>
</tr>
<tr>
<td>Max. COP</td>
<td>1.1-1.4</td>
<td>1.6-1.8</td>
<td>0.6-0.7</td>
</tr>
</tbody>
</table>
Condenser Water Temperature & Efficiency

- Cooling-Water Inlet Temperature
- 32°C
- 31°C
- 29.5°C
- 27°C

- Standard Point
  - 88 °C

- 7°C Chilled water Condition
Steam Driven Vs Absorption Chillers

- Applicable to large tonnage from 100 to 5000 TR with free source of steam
- Machine COP = 1.8.
- Steam driven centrifugal chiller at capacities more than 1000 TR are most cost effective than two-stage absorption chiller.
Steam Driven Centrifugal vs Absorption Chillers

Figure 1: ECWT operating envelope.

Figure 2: Coefficient of performance comparison.

<table>
<thead>
<tr>
<th>Chiller Type</th>
<th>IPLV\textsuperscript{a} (COP Basis)</th>
<th>Capital Cost \textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric, Constant-Speed Centrifugal</td>
<td>7.0</td>
<td>Base</td>
</tr>
<tr>
<td>Electric, Variable-Speed Centrifugal</td>
<td>9.9</td>
<td>+25</td>
</tr>
<tr>
<td>Electric Screw</td>
<td>7.5</td>
<td>+0</td>
</tr>
<tr>
<td>Steam/Hot-Water, Single-Stage Absorption</td>
<td>0.8</td>
<td>+35</td>
</tr>
<tr>
<td>Steam, Two-Stage Absorption</td>
<td>1.3</td>
<td>+220</td>
</tr>
<tr>
<td>Steam-Turbine Centrifugal</td>
<td>1.8</td>
<td>+210</td>
</tr>
</tbody>
</table>

\textsuperscript{a} IPLV values are calculated according to Air-Conditioning and Refrigeration Institute Standards 560-2000 and 550/560-1998.

\textsuperscript{b} Capital Cost \textsuperscript{b} includes the chiller, pumps and tower, but not the boiler.

Table 1: Typical water-cooled chiller efficiencies and costs.

\[ \text{Efficiency Absorption Chiller} = (\text{Efficiency @ Full Load} \times (0.1356 + 0.3944x + 4.0933x^2 - 4.4598x^3 + 1.6248x^4) + [1 - 0.00949 \times (85 - \text{ECWT}) + 0.00014 \times (85 - \text{ECWT})^2}] \]
Adsorption Refrigeration Machines
Adsorption Refrigeration Machines

Leading small capacity adsorption chillers in Europe

- EAW
- SorTech AG
- PINK
- ClimateWell
- SK SonnenKlima GmbH
Open Cycle Adsorption System

Air System

Water System

Solid Desiccants
Leading Solar Cooling Experiences

Infrastructure, Competition & Non Competition Venues

1. 2022- bid Showcase Stadium, Doha,
2. Masdar City, Abu Dhabi, UAE
3. ESAB Head Office, UAE
4. UEFA HQ, Nyan, Switzerland
Leading Experiences: Competition Venues

2022-Bid Show Case Stadium, Doha

- 500-seats model stadium with retractable roof.
- A Mirroxx linear Fresnel collector with uniaxial tracking and a total mirror aperture area of 1040m² heats the pressurized water directly.
- Thermal storage PV arrays for electricity generation with a monitoring system and not connected to the local electrical grid.
- Double-Effect 150 TR Thermax absorption chiller with dual fuel source and underground chilled water storage tank.
- Displacement ventilation for air delivery System for the pitch coupled with UFAD for Spectator stands.
- Water consumption = ?
Leading Experiences: Non Competition Venues

Masdar City Solar Cooling Plant Solution Pilot

• A Sopogy micro-parabolic trough collector with uniaxial tracking and a total mirror aperture area of 334 sq m. Synthetic oil as thermal media.

• Heat is transferred to the system’s pressurized water circuit through a heat exchanger.

• A Mirroxx linear Fresnel collector with uniaxial tracking and a total mirror aperture area of 132 m² heats the pressurized water directly.

• The two solar thermal collector systems have been in successful test operation already for more than three months.
Leading Experiences: Non Competition Venues

Masdar City Solar Cooling Plant Solution Pilot

- Schneider Electric provided the control system components for the pilot plant.
- Fraunhofer Institute of Solar Energy to analyze the monitored data and assess system performance.
- Collector’s thermal energy has been driving the Broad 50 refrigeration-ton double-effect absorption chiller cooling 1700 m² of office building.
- Air delivery system uses chilled beams coupled with fresh air energy recovery units.
- Water consumption: Not Available.
Leading Experiences: Non Competition Venues

**ESAB Head Office, Jafza, UAE**

- 6,500 m² built to achieve LEED Platinum.
- $1 million solar thermal cooling system, one of the large-scale applications in the region.
- Solar system use 1,500 solar vacuum tubes.
- 70% Energy Reduction compared to a As-Usual Building by using solar thermal and efficient lighting systems.
- Six Packaged Absorption Units (Climate Well) to serve roof mounted AHUs handling latent loads.
- Radiant Cooling System using Thermo-deck approach (hallow core ceiling slab) handling sensible loads.
**Design Intent:** Must be a sustainable & energy efficient building operating in 2010.

- **Building’s Cooling Load:** 100 TR.
- **Renewable Energy Source:** Geothermal, Thermal Solar & PV (200 m²).
- **Thermal Array:** 90 vacuum tubes over 110 m² area generating 55 KW used for heating and domestic water in winter and cooling in summer to cover 10% only of the loads.
- **Water temperature:** Hot at 88°C for generator and Chilled water at 7°C.
- **Storage tank:** 3,000 Liters.
- **Refrigeration Machine:** absorption chiller with cooling capacity of 10 TR.

**Leading Experiences: Non Competition Venues**

**UEFA HQ, Nyon, CH**

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Leading Experiences: Non Competition Venues

UEFA HQ, Nyon, CH

Diagram of a cooling system with the following components:
- Solar Collector
- Hot water Storage tank
- Electrical Compression Chiller
- Cooling Demand
- WFC-SC10
- Cooling Tower
Delivering Promises

• Comparison
• Scalability
• Context Integration
• Infrastructure integration
• The bath towards net-zero
• Controls Integration Challenges

Simulation outputs video
Context Integration

• Integration with other aspects:
  - Event, Accommodation, Medical, Mobility & Education
  - District cooling plants locations
  - Chilled water reticulation optimization
  - Solar fields location
  - Relationship with other utilities
  - Use recycled water for heat rejection
  - Used cooling tower blow down water for irrigation
# Systems Selection Justification

<table>
<thead>
<tr>
<th>Systems Descriptions</th>
<th>Evacuated tube collector, single effect absorption chiller</th>
<th>Parabolic trough, double effect absorption chiller</th>
<th>Flat collectors &amp; adsorption chiller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Collector efficiency</td>
<td>60 %</td>
<td>50 %</td>
<td>55 %</td>
</tr>
<tr>
<td>Chiller efficiency (COP)</td>
<td>0.75</td>
<td>1.3</td>
<td>0.45</td>
</tr>
<tr>
<td>Temperature © (°C)</td>
<td>80 to 110</td>
<td>144 (4 bar)</td>
<td>60 to 85</td>
</tr>
<tr>
<td>Solar Irradiation on collector surface</td>
<td>1,000 kW</td>
<td>1,000 kW</td>
<td>1,000 kW</td>
</tr>
<tr>
<td>Collector's efficiency</td>
<td>60 %</td>
<td>50 %</td>
<td>55 %</td>
</tr>
<tr>
<td>Heat absorbed by the captor supplied to the Chiller</td>
<td>600 kW</td>
<td>500 kW</td>
<td>550 kW</td>
</tr>
<tr>
<td>Absorption Chiller COP</td>
<td>0.75</td>
<td>1.3</td>
<td>0.45</td>
</tr>
<tr>
<td>Heat absorbed by Chiller</td>
<td>450 kW</td>
<td>650 kW</td>
<td>248 kW</td>
</tr>
<tr>
<td>Overall system performance</td>
<td>45%</td>
<td>65%</td>
<td>25%</td>
</tr>
<tr>
<td>Increase in cooling yield</td>
<td>44%</td>
<td>-81.82%</td>
<td></td>
</tr>
</tbody>
</table>
Cost Effectiveness

- Thermal absorption solar refrigeration system cost almost 3 to 4 times the cost of a conventional vapor compression system.
- Double effect direct-fired/steam absorption chiller cost between 1.8 to 2 times the cost a vapor compression chiller.
- The cost of reduced scale cooling system using adsorption machine is almost 4 times compared to a non-solar assisted system.
- The cost of a direct-fired & steam absorption chiller is 35% higher than the direct-fired chiller.
- The cost of a direct-fired & hot water absorption chiller is 35% higher than the direct-fired chiller.
- The square meter of a thermal solar flat collector cost between 1700 to 3400 QR
- The square meter of solar evacuated tubes cost between 3400 to 3970 QR
At the present, most solar cooling systems are assemblies of single components and don’t provide a fully integrated system, these components in many cases have their own control units.

The performance of the solar cooling solution depends a lot on the availability of a single source centralized control.

The industry will follow the market momentum in embracing a fully integrated solution for solar cooling system.
Full Integration

- Voice and Data Comms
- Structured Cabling and Cable Management
- IP Convergence
- Service and Maintenance
- IPTV Network & Electronic Messaging
- Large Format Video/Scoreboards
- Fire Suppression Reporting
- Closed Circuit Television & Digital Video Surveillance
- Lift Integration Management
- People Location Management
- Mass Access Control
- Parking Access Control
- Internal Access Control
- Fire Detection and Alarm
- Public Address and Voice Announcement (PA/VA)
- Lighting
- Heating, Ventilation and Air Conditioning (HVAC)
- Energy Management
- Business Systems
- System Validation
- Stadium Control Room: Systems Integration
- Links to External Authorities
Conclusion

1. Major benefit of performing this study is to show the feasibility of a carbon neutral solution for a cooling plant at different scale

2. Cooling system efficiency is sensitive towards high condenser water temperature

3. Adverse impact of dust/ humidity on system’s efficiency

4. High rates of water depletion and pollution (evaporation & bleed-off)

5. Higher cost

6. Needs a vast area for solar field (15 to 20 times the football pitch size)

7. Requires a single source control system for all system’s components

8. Cooling plant reticulation needs be integrated in the city infrastructure

9. “Opportunity Document” needs to be developed for each venue
THANK YOU