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## **Solar-Driven Air Cooling In The GCC: 3 in-field studies, results and economics**

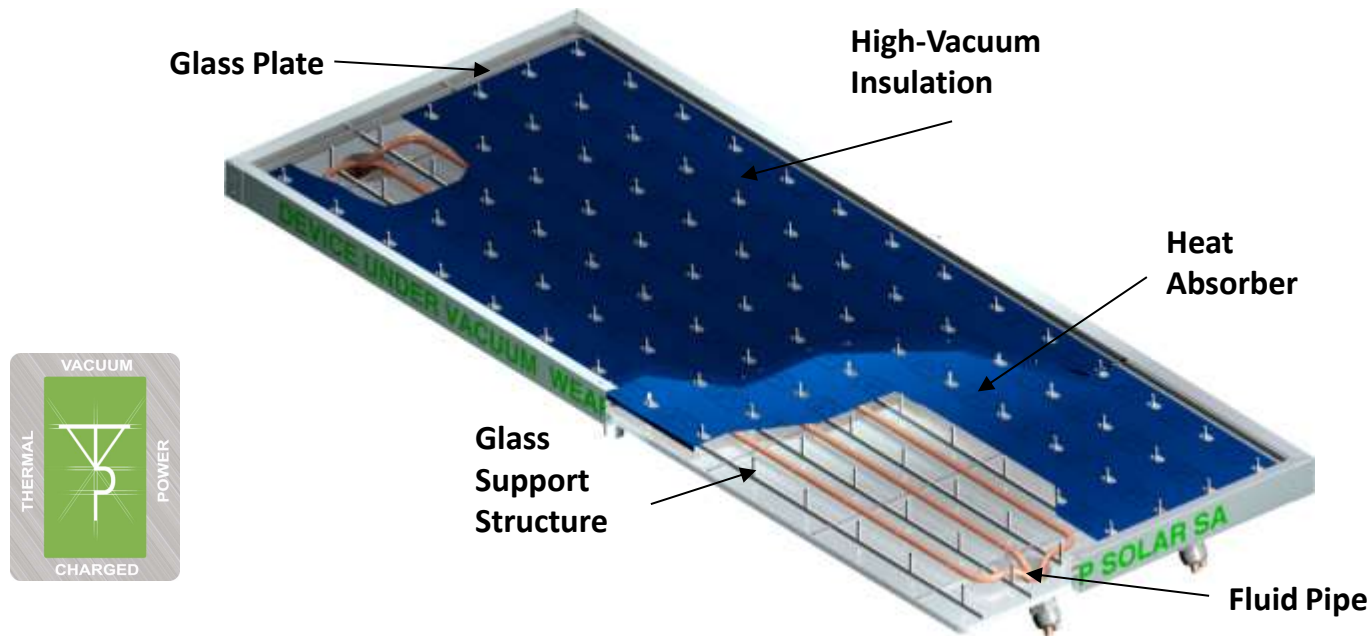
Solar Air-Conditioning Workshop at Aramco PSPD

May 2<sup>nd</sup> 2017

# Thermal Vacuum Power Charged™ Products

## Industry-changing solar thermal panels for applications 80°C-180°C

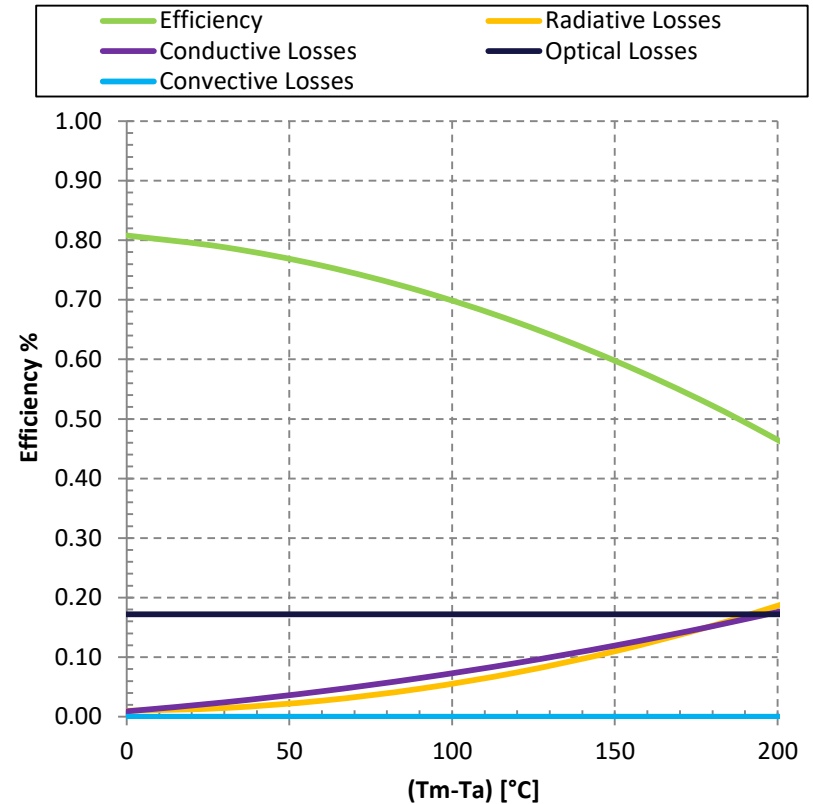
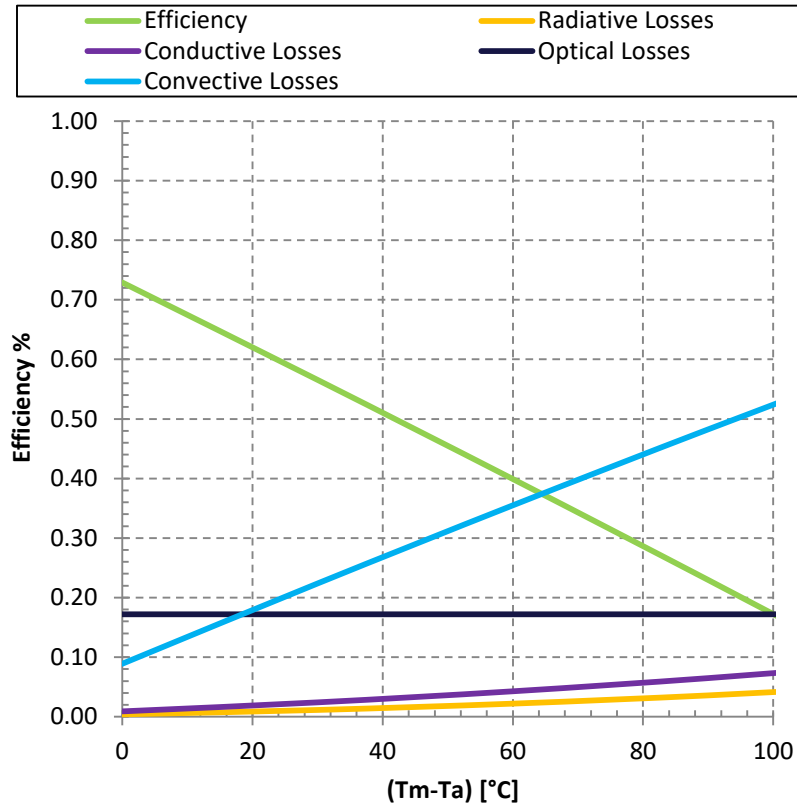
TVP solar thermal panels take full advantage of high-vacuum insulation in a planar layout, achieving high efficiencies up to 180°C without concentration



- The only solar thermal collector without mirrors able to operate a 2E VAM up to 180°C
- Proven in-field to outclass concentrators in terms of thermal energy output and efficiency

# High-Vacuum Delivers Best Solar Thermal Collector Performance

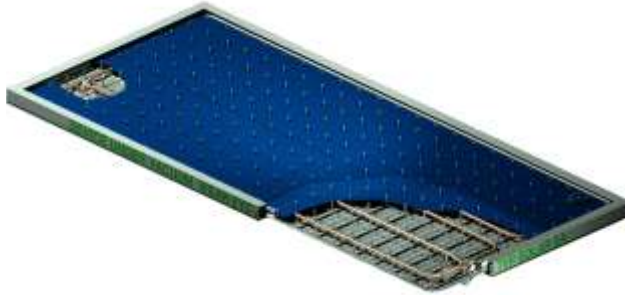
High-vacuum is the best transparent insulator, suppressing thermal losses due to convection



TVP MT-Power panel is a Solar Key-Mark certified as most performant solar thermal collector up to 200°C in any weather condition

# TVP SAC: Solar Directly Driving Absorption Chillers

## Combining best-of-breed solar thermal panels and absorption chillers



### TVP panels:

- Highest sun-to-thermal efficiency up to 200°C in any weather condition at any operating temperature
- The only solar panel Solar KeyMark certified up to 200°C
- Ideally suited for high ambient temperature environments
- Ideally suited for dusty, humid, hazy, coastal environments because of its ability to capture diffuse light
- High durability & no performance degradation over time
- Minimal maintenance: no panel cleaning
- Smallest installation footprint
- Easy architectural integration or no ground preparation
- Proven in Middle East for SAC



### Absorption chillers:

- Requires/consumes minimal electricity
- High COP up to 1.41
- Efficient hybrid operation with dual firing: solar with combustible auxiliary
- Flexible firing source: LNG, LPG, diesel, biogas
- Wide range of machine capacities (up to 5MW), modular for large deployments and redundancy
- High reliability
- Remote monitoring and control
- Easy maintenance
- Operationally proven in high irradiance regions

# Consistent and Predictable Energy Output

## Simulation results confirmed across multiple regional field tests and deployments

City	GHI kWh/m <sup>2</sup> /year		Tout (°C)									
			60	95	110	120	130	140	150	165	180	190
Riyadh (KSA) Jeddah (KSA)	2200	kWh/m <sup>2</sup> /year	1687	1500	1413	1353	1291	1228	1163	1063	961	893
		Efficiency (%)	77%	68%	64%	62%	59%	56%	53%	48%	44%	41%
Kuwait City (KW) Dubai (UAE) Amman (JOR)	2000	kWh/m <sup>2</sup> /year	1515	1334	1250	1192	1133	1073	1012	918	824	762
		Efficiency (%)	76%	67%	63%	60%	57%	54%	51%	46%	41%	38%
Abu Dhabi (UAE) Dammam (KSA) Muscat (OMN)	1950	kWh/m <sup>2</sup> /year	1491	1308	1223	1164	1104	1042	980	884	787	722
		Efficiency (%)	76%	67%	63%	60%	57%	53%	50%	45%	40%	37%
Doha (QAT)	1703	kWh/m <sup>2</sup> /year	1272	1093	1011	955	898	841	783	696	610	553
		Efficiency (%)	75%	64%	59%	56%	53%	49%	46%	41%	36%	32%

**SAC with 2E VAM**

- ✓ Consistent and predictable energy output on yearly basis in any location, at any irradiance
- ✓ The higher the ambient temperature, the higher the solar thermal efficiency (as opposed to PV)
- ✓ Proven to work in dusty environment without any precision/water cleaning

# Masdar City, UAE: Up To 175°C To Drive Air Conditioning

Solar thermal driving 2E VAM relieves electric chiller daytime peak cooling need (comm. Jan 2012)



# Masdar City, UAE: Measured Results

Solar field output up to 175°C consistent in any weather conditions even without cleaning (2014)

Operating Year: 2014	Input Energy on the collector plane (kWh/m <sup>2</sup> /day)	Average daily energy produced by solar field (kWh/m <sup>2</sup> /day)	Solar Field System Efficiency	Average daily energy produced by solar field (kWh/day)
<i>January</i>	4.89	2.09	43%	87.88
<i>February</i>	5.45	2.24	41%	94.02
<i>March</i>	5.52	2.28	41%	95.58
<i>April</i>	5.73	2.44	43%	102.34
<i>May</i>	4.74	1.74	37%	72.98
<i>June</i>	4.46	1.73	39%	72.58
<i>July</i>	4.68	1.84	39%	77.26
<i>August</i>	4.97	2.22	45%	93.19
<i>September</i>	5.52	2.48	45%	104.02
<i>October</i>	5.70	2.20	39%	92.59
<i>November</i>	4.87	2.07	42%	86.78
<i>December</i>	4.81	2.03	42%	85.29
<b>Month Average</b>	<b>5.11</b>	<b>2.11</b>	<b>41%</b>	<b>88.71</b>
<b>Year Total</b>	<b>1,865.56</b>	<b>770.92</b>	<b>41%</b>	<b>32,378.63</b>

- ✓ In-field solar energy output consistent with simulated expectations
- ✓ Solar thermal panels were never cleaned during the period, and still delivered consistent, expected thermal energy



# Dhahran, KSA: Up To 175°C To Drive Air Conditioning

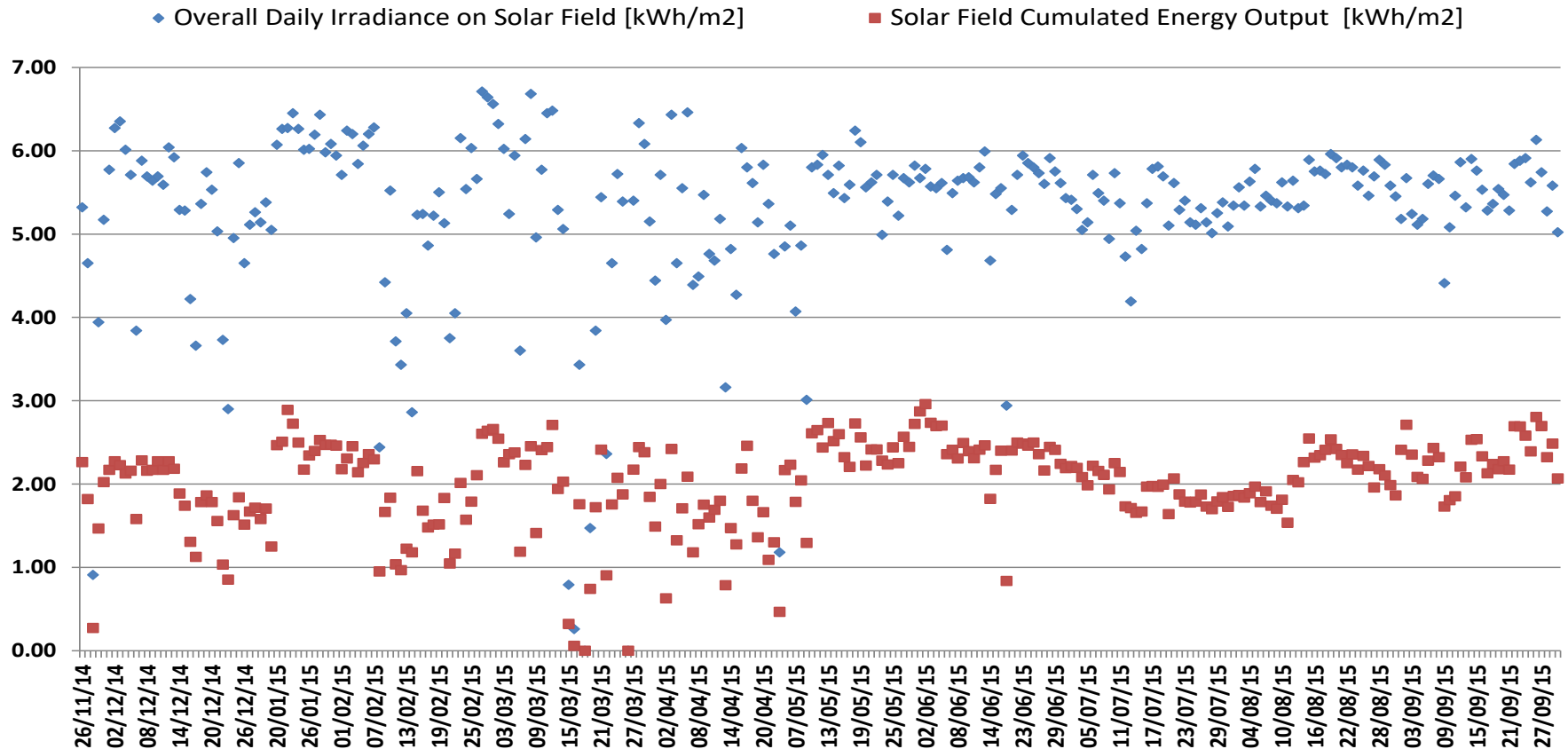
Solar thermal + diesel hybrid drive 2E VAM to relieve electric chiller daytime peak (comm. Nov 2014)





# Dhahran, KSA: Measured Results

## Solar field output up to 175°C consistent in any weather conditions even without cleaning (2015)



✓ Solar field average production: 2.13 kWh<sub>th</sub>/m<sup>2</sup>/day, up to 175°C

✓ Average sun irradiance: 5.26 kWh<sub>th</sub>/m<sup>2</sup>/day sun irradiance (40% av. efficiency)

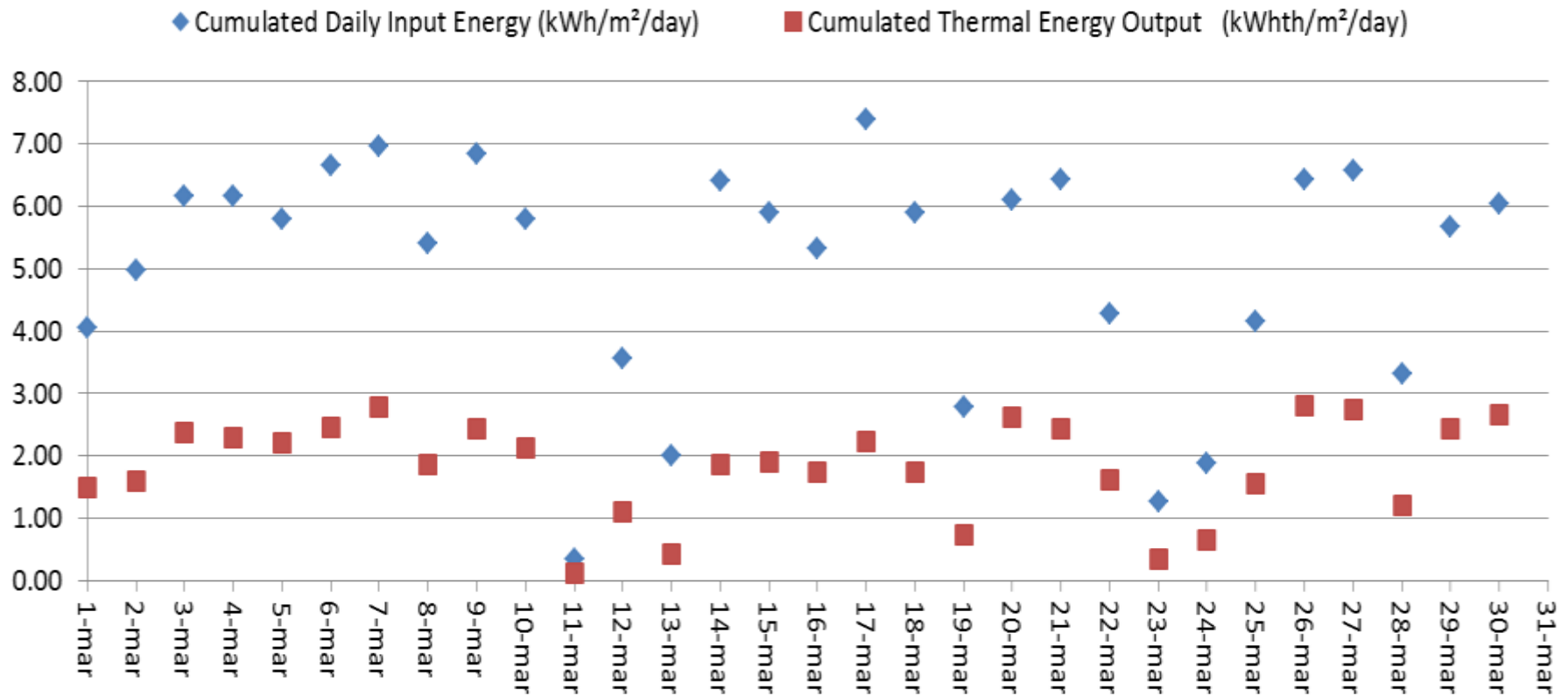
# Sulaibiya, KW: Up To 165°C To Drive Air Conditioning

Solar thermal + diesel hybrid drive 2E VAM to relieve electric chiller daytime peak (comm. Feb 2017)



# Sulaibiya, KW: Measured Results

Solar field output up to 165°C consistent in any weather conditions even without cleaning (2017)

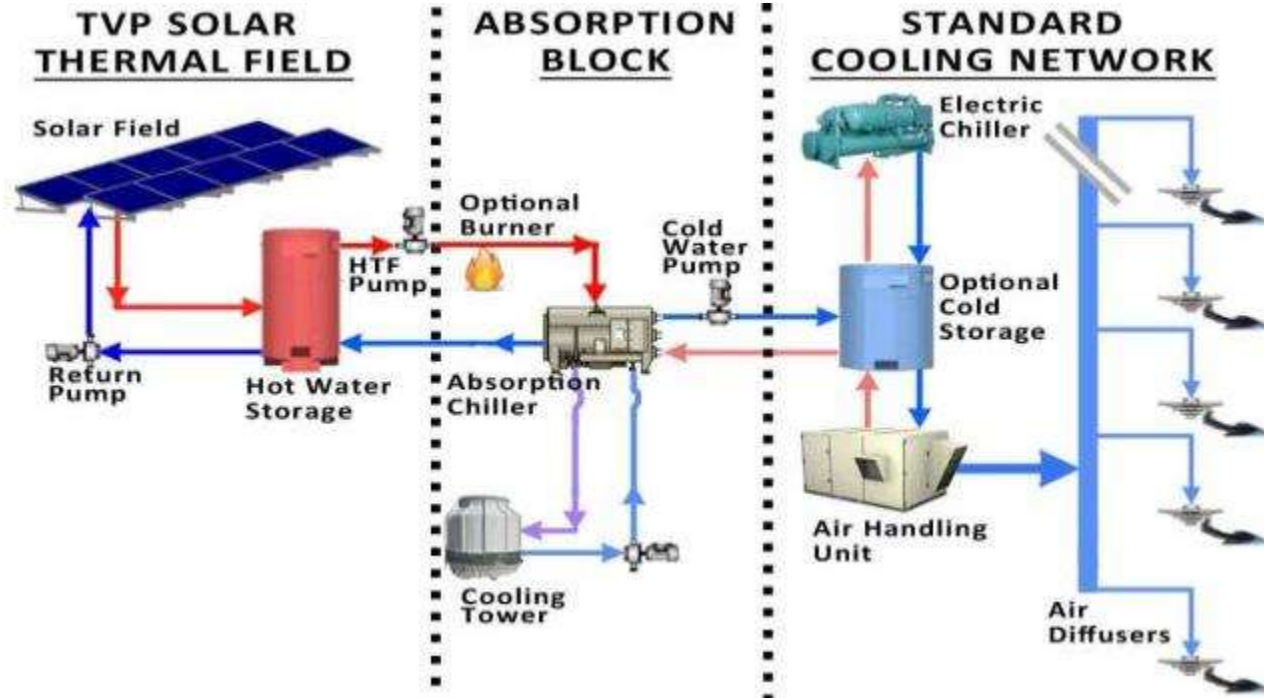


✓ Solar field average production: 2.1 kWh<sub>th</sub>/m<sup>2</sup>/day, up to 165°C

✓ Average sun irradiance: 5.7 kWh<sub>th</sub>/m<sup>2</sup>/day sun irradiance (37% av. efficiency)

# TVP SAC: Existing Electric Peak Relief (Hybrid) For Large-Scale

Solar thermal + diesel drive 2E VAM during daylight hours to relieve electric chillers of peak demand

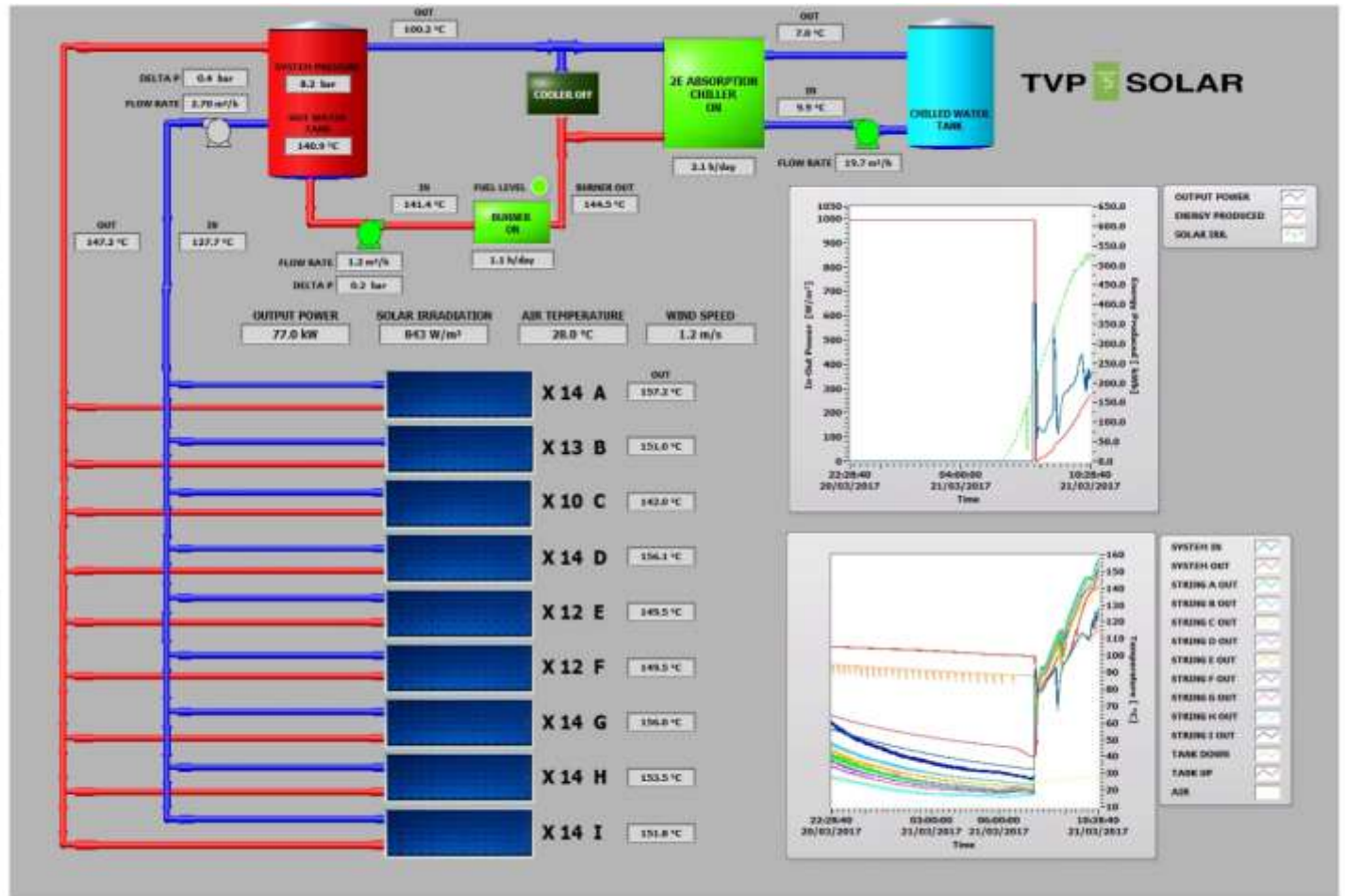


Absorption chiller driven by hybrid solar + combustible operates only during daylight providing peak cooling relief for an electric ducted chiller via shared chilled water storage tank operating in a standard cooling distribution network.

Maximizes the use of solar energy and absorption chiller during daylight (up to 8 hours/day) while minimizing combustible and electricity consumption. The burner only becomes operational to provide the lift between solar field temperature output and the minimum chiller temperature requirement.

# TVP SAC Control & Monitoring System

TVP-developed, autonomous , live monitoring of system operation and outputs via Web





# Solar Proven High Performance In Harsh, Dusty Conditions

Solar panels do not need any water-based cleaning



May 12th

before cleaning

2,44kWh<sub>th</sub> with 5.95 kWh<sub>th</sub> (40% efficiency)

Peak panel operating temperature 164°C

Peak ambient temperature 43,6°C



May 13th

after dry-cleaning

2,73kWh<sub>th</sub> with 5.71 kWh<sub>th</sub> (47% efficiency)

Peak panel operating temperature 176°C

Peak ambient temperature 47,5°C

**TVP panels show unique diffuse light capturing**

**Only 14% performance difference vs cleaned!!!**



# Consistent and Predictable Energy Savings And Cost Of Cooling

## TVP for SAC saves either combustibles or electricity, and reduces CO<sub>2</sub> emissions

City	GHI kWh/m <sup>2</sup> /year		Tout (°C)									
			60	95	110	120	130	140	150	165	180	190
Riyadh (KSA)	2217	kWh/m <sup>2</sup> /year	1686.7	1500.5	1413.2	1353.0	1291.2	1227.7	1162.8	1063.1	961.3	892.6
		Efficiency (%)	76%	68%	64%	61%	58%	55%	52%	48%	43%	40%
Jeddah (KSA)	2207	kWh/m <sup>2</sup> /year	1670.0	1485.3	1398.3	1337.9	1275.7	1211.9	1146.6	1046.3	943.8	874.6
		Efficiency (%)	76%	67%	63%	61%	58%	55%	52%	47%	43%	40%
Kuwait (KW)	1988	kWh/m <sup>2</sup> /year	1515.3	1334.3	1250.3	1192.4	1133.2	1072.9	1011.6	918.5	824.5	761.7
		Efficiency (%)	76%	67%	63%	60%	57%	54%	51%	46%	41%	38%
Abu Dhabi (UAE) Dammam (KSA)	1957	kWh/m <sup>2</sup> /year	1490.6	1308.3	1223.1	1164.2	1103.9	1042.3	979.6	884.1	787.2	722.4
		Efficiency (%)	76%	67%	62%	59%	56%	53%	50%	45%	40%	37%
Doha (QAT)	1703	kWh/m <sup>2</sup> /year	1271.8	1093.1	1011.2	955.2	898.5	841.1	783.3	696.5	610.0	553.3
		Efficiency (%)	75%	64%	59%	56%	53%	49%	46%	41%	36%	32%

- TVP cost of kWh<sub>cool</sub> ranges between 0.02 USD/kWh<sub>cool</sub> and 0.03 USD/kWh<sub>cool</sub>
  - Considering a 2E VAM operating @165°C and large scale deployments (>1,500 m<sup>2</sup> or 300 TR),
- TVP energy savings range between 696.5 kWh<sub>th</sub>/m<sup>2</sup>/year and 1063.1 kWh<sub>th</sub>/m<sup>2</sup>/year equivalent to:
  - Diesel: 80.1 – 122.3 liters/m<sup>2</sup>/year (considering 90% burner efficiency, diesel LHV = 9.656 kWh/liter)
  - Fuel gas: 80.4 – 122.7 m<sup>3</sup>/m<sup>2</sup>/year (considering 90% burner efficiency, fuel gas LHV = 9.63 kWh/m<sup>3</sup>)
  - Equivalent Electricity: 362.2 – 552.8 kWh<sub>e</sub>/m<sup>2</sup>/year (considering electric chiller yearly average COP = 2.5)

# TVP Targets Large Scale And District SAC Deployments

SAC integrates with centralised air conditioning units/ducts, for existing and new-build facilities

**Shopping Centers**



**Warehouses**



**Office Buildings**



**Datacenters**



