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Laboratories for the 21st Century
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Integrated Laboratory Energy Systems: Emerging Methods for Matching Distributed Generation Systems with Building Thermal Systems

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Presentation Background

- This presentation is a follow up to:

  "Integrated Laboratory Energy Systems; Emerging Methods in Laboratory Energy Production, Recovery, and Distribution"

  Presented at:

  Laboratories for the 21st Century Conference

  Washington, DC, January 7-11, 2002

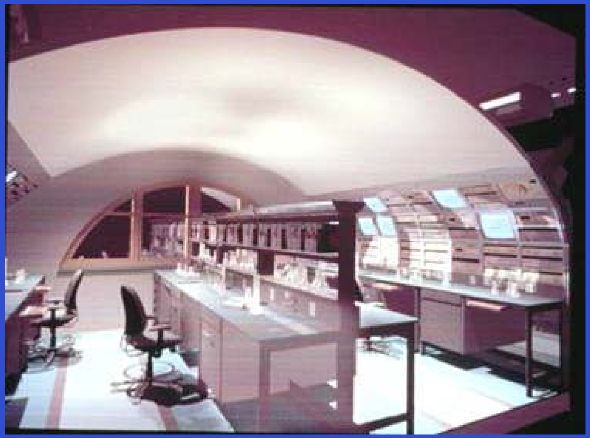
- Matching of building thermal loads to heat from distributed generation system is investigated

Presentation Summary

- “Strawman” Lab Building
- Components of laboratory energy use
- Areas of the country in the study
- Technologies for distributed generation (DG)
- Integration of DG with building thermal systems
- Economic considerations
- Environmental impacts
- Future investigations

Mission-Critical Building – Case Study

- Components of Lab Energy Use
  - Fume hoods
  - Ventilation
  - Heating
  - Cooling
  - Service hot water
  - Lighting
  - Equipment energy

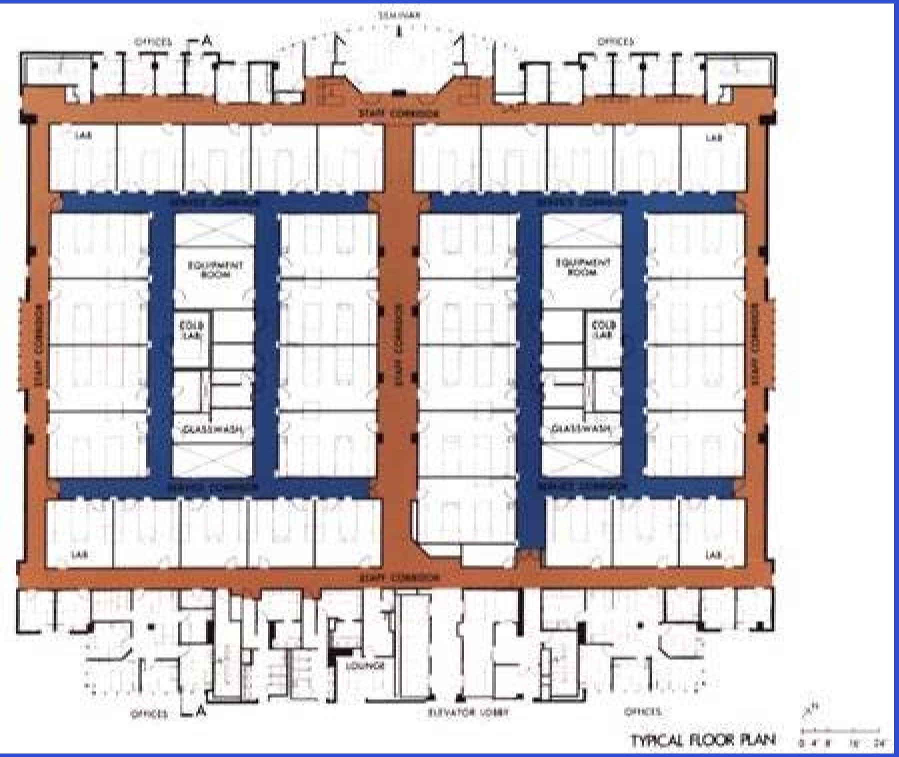


"Strawman Lab Building" – Background

- Biomedical Science Tower in Pittsburgh
  - Built in 1991
  - Gross area: 440,000 SF
  - Total usable area: 244,981 net sq. ft. (NSF)
  - Total labs: 130, 500 NSF
  - Offices: 42,772 NSF
  - Lab support: 60,784 NSF
  - Animal areas: 13,000 NSF

"Strawman Lab Building" – Background

- HVAC System
  - Offices: 1 CFM/NSF
  - Labs: 1.5 CFM/NSF
  - VAV Fume Hoods: (about 325)
- Power – Offices
  - Lights: 1.2 W/NSF
  - Equipment: 1.5 W/NSF
  - HVAC: 3.7 W/NSF



"Strawman Lab Building" – Background

- Power – Labs
  - Lights: 2.5 W/NSF
  - Equipment: 16 W/NSF
  - HVAC: 5.6 W/NSF
- Occupants: 1200
- Outside air: 500,000 CFM

Methodology Used For Evaluation of Case Study

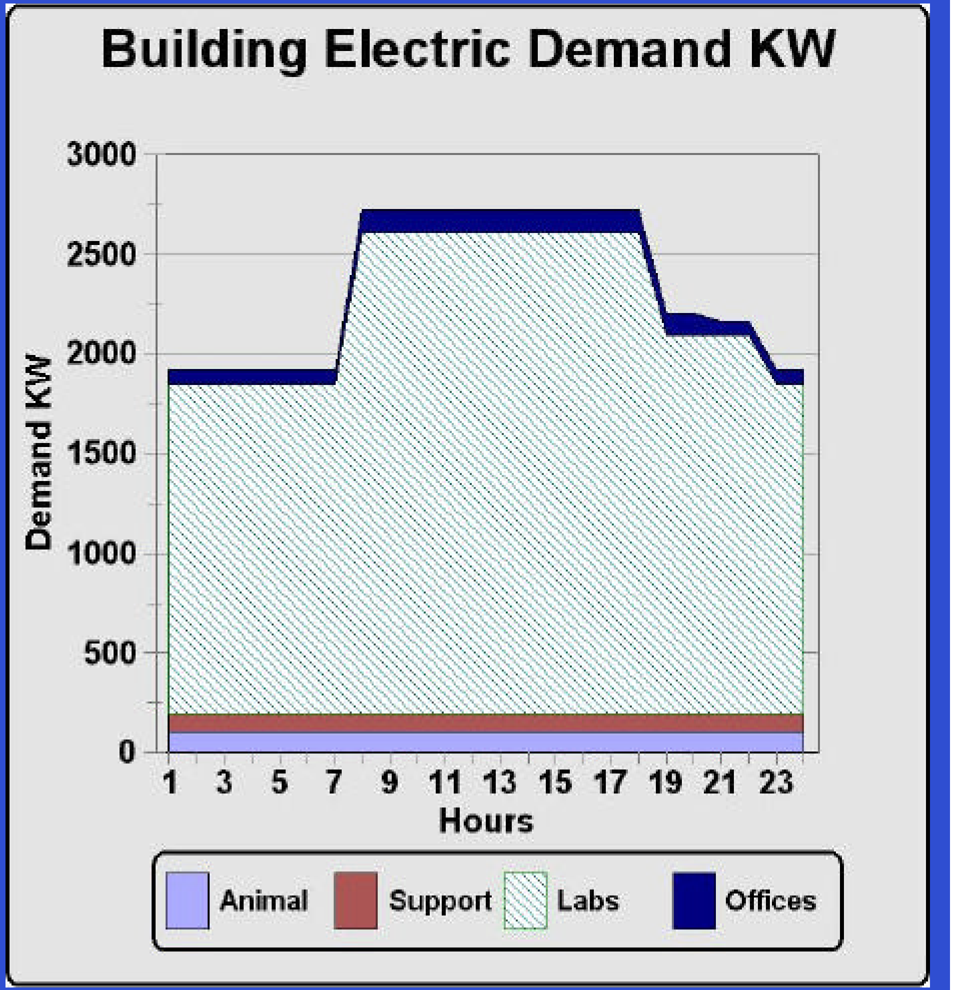
- Develop power use profile for the building, without electric chillers, (thermal energy-driven cooling is evaluated)
- Use TMY2 hourly weather data
- Use transient simulation system (TRNSYS) for hour-by-hour analysis of thermal options

Methodology Used For Evaluation of Case Study

- Evaluate the use of absorption cooling and desiccant cooling system
- Evaluate the matching of thermal and electric loads
- Estimate environmental impact
- Evaluate system economics

Methodology Used For Evaluation of Case Study

- Building Electric Load profile
  - Fuel cell system size with no sell back: 1.9 MW
  - Fuel cell system size with sell back: 3 MW or more
  - This study uses 1.9 MW generation



Methodology Used For Evaluation of Case Studies

- Cities Studied – Weather Data (TMY2 weather data was used)

City	Heating °F Days*	Cooling °F Days*	Cooling Design: 1% Dry Bulb °F	Cooling Design: 1% Wet Bulb °F	Cooling Design: 1% Humidity Ratio gr/lb** of air	Remarks Summer/Winter
Pittsburgh, PA	5,929	646	89	72	90	Cold/Mild
Houston, TX	1,433	2,889	97	77	110	Mold/Hot Humid
Phoenix, AZ	1,552	3,506	109	71	52	Mild/Hot Dry
Seattle, WA	5,184	128	85	68	76	Mild/Mild
Minneapolis, MN	8,258	585	92	75	104	Cold/Hot
Chicago, IL	6,125	923	94	75	1,000	Cold/Hot Humid
Colorado Springs, CO	6,473	461	93	59	20	Cold/Dry
Atlanta, GA	3,094	1,588	94	74	92	Cool/Warm
Washington, DC	5,009	940	93	75	102	Cold/Humid
Los Angeles, CA	1,818	614	98	70	74	Mild/Mild

* Degree days based on 65°F

** gr = grains of moisture

Methodology Used For Evaluation of Case Studies

- Assumptions Made for the Evaluation
  - Heating Energy Use
    - Efficiency of gas use: 80%
    - Gas cost: $3.50 per million BTU
  - Electricity cost: approximately $0.085/kWh (including demand)
  - Seasonal COP of electric cooling equipment: 2
  - Laboratory air conditions: 76°F dB, 70 gr/lb. of air
  - Laboratory supply air: 66°F, 50 gr/lb. of air

Thermally Driven Cooling System

- Absorption Cooling
  - Double effect cooling
  - Seasonal COP 1.21
  - Hot water fired
- Desiccant Cooling
  - Active regeneration of desiccant
  - Hot water/gas heat used for desiccant regeneration

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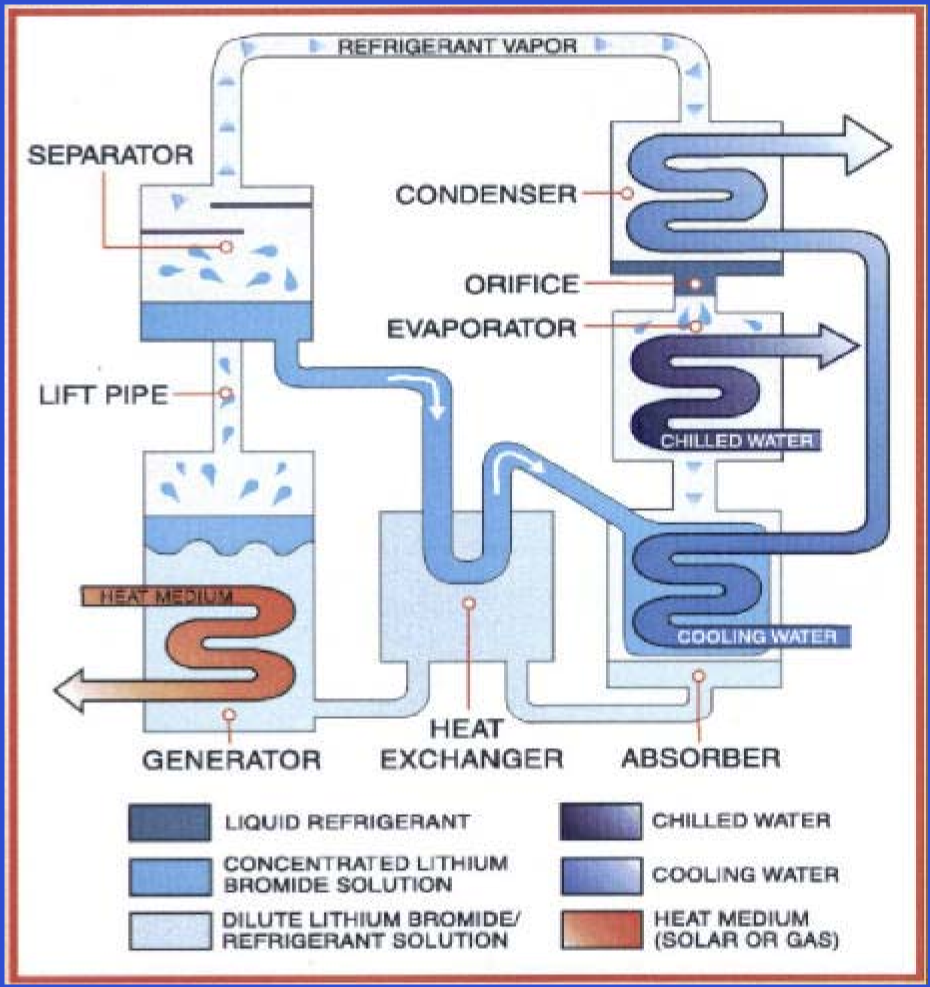
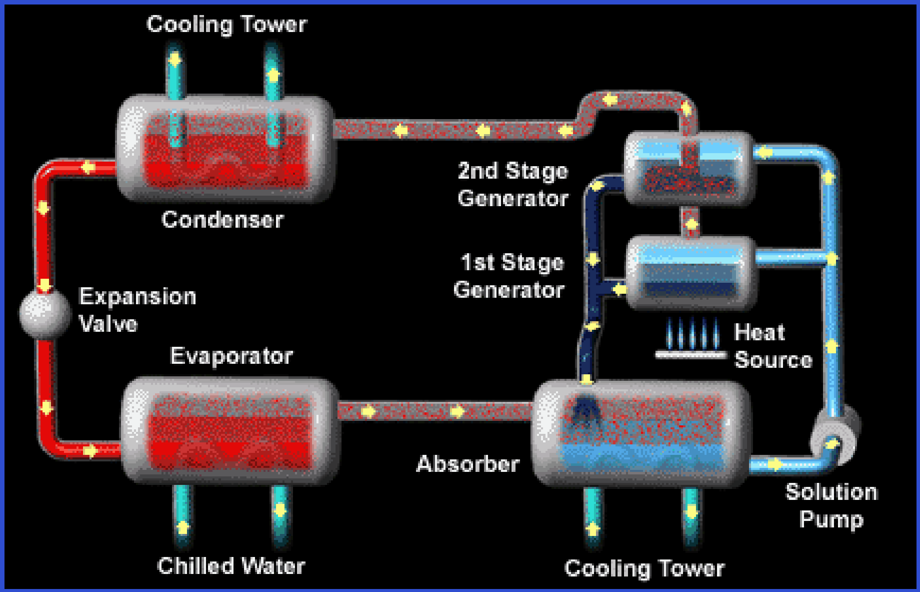
Thermally Driven Cooling System

- Absorption Cooling System



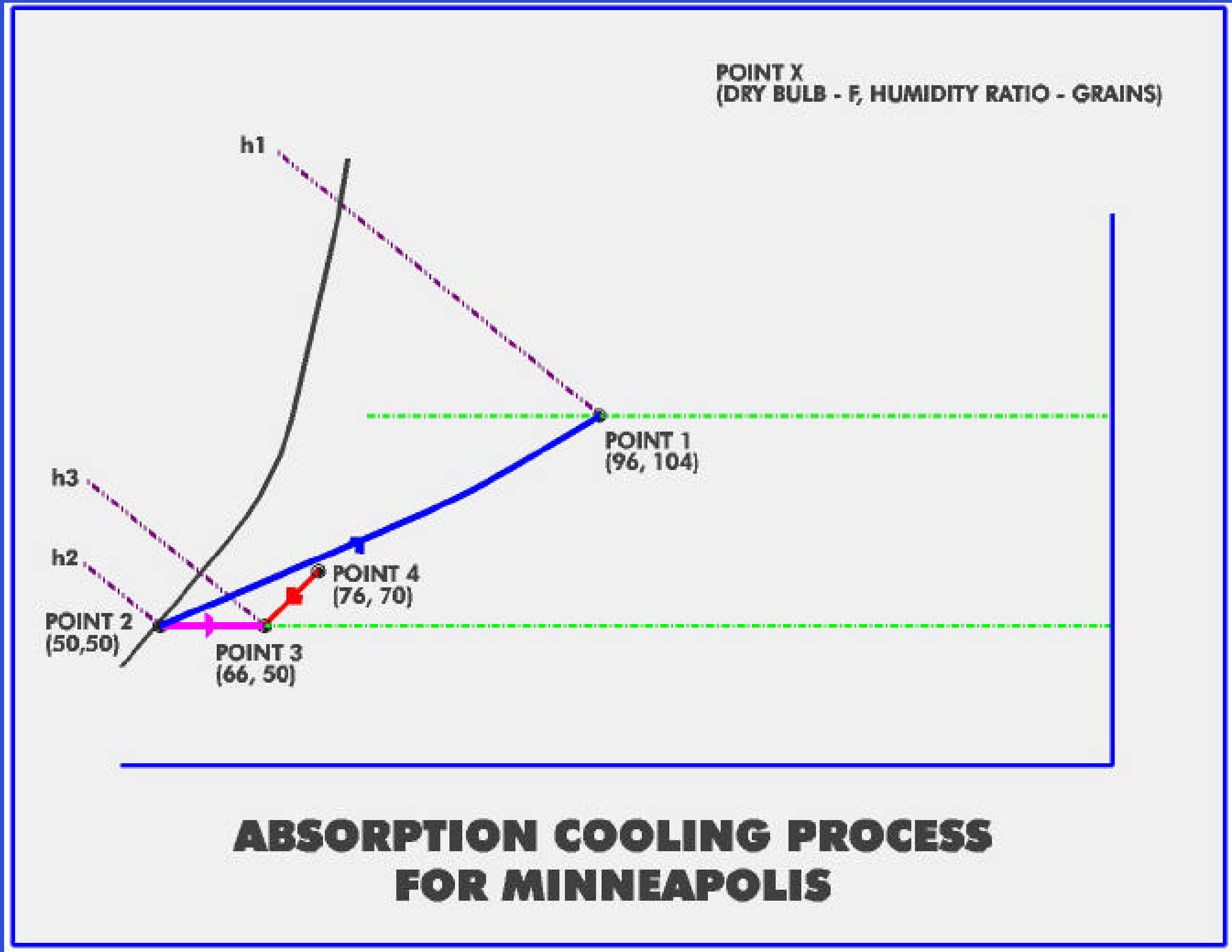
Source: U.S. DOE



Source: www.bchp.org

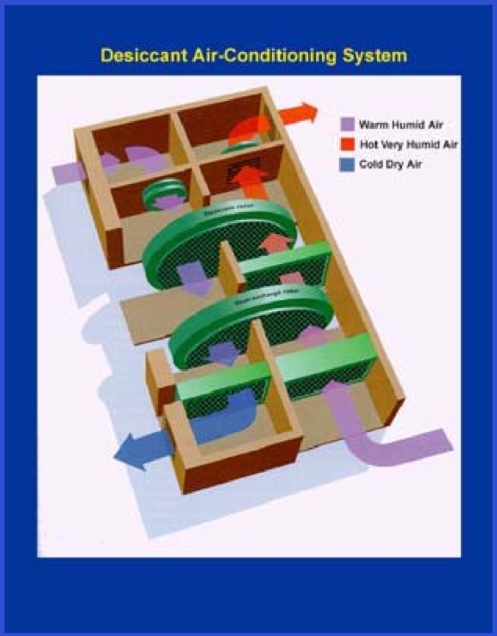
Thermally Driven Cooling System

- Absorption Cooling Process



Thermally Driven Cooling System

- Desiccant Cooling Process



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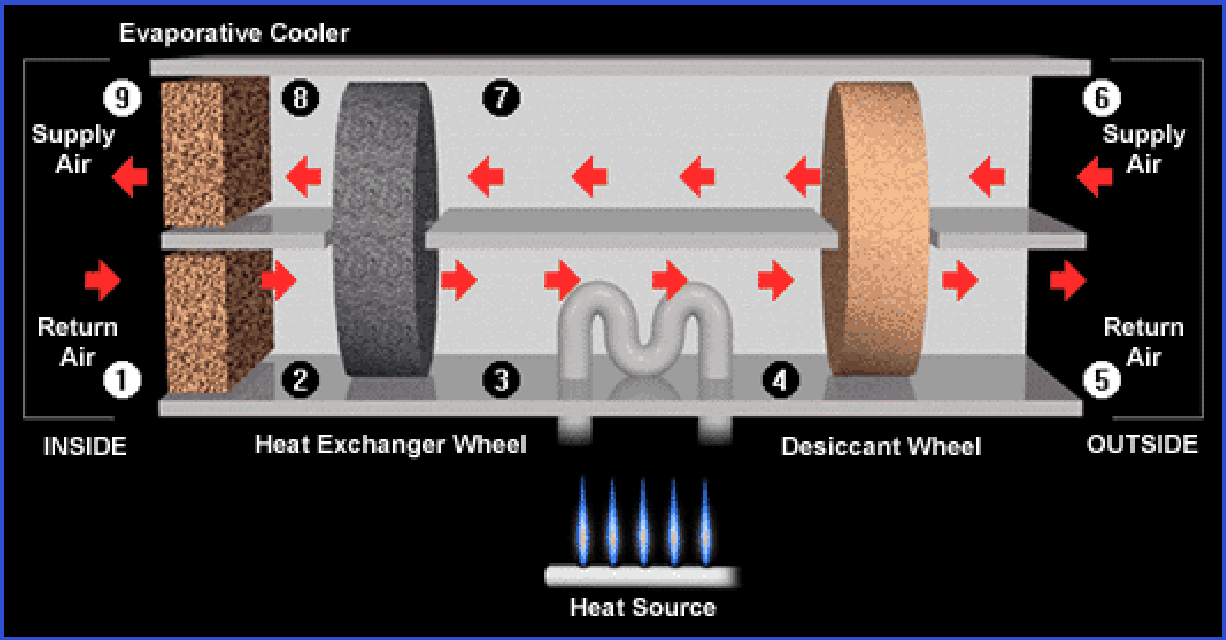

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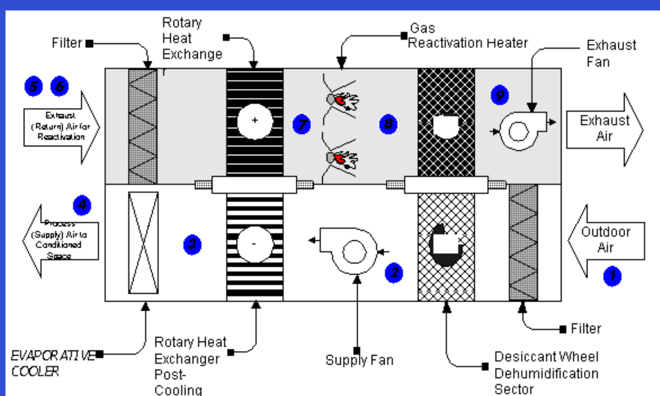
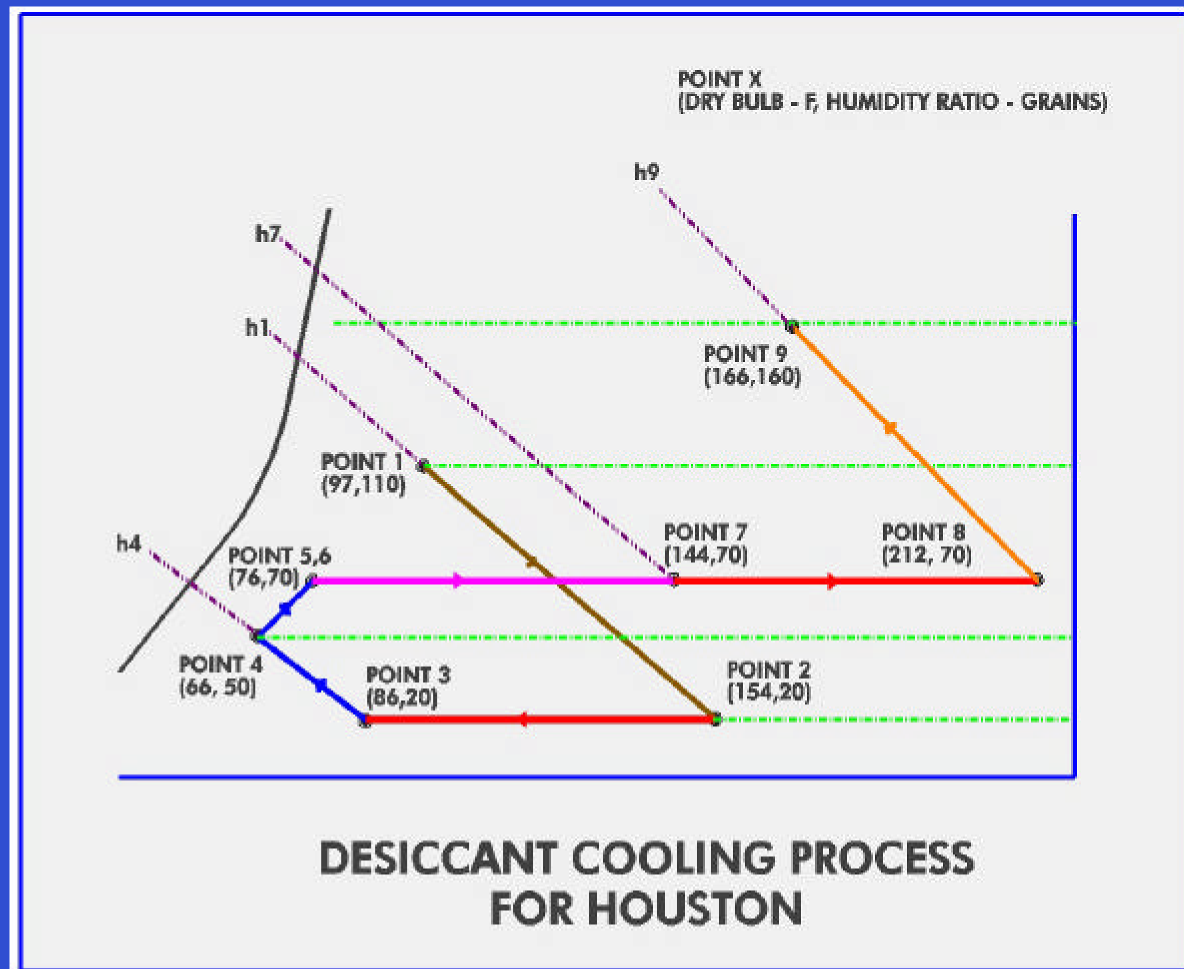
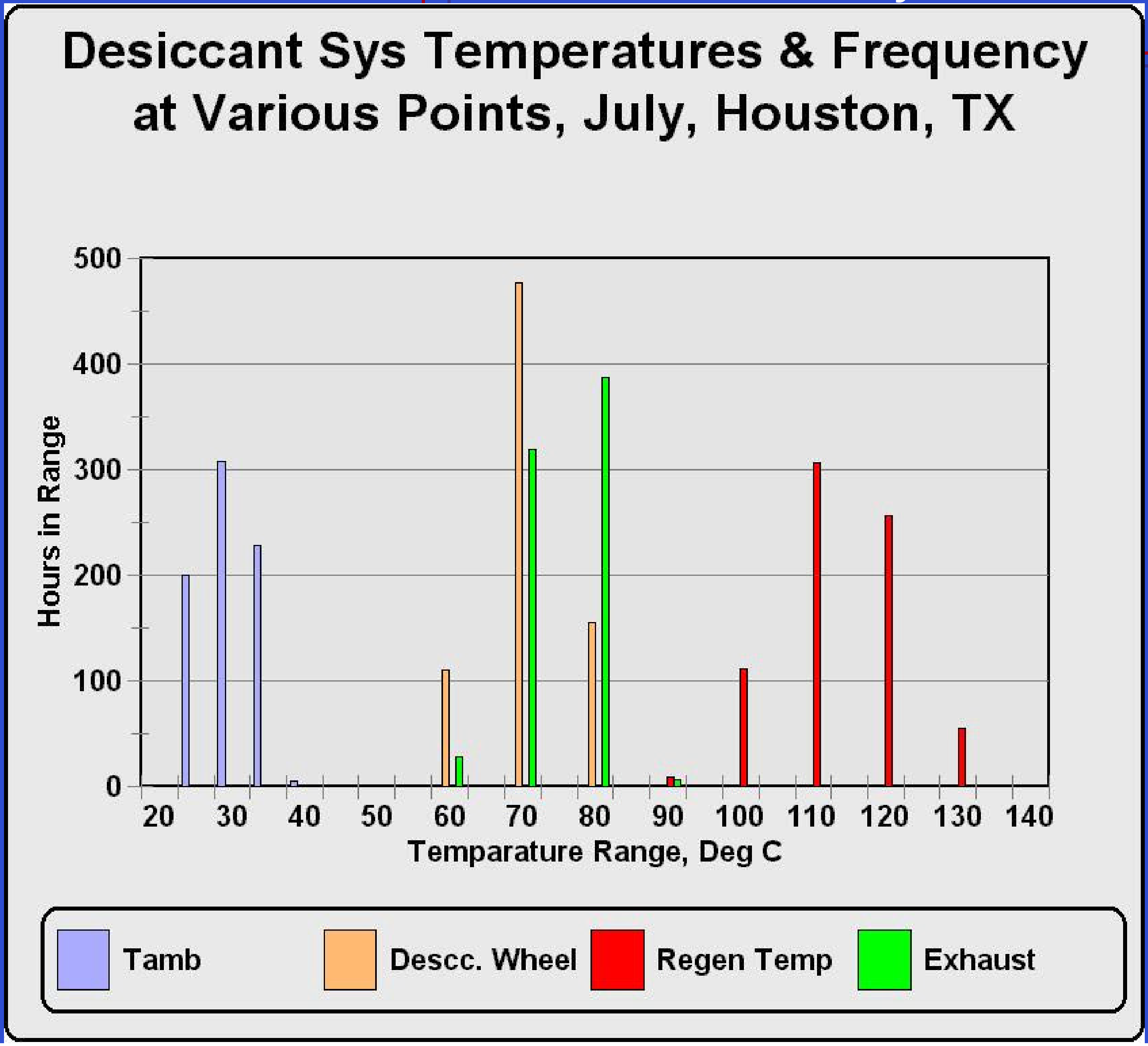
Thermally Driven Cooling System

- Desiccant Cooling Process

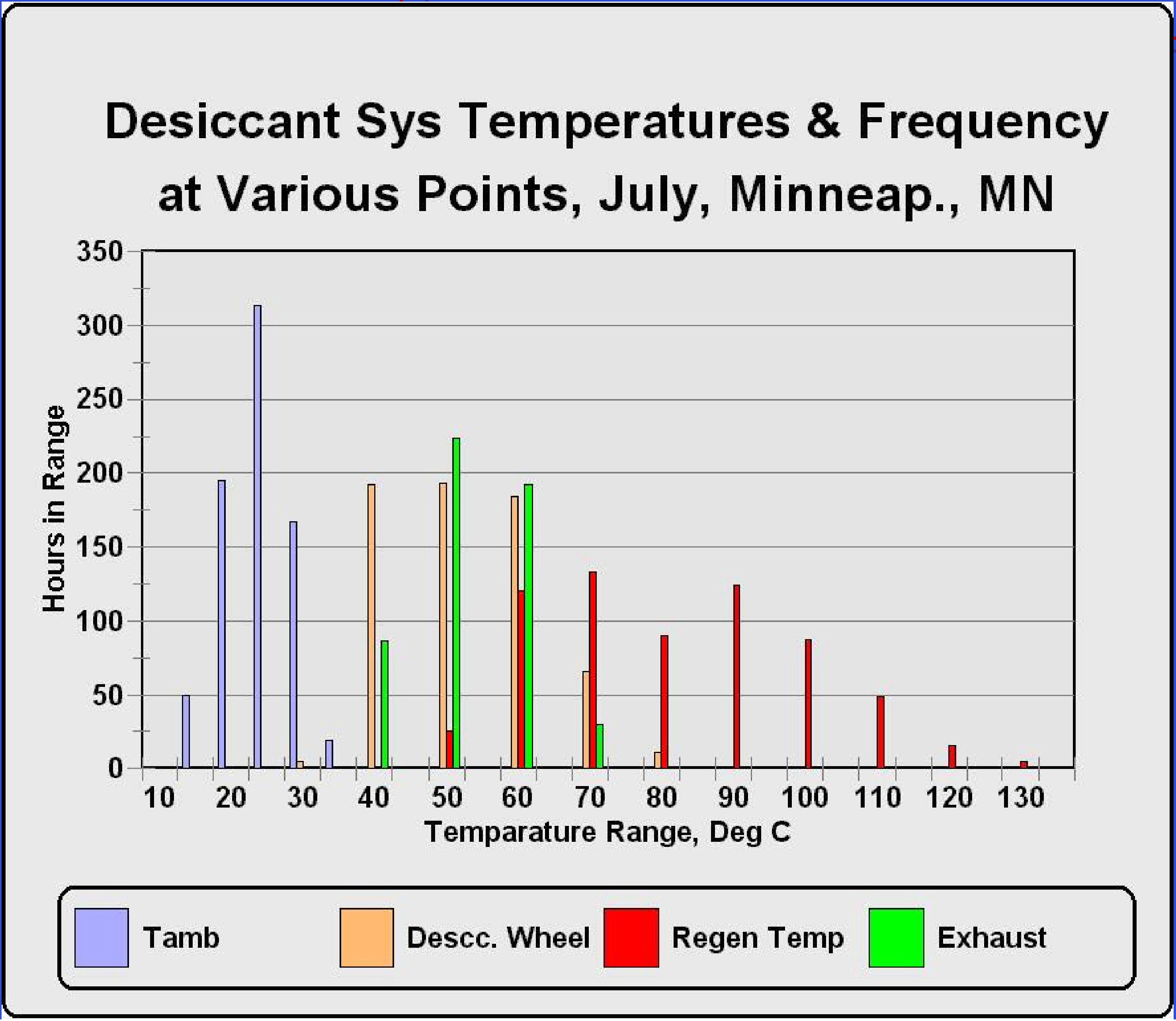




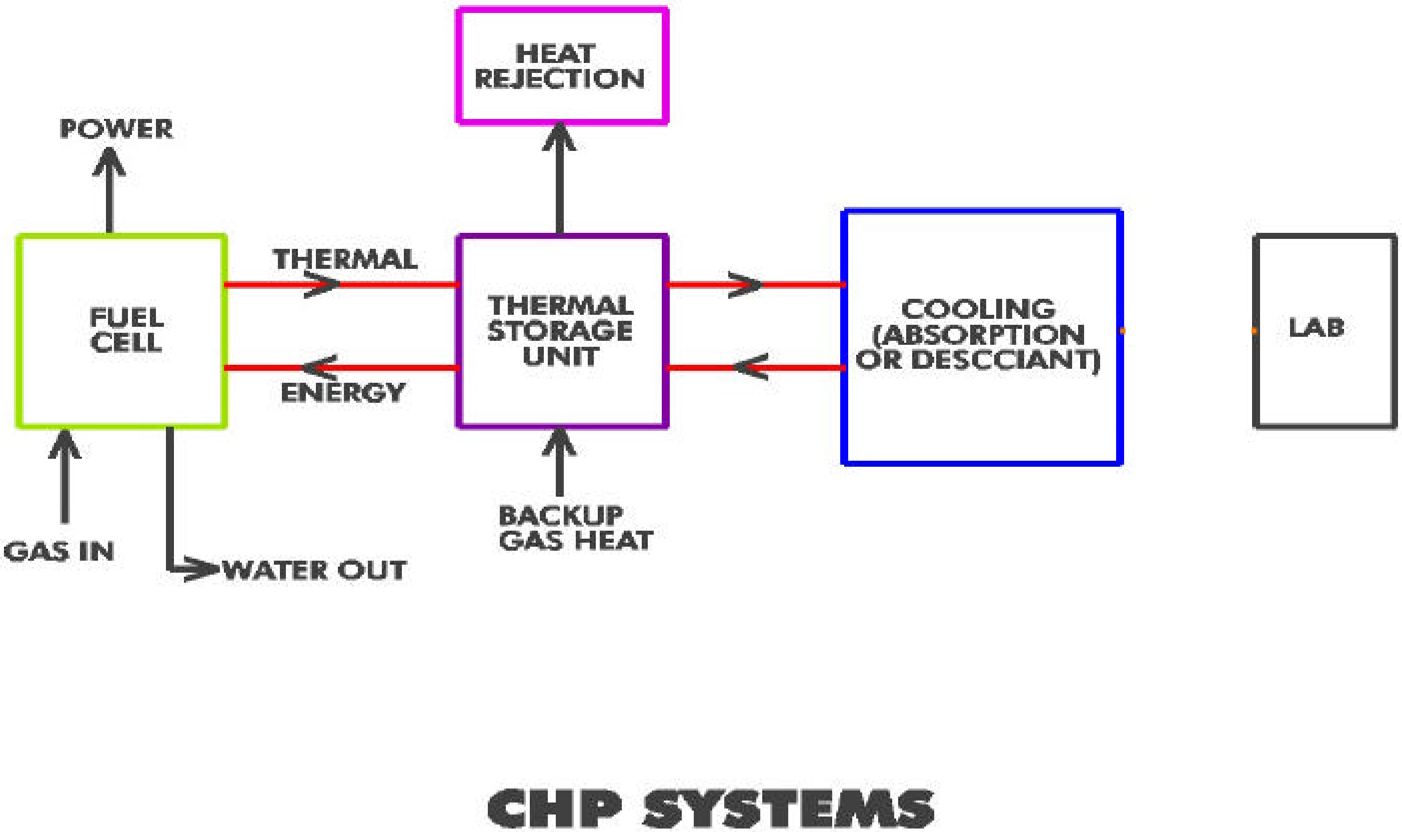
Desiccant System Analysis



Desiccant System Analysis



CHP Systems Studied



Distributed Power Generation – Fuel Cells

- 1.9 MW total, each unit 200 KW
- Total 10 units
- Characteristics
  - Availability: 97%
  - Yearly generation: 16,644 MWH
- Total efficiency (heat and power): 87%
- Electrical efficiency: 37%
- Thermal efficiency: 50%
- Noise level: 60 dBA at 30 ft.
- Unit size: 10’ x 10’ x 18’

Distributed Power Generation – Fuel Cells

- Characteristics of 200 KWe Fuel Cell

Gas 2.1 X 10^6 BTU
2,100 CFH

Fuel Cell Unit

Power
0.2 MW

Heat
900,000 BTUH at 140°F
or
450,000 BTUH at 250°F

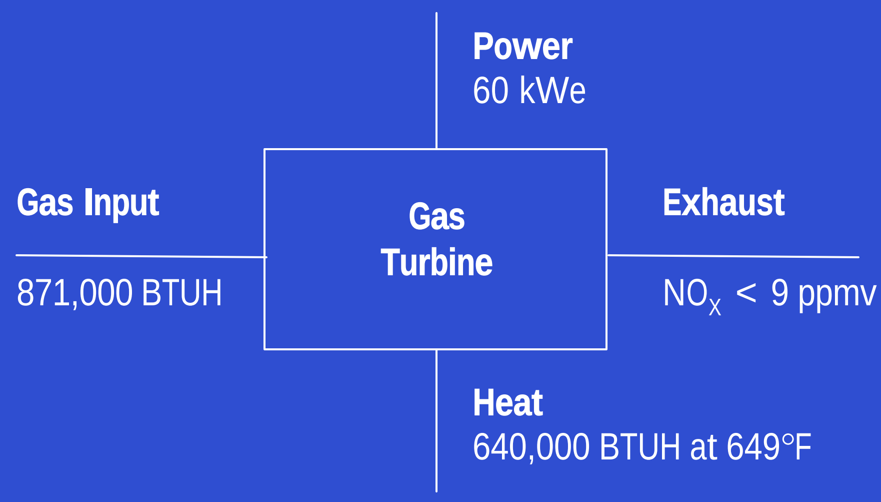
CO < 2 ppmv
NO_X < 1 ppmv
SO_X ≈ 0

Exhaust

Distributed Power GeneratioN

- Gas Micro Turbines
  - Use 60 kWe Turbines
  - Total 32 Units

Performance of units is as follows:



Base Case Heating/Cooling System Performance

- COP of Cooling Equipment = 2

	Energy in Millions of BTU		Electricity for Providing Cooling MW Hrs.
City	Heating Requirements	Cooling Requirements	
Pittsburgh	77,355	39,436	5,777
Houston	24,176	102,717	15,048
Phoenix	21,061	75,610	11,076
Seattle	58,386	13,885	2,034
Minneapolis	104,140	36,268	5,313
Chicago	84,640	40,432	5,923
Colorado Springs	83,141	22,118	3,240
Atlanta	44,387	70,896	10,382
Washington	64,931	53,777	7,878
Los Angeles	19,557	29,705	4,351

Heating and Cooling for CHP Analysis

- Thermal Loads for Heating and Cooling

	Energy in Millions of BTU		
City	Heating	Cooling[1]	Cooling[2]
Pittsburgh (PA)	77,355	39,436	37,141
Houston (TX)	24,176	102,717	112,202
Phoenix (AZ)	21,061	75,610	54,820
Seattle (WA)	58,386	13,885	7,312
Minneapolis (MN)	104,140	36,268	35,813
Chicago (IL)	84,640	40,432	39,626
Colorado Springs (CO)	83,141	22,118	5,683
Atlanta (GA)	44,387	70,896	72,917
Washington (DC)	64,931	53,777	56,196
Los Angeles (CA)	19,557	29,705	30,559

1. Cooling based on dry bulb temperature control
2. Cooling based on enthalpy control, need for desiccant cooling

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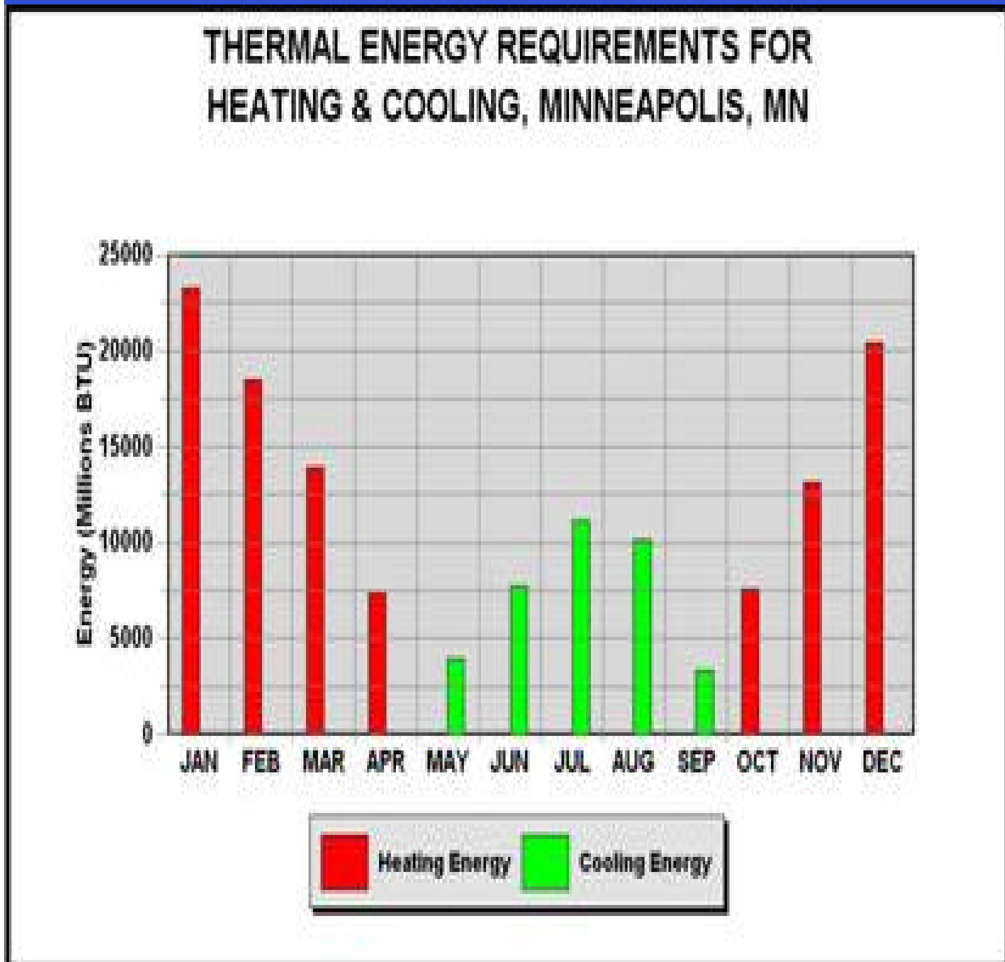
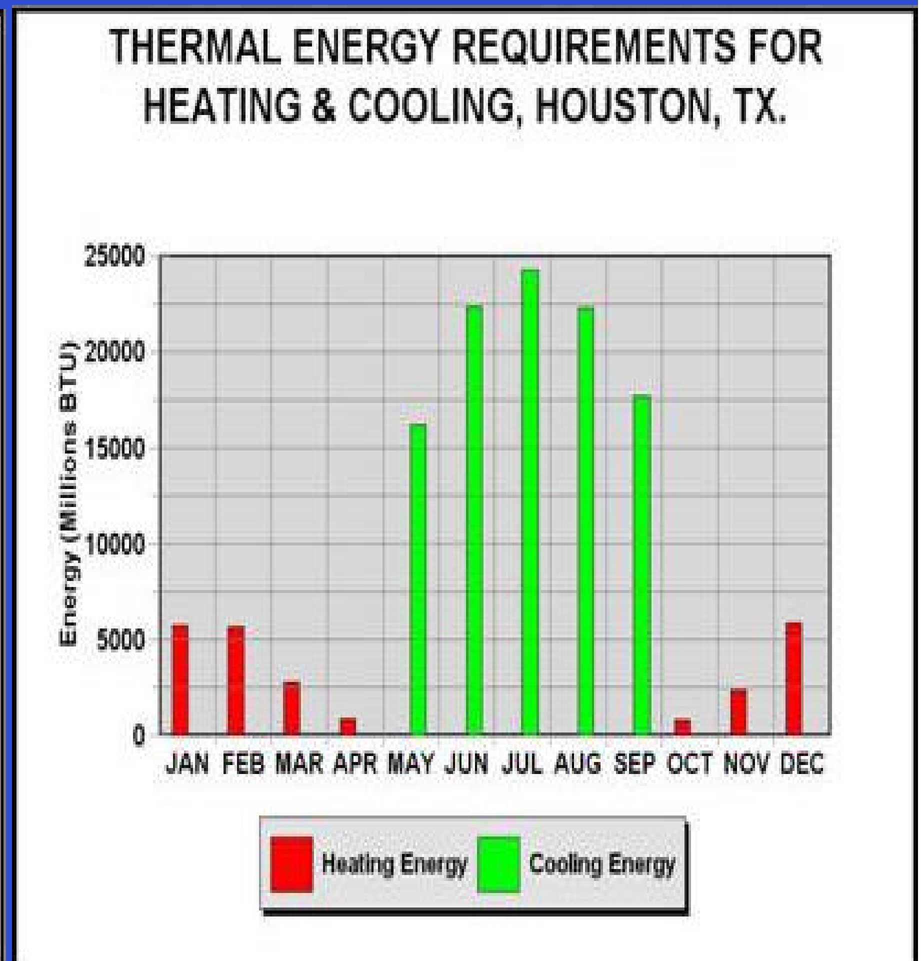
Performance of Fuel Cell – CHP

- Monthly Thermal Energy Requirements for Heating and Cooling





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Performance of Fuel Cell – CHP for Absorption Cooling

	Energy in Million BTU					
Cities	Heat Supplied to Thermal Load	Useful Heat from Fuel Cell	Auxiliary Heat from Gas**	Rejected Heat from Fuel Cell	Ratio, Fuel Cell Heat to Total Heat for Load	Utilization of Heat Produced by Fuel Cell
Pittsburgh	109,641	29,174	81,339	2,393	0.266	92.4%
Houston	108,882	23,028	86,489	7,293	0.211	75.9%
Phoenix	83,274	24,745	59,335	7,217	0.297	77.4%
Seattle	69,796	26,983	43,752	4,986	0.386	84.4%
Minneapolis	134,016	29,126	105,847	2,727	0.217	91.4%
Chicago	117,987	29,155	89,752	2,647	0.247	91.6%
Colorado Springs	101,294	28,169	74,083	3,976	0.278	87.6%
Atlanta	102,907	28,406	75,354	3,311	0.276	89.5%
Washington	113,434	28,794	85,512	2,740	0.253	91.3%
Los Angeles	44,055	26,566	18,371	5,057	0.602	84.0%

* Electric Power produced = 16,644,000 kWh per year.

** This energy is for the thermal systems and does not include the gas used to run the fuel cell.

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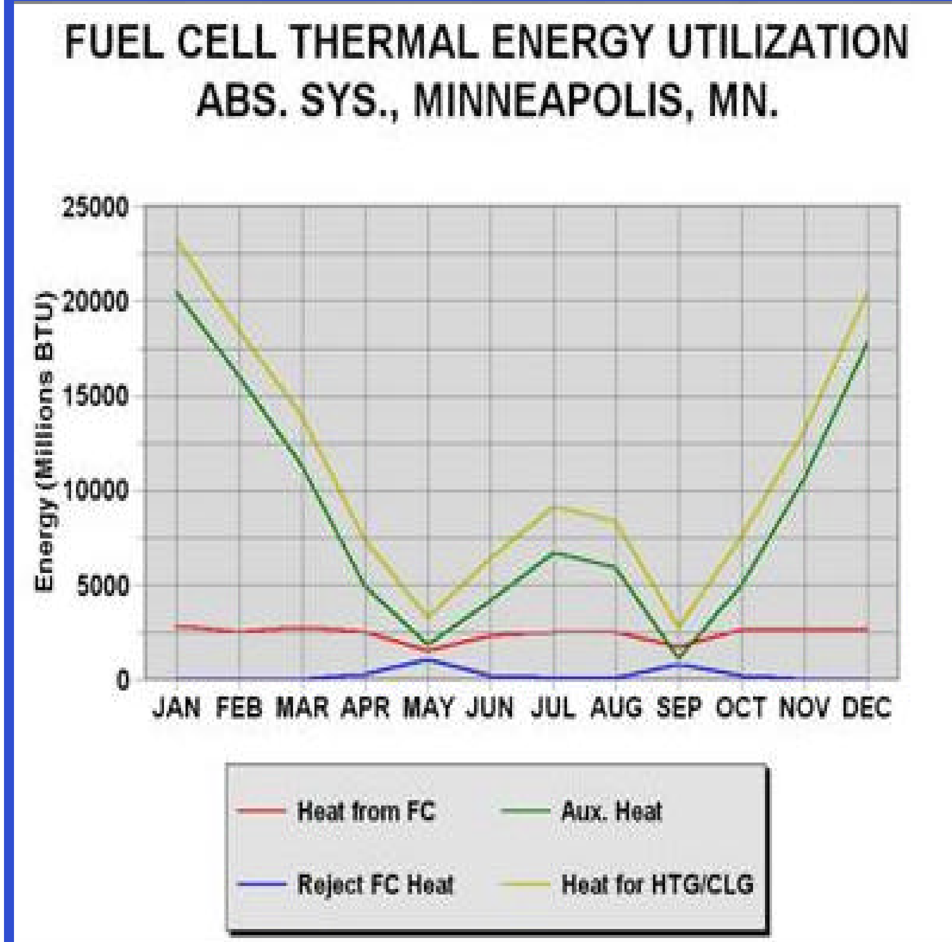
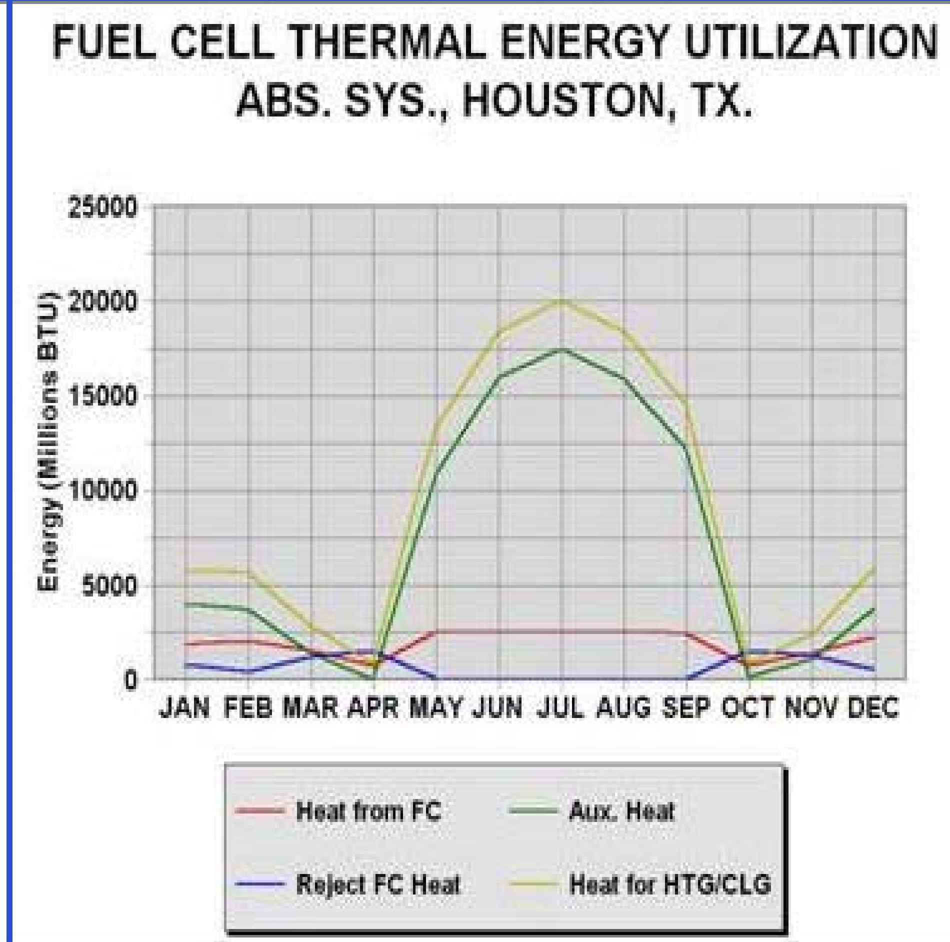
Performance of Fuel Cell – CHP for Absorption Cooling

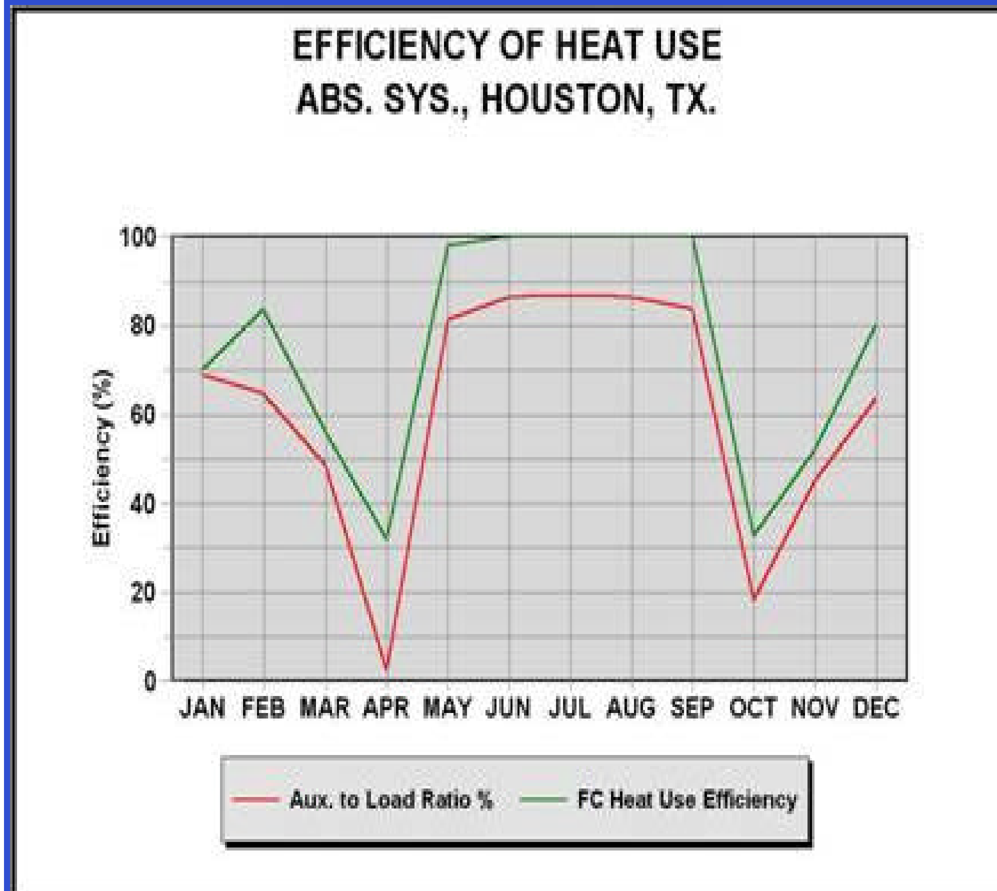
- Comparison of monthly thermal energy utilization

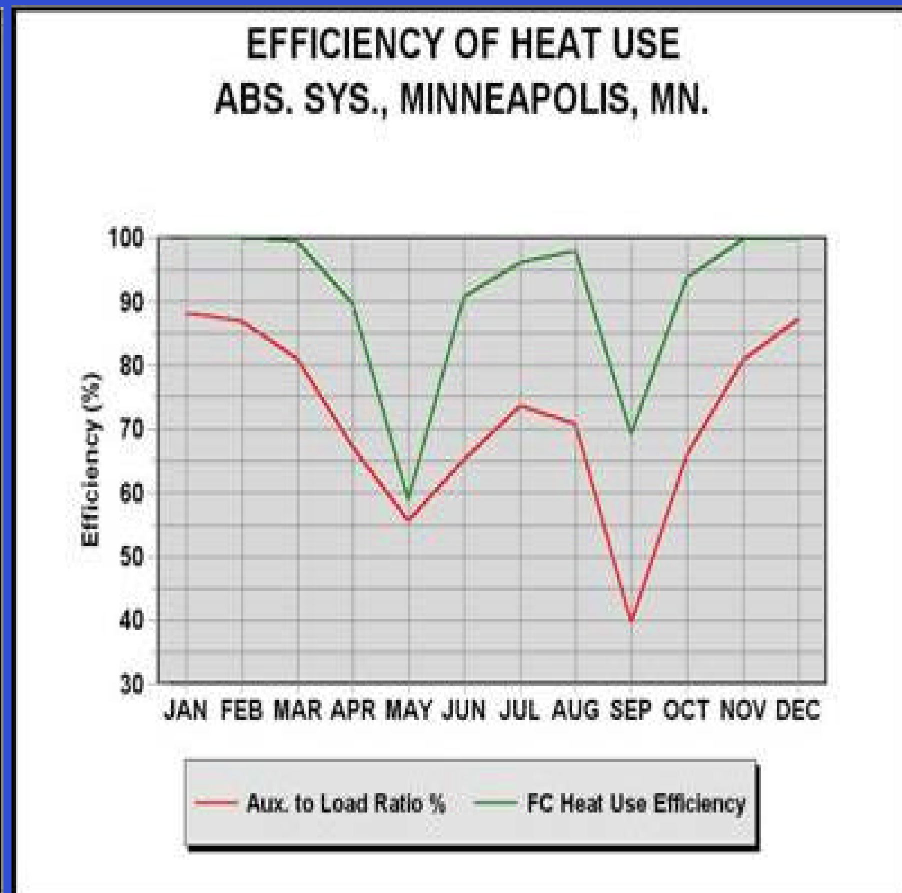




Performance of Fuel Cell – CHP for Absorption Cooling

- Efficiency of Fuel Cell Heat Use – Monthly Comparison





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Performance of Micro Turbine – CHP for Absorption Cooling

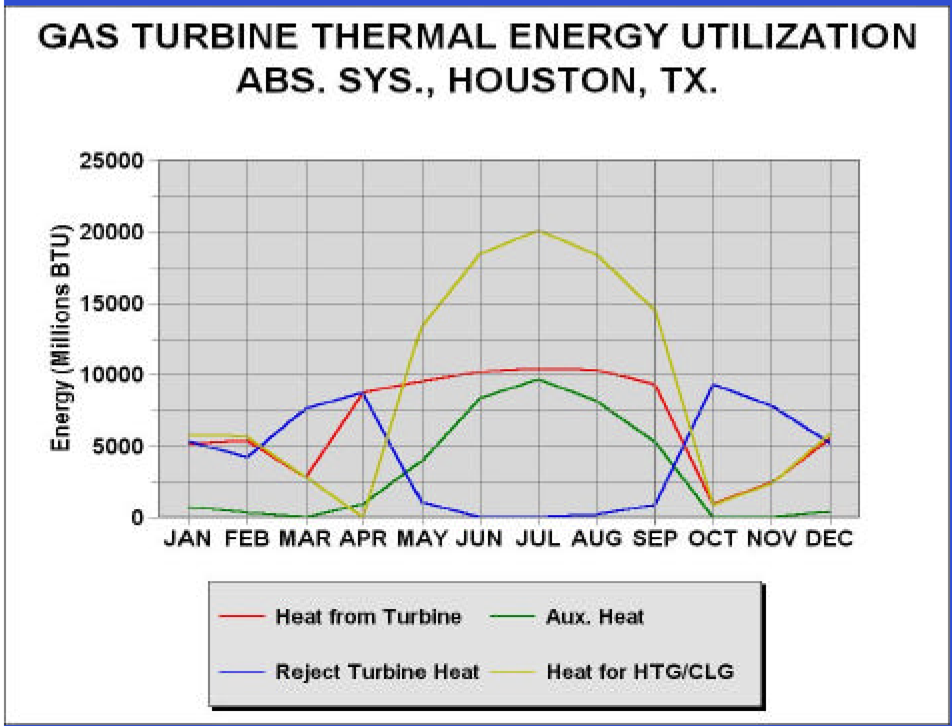
	Energy in Million BTU					
Cities	Heat Supply to Thermal Load	Useful Heat from Turbine	Auxiliary Heat from Gas**	Rejected Heat from Turbine	Ratio: Turbine Heat to Total Heat for Load	Utilization of Heat Produced by Turbine
Pittsburgh	109,830	87,893	22,914	37,700	0.8	69.9
Houston	108,977	73,011	36,856	50,220	0.66	59.2
Phoenix	83,321	69,113	15,032	56,157	0.83	55.1
Seattle	69,815	68,563	2,219	56,745	0.98	54.7
Minneapolis	133,636	91,117	43,287	34,087	0.68	72.7
Chicago	117,892	91,165	27,694	34,277	0.77	72.6
Colorado Springs	101,294	80,713	21,529	45,079	0.79	64.1
Atlanta	102,907	83,302	20,505	41,855	0.81	66.5
Washington	113,434	90,947	23,464	34,409	0.8	72.5
Los Angeles	44,093	44,966	36	80,343	1	35.8

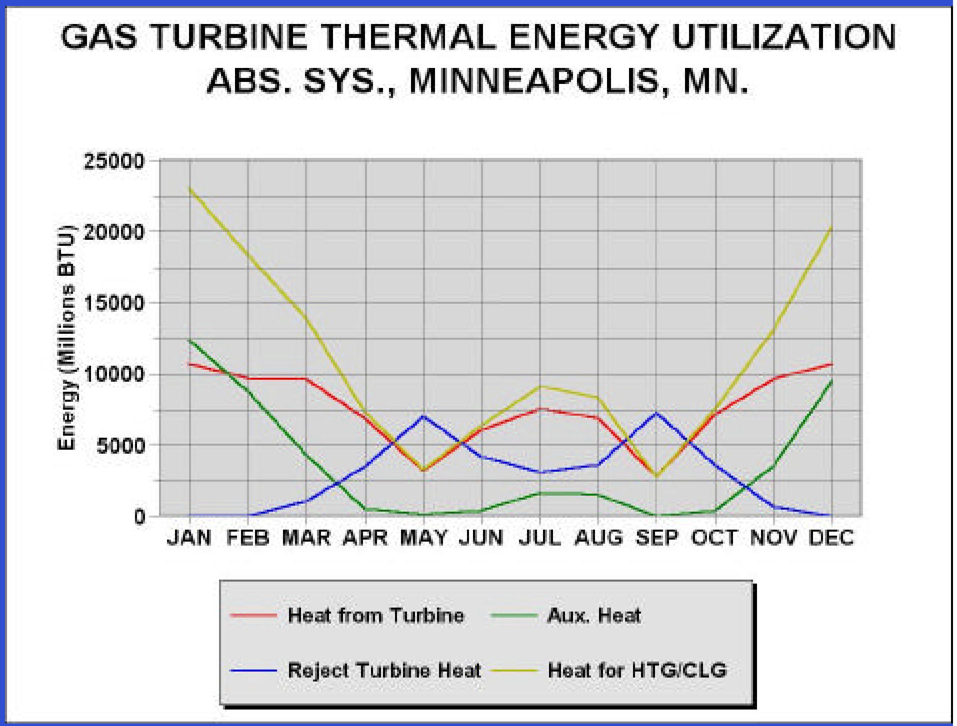
* Electric power produced: 16,644,000 kWh/year

** This energy is for thermal systems and does not include the gas used to run the turbines.

Performance of Turbines – CHP for Absorption Cooling

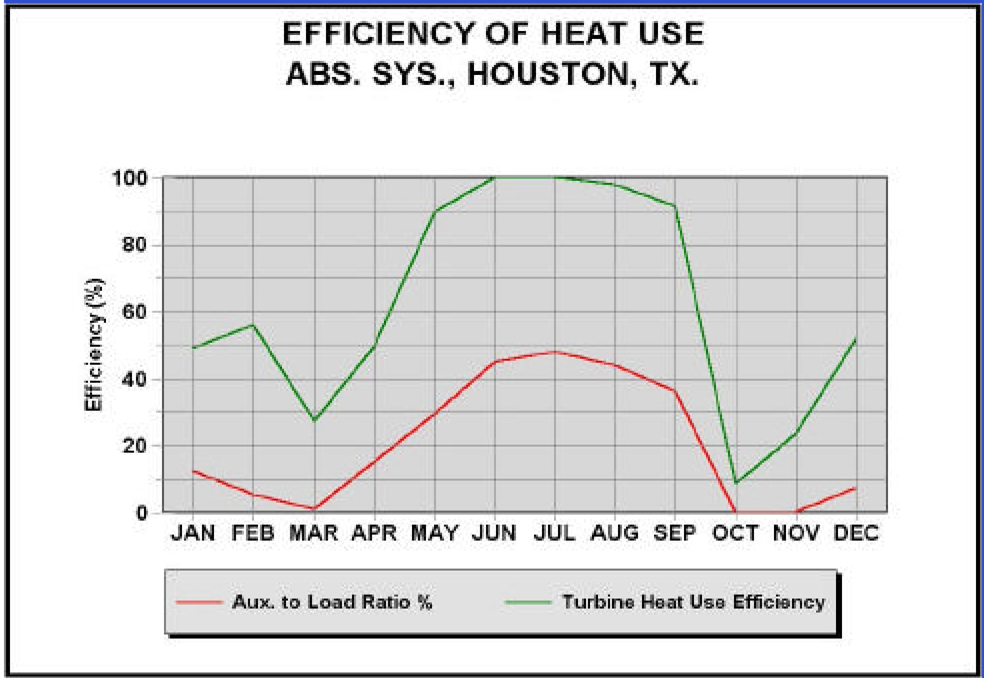
- Comparison of monthly thermal energy utilization

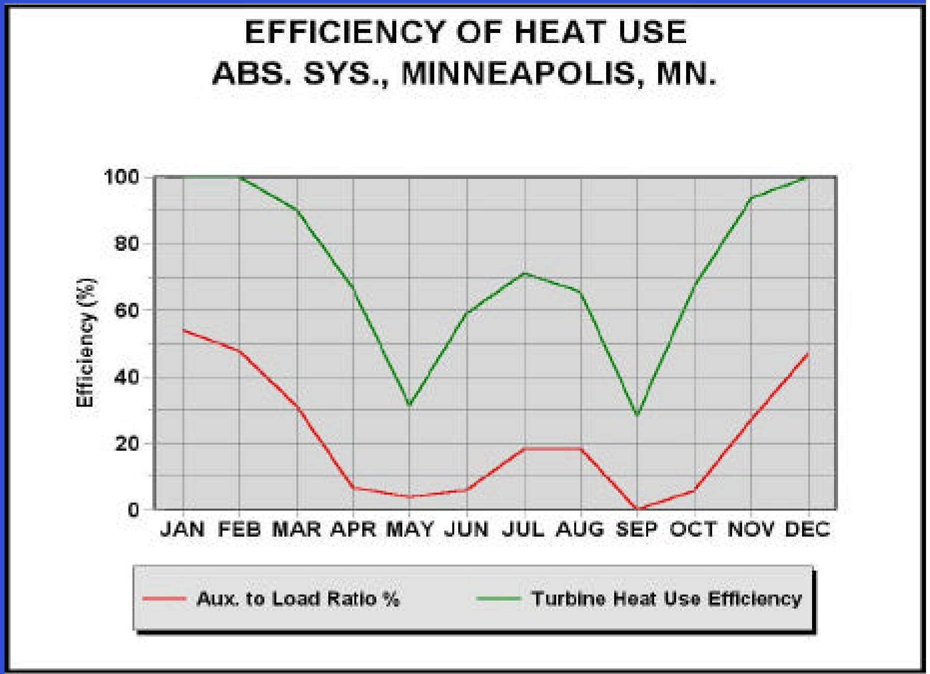




Performance of Turbines – CHP for Absorption Cooling

- Efficiency of turbine heat use – monthly comparison





Performance of Fuel Cell – CHP for Desiccant Cooling

	Energy in Million BTU					
Cities	Heat Supplied to Thermal Load	Useful Heat from Fuel Cell	Auxiliary Heat from Gas**	Rejected Heat from Fuel Cell	Ratio, Fuel Cell Heat to Total Heat for Load	Utilization of Heat Produced by Fuel Cell
Pittsburgh	164,272	30,009	135,154	3,633	0.182	89.1%
Houston	190,923	24,138	167,686	7,303	0.126	76.7%
Phoenix	102,622	24,650	78,749	7,533	0.240	76.5%
Seattle	94,940	25,352	70,536	5,130	0.260	83.1%
Minneapolis	187,604	29,335	159,245	3,377	0.156	89.6%
Chicago	173,576	30,028	144,638	3,057	0.172	90.7%
Colorado Springs	110,115	24,327	86,736	7,074	0.220	77.4%
Atlanta	178,214	31,137	147,958	3,418	0.174	90.1%
Washington	179,826	30,322	150,424	3,424	0.168	89.8%
Los Angeles	122,919	28,966	94,826	5,571	0.235	83.8%

* Electric Power produced = 16,644,000 kWh per year.

** This energy is for the thermal systems and does not include the gas used to run the fuel cell.

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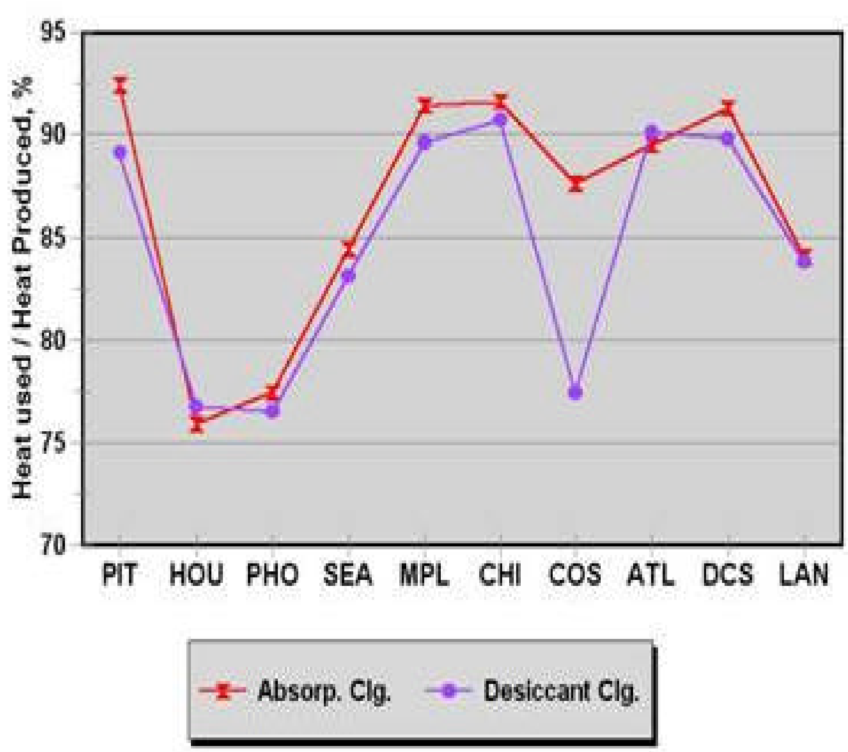
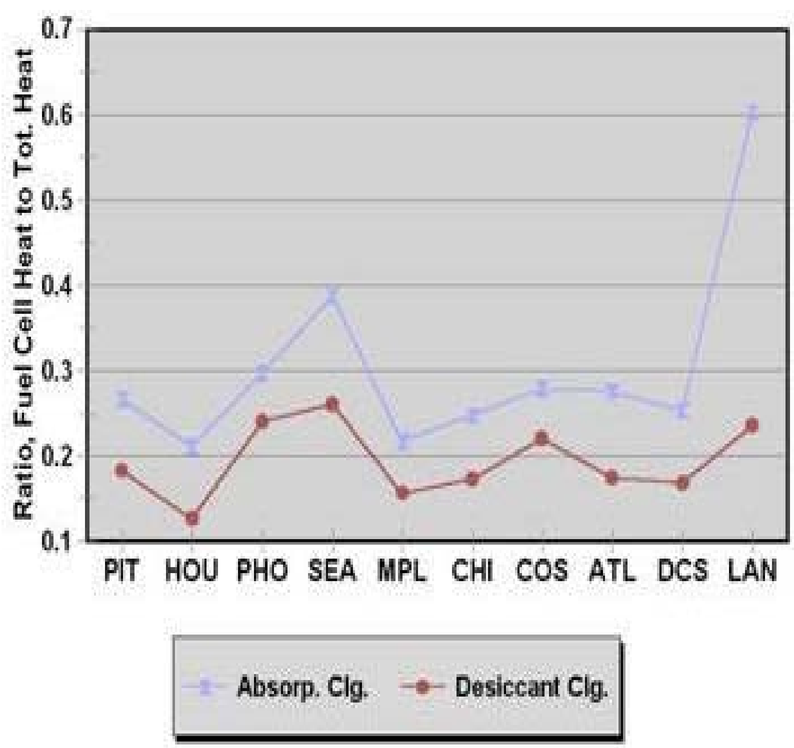
Comparison of Fuel Cell Thermal Energy Use

Utilization of Heat from Fuel Cells Absorption & Desiccant Cooling.



Ratio, Fuel Cell Heat to Total Heat, Absorption & Desiccant Cooling.



Performance of Turbine – CHP for Desiccant Cooling

	Energy in Million BTU					
Cities	Heat Supplied to Thermal Load	Useful Heat from Fuel Cell	Auxiliary Heat from Gas**	Rejected Heat from Fuel Cell	Ratio, Fuel Cell Heat to Total Heat for Load	Utilization of Heat Produced by Fuel Cell
Pittsburgh	164,177	99,208	65,926	28,681	0.604	77.5
Houston	190,923	75,705	116,090	48,361	0.396	61
Phoenix	102,622	67,766	35,671	58,054	0.66	53.8
Seattle	94,940	78,522	17,404	48,162	0.827	61.9
Minneapolis	187,603	102,907	85,654	24,384	0.548	80.8
Chicago	173,756	103,001	71,655	24,432	0.592	80.8
Colorado Springs	110,020	80,855	30,113	45,089	0.735	64.1
Atlanta	178,214	93,156	85,891	35,102	0.522	72.6
Washington	179,731	100,725	79,973	26,072	0.56	79.4
Los Angeles	123,014	69,208	54,649	57,855	0.562	54.4

* Electric power produced = 16,644,000 kWh per year.

** This energy is for the thermal systems and does not include the gas used to run the fuel cell.

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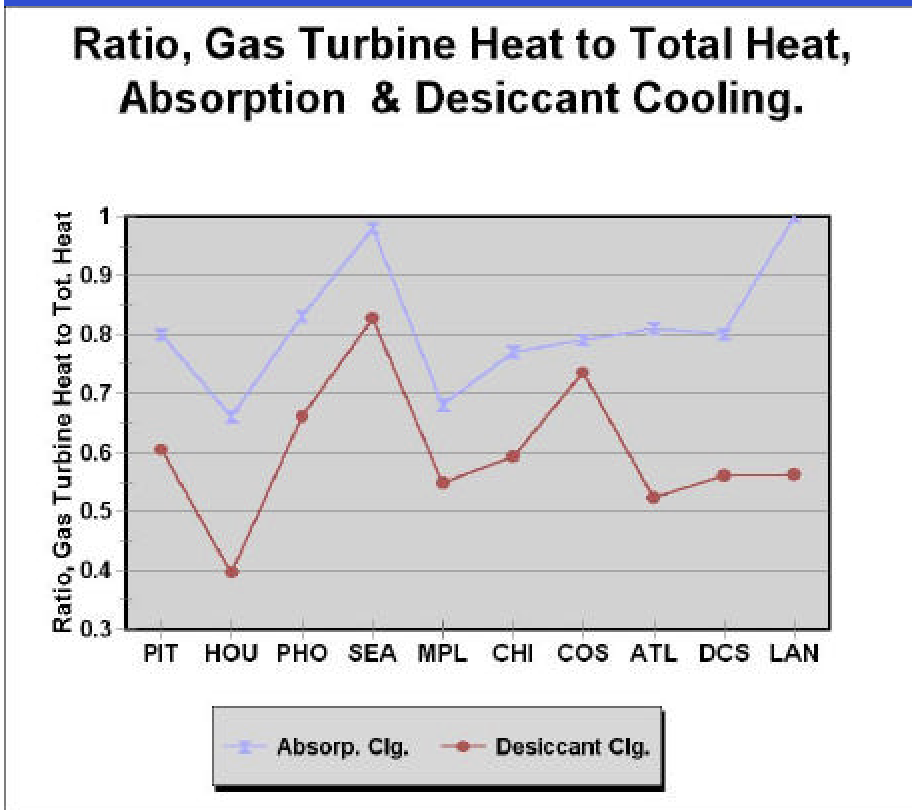
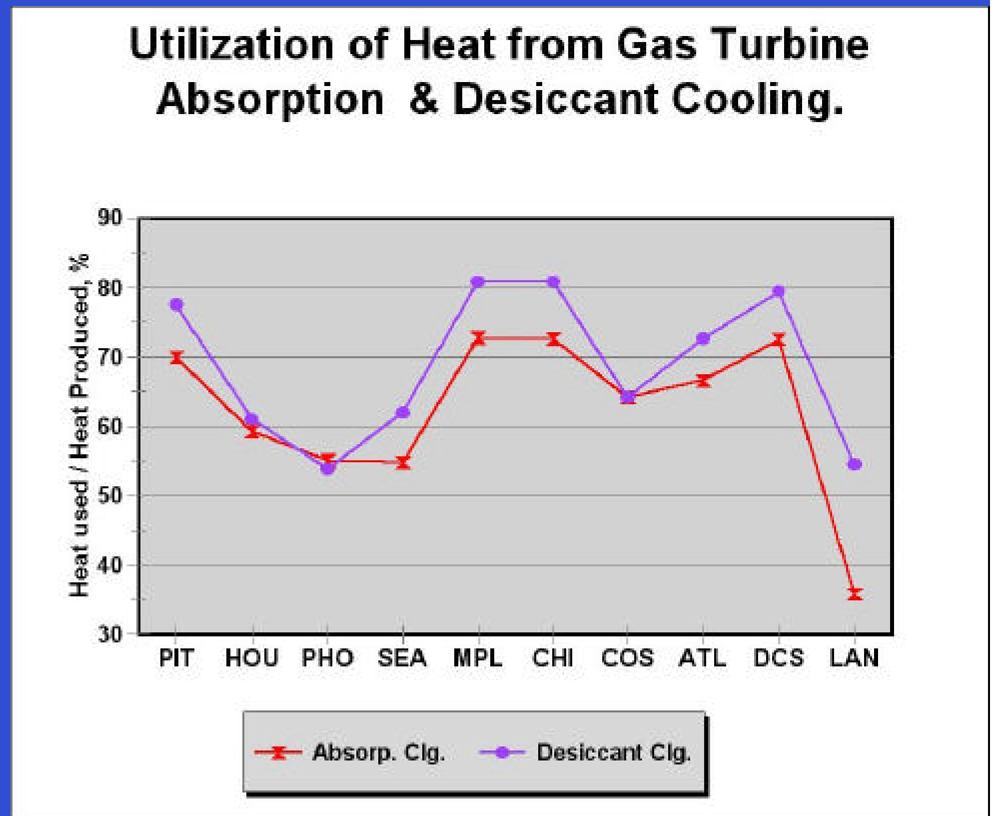
Comparison of Turbine Thermal Energy





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Annual Operating Cost

- Base Case System: Gas Heat, and Vapor Compression Cooling

City	Gas Energy X10^6 Btu	Electric for Cooling MWHR	Cost of Gas $	Cost of Electric $	Cost of Purchasing 1.9 MW Base Power $	Total Annual Cost
Pittsburgh	96693l75	5,777	$338,428	491,045	$1,414,740	$2,244,213
Houston	30220	15,048	$105,770	$1,279,080	$1,414,740	$2,799,590
Phoenix	26326.25	11,076	$92,142	$941,460	$1,414,740	$2,448,342
Seattle	72982.5	2,034	$255,439	$172,890	$1,414,740	$1,843,069
Minneapolis	130175	5,313	$455,713	$451,605	$1,414,740	$2,321,958
Chicago	105800	5,923	$370,300	$503,455	$1,414,740	$2,288,495
Colorado Springs	103926.3	3,240	$363,740	$275,400	$1,414,740	$2,053,882
Atlanta	55483.75	10,382	$194,193	$882,470	$1,414,740	$2,491,403
Washington	81163.75	7,878	$284,073	$669,630	$1,414,740	$2,368,443
Los Angeles	24446.25	4,351	$85,562	$369,835	$1,414,740	$1,870,137

Annual Operating Cost

- Fuel Cell – CHP, Absorption Cooling

City	Gas Cost for Fuel Cells $	Gas Energy Auxiliary* 10^6 Btu	Cost of Gas Energy $	Total Annual Cost $
Pittsburgh	$643,860	101,673	$355,855	$999,715
Houston	$643,860	108,111	378,388	1,022,248
Phoenix	$643,860	74,168	259,588	903,488
Seattle	$643,860	54,690	191,415	835,275
Minneapolis	$643,860	132,308	463,078	1,106,938
Chicago	$643,860	112,190	392,665	1,036,525
Colorado Springs	$643,860	92,603	324,110	967,970
Atlanta	$643,860	94,192	329,672	973,532
Washington	$643,860	106,890	374,115	1,017,975
Los Angeles	$643,860	22,963	80,370	724,230

* Includes 80% efficiency of gas use

Annual Operating Cost

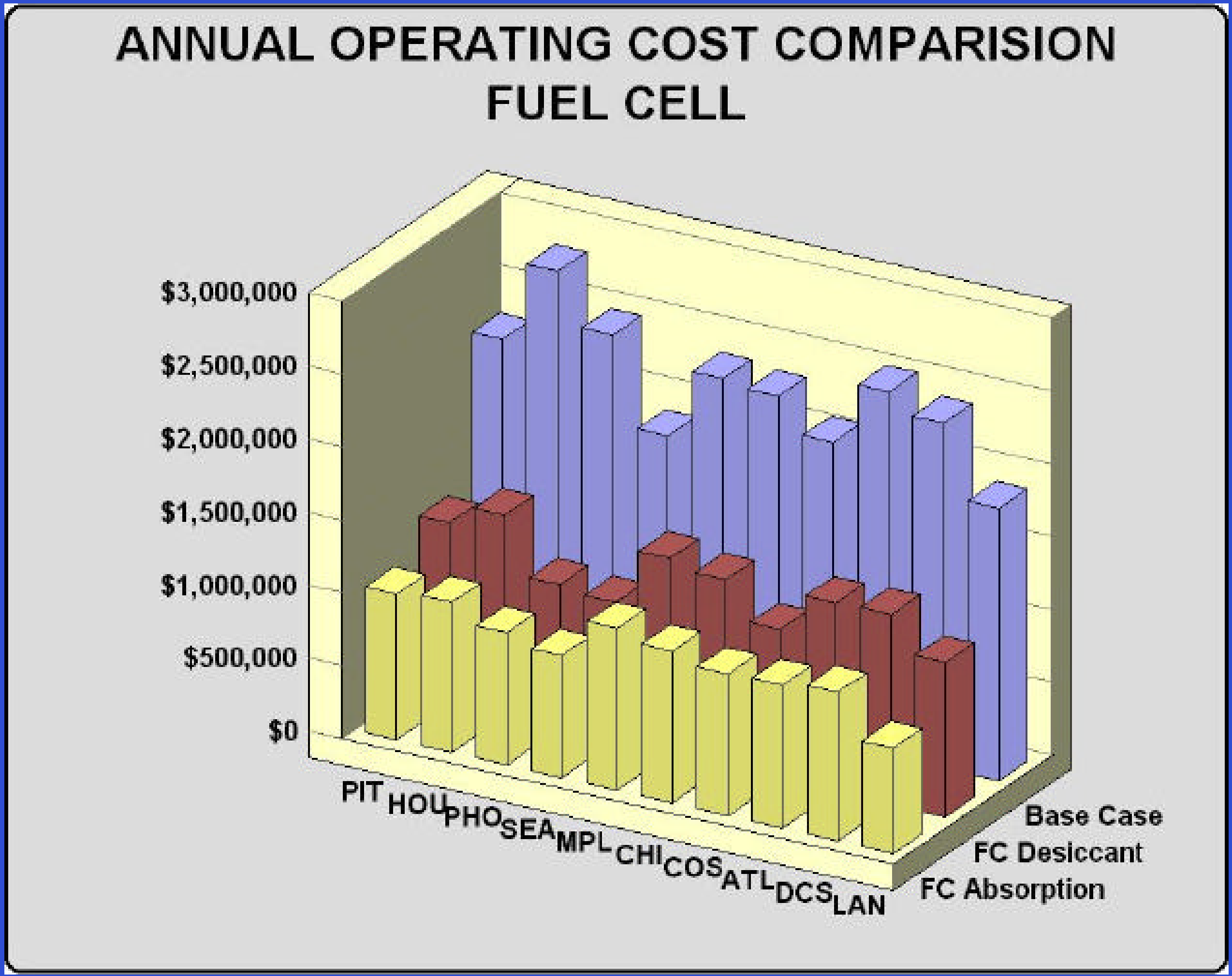
- Fuel Cell – CHP – Desiccant Cooling

City	Gas Cost for Fuel Cells $	Gas Energy Auxiliary* 10^6 Btu	Cost of Gas Energy $	Total Annual Cost $
Pittsburgh	$643,860	168,942	$591,298	$1,235,158
Houston	$643,860	209,607	733,626	1,377,486
Phoenix	$643,860	98,436	344,526	988,386
Seattle	$643,860	88,170	308,595	952,455
Minneapolis	$643,860	199,056	696,696	1,340,556
Chicago	$643,860	180,797	632,791	1,276,651
Colorado Springs	$643,860	108,420	379,470	1,023,330
Atlanta	$643,860	184,947	647,310	1,291,176
Washington	$643,860	188,030	658,105	1,301,965
Los Angeles	$643,860	118,532	414,863	1,058,723

* Includes 80% efficiency of gas use

Comparison of Annual Operation Costs

- Base System, Absorption and Desiccant System



Annual Operating Cost

- Turbine – CHP – Absorption Cooling

City	Gas Cost for Fuel Cells $	Gas Energy Auxiliary* 10^6 Btu	Cost of Gas Energy $	Total Annual Cost $
Pittsburgh	$801,145	28,642	$100,251	$901,396
Houston	$801,145	46,070	161,249	962,394
Phoenix	$801,145	18,790	65,769	866,914
Seattle	$801,145	2,773	9,710	810,855
Minneapolis	$801,145	54,108	189,382	990,527
Chicago	$801,145	34,617	121,165	922,310
Colorado Springs	$801,145	26,911	94,193	895,338
Atlanta	$801,145	25,631	89,712	890,857
Washington	$801,145	29,330	102,658	903,803
Los Angeles	$801,145	45	158	801,303

* Includes 80% efficiency of gas use

Annual Operating Cost

- Turbine – CHP – Desiccant Cooling

City	Gas Cost for Turbines $	Gas Energy Auxiliary* 10^6 Btu	Cost of Gas Energy $	Total Annual Cost $
Pittsburgh	$801,145	82,407	$288,430	$1,089,575
Houston	$801,145	145,112	507,896	1,309,041
Phoenix	$801,145	44,588	156,002	957,207
Seattle	$801,145	21,755	76,143	877,288
Minneapolis	$801,145	107,067	374,739	1,175,884
Chicago	$801,145	89,568	313,493	1,114,638
Colorado Springs	$801,145	37,641	131,746	932,891
Atlanta	$801,145	107,363	375,777	1,176,922
Washington	$801,145	99,966	349,884	1,151,029
Los Angeles	$801,145	68,311	239,093	1,040,238

* Includes 80% efficiency of gas use

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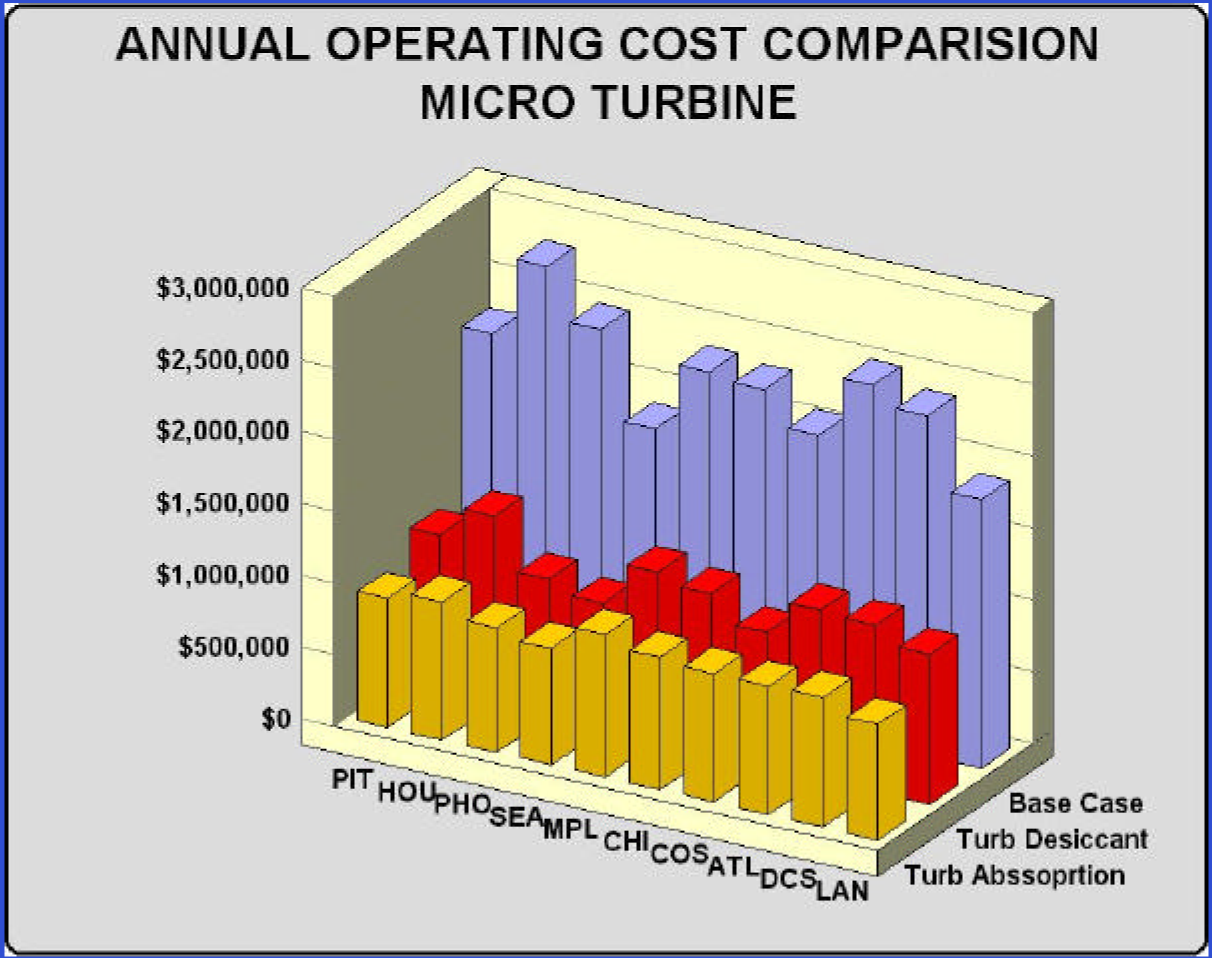
Comparison of Annual Operating Costs

- Base System, Absorption and Desiccant Systems – Turbines



LABS FOR THE 21ST CENTURY

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Environmental Emissions

- Power Generation[1]
  - Sulphur Dioxide SO_2: 19.157 Metric Tons/MW
  - Nitrogen Oxide NO_X: 7.894 Metric Tons/MW
- Gas Boilers[2]
  - Particulates: 0.00095 lbs/million Btu
  - SO_2: 0.00057 lbs/million Btu
  - NO_2: 0.1333 lbs/million Btu
- Micro Turbines[3]
  - NO_X 0.00049 lbs/kWh

Sources:

1. *Tina M. Kaarsberg, "An Integrated Assessment of the Energy Saving and Emission Reductive Potential for CHP," Northeast, Midwest Institute*
2. *U.S. DOE, Publication DOE/EE-0217, Assessment of Donlee 3000 Horsepower Turbo-Fired XL Boiler*
3. *FEMP: Distributed Energy Sources: How To Guide*

Shadow Prices for Environmental Pollutants

Pollutant	Shadow Price US $/kg
Carbon Dioxide CO_2	$0.017
Sulpher Dioxide SO_2	$1.800
Nitrogen Dioxide NO_X	$1.086
Carbon Monoxide CO	$0.562
Volatile Organic Compounds	$398
Nitrous Oxide N_2O	$2981
Methane CH_4	$170
Source: Oakridge National Lab, 1995, The Effects of Considering Externalities on Electric Utilities Mix of Resources	

Comparison of Air Emissions – Absorption Cooling

- Base Case, Fuel Cells and Turbine - Absorption

	All Quantities in Metric Ton/Year					
	Base Case[1]		Absorption Fuel Cell[2]		Absorption Turbine[2]	
	SO_2	NO_X	SO_2	NO_X	SO_2	NO_X
Pittsburgh	49.05	26.05	0.026	6.14	0.0074	5.438
Houston	69.31	30.38	0.028	6.53	0.0119	6.492
Phoenix	60.02	26.57	0.017	4.48	0.0048	4.843
Seattle	40.86	21.24	0.014	3.30	0.0007	3.874
Minneapolis	48.05	27.65	0.034	7.99	0.0140	6.978
Chicago	49.37	26.73	0.027	6.78	0.0089	5.799
Colorado Springs	43.51	24.20	0.023	5.59	0.00697	5.333
Atlanta	59.11	27.70	0.024	5.69	0.00664	5.256
Washington	53.64	27.00	0.027	6.49	0.00759	5.480
Los Angeles	45.91	20.39	0.005	1.38	0.00001	3.709

1. Includes emissions from 1.9 MW power generation, power for chiller, and gas for heating
2. Emissions from auxiliary gas heating and for turbine emissions are negligible

Comparisons of Air Emissions – Desiccant Cooling

- Base Case, Fuel Cells and Turbine - Desiccant

	All Quantities in Metric Ton/Year					
	Base Case[1]		Absorption Fuel Cell[2]		Absorption Turbine[2]	
	SO_2	NO_X	SO_2	NO_X	SO_2	NO_X
Pittsburgh	49.05	26.05	0.043	10.21	0.0213	8.688
Houston	69.31	30.38	0.034	12.67	0.037	12.477
Phoenix	60.02	26.57	0.025	5.95	0.011	6.397
Seattle	40.86	21.24	0.022	5.33	0.005	5.017
Minneapolis	48.05	27.65	0.051	12.03	0.027	10.177
Chicago	49.37	26.73	0.046	10.93	0.023	9.117
Colorado Springs	43.51	24.20	0.028	6.55	0.009	5.977
Atlanta	59.11	27.70	0.047	11.18	0.027	10.197
Washington	53.64	27.00	0.048	11.36	0.025	9.747
Los Angeles	45.91	20.39	0.030	7.16	0.017	7.827

1. Includes emissions from 1.9 MW power generation, power for chiller, and gas for heating
2. Emissions from auxiliary gas heating and for turbine emissions are negligible

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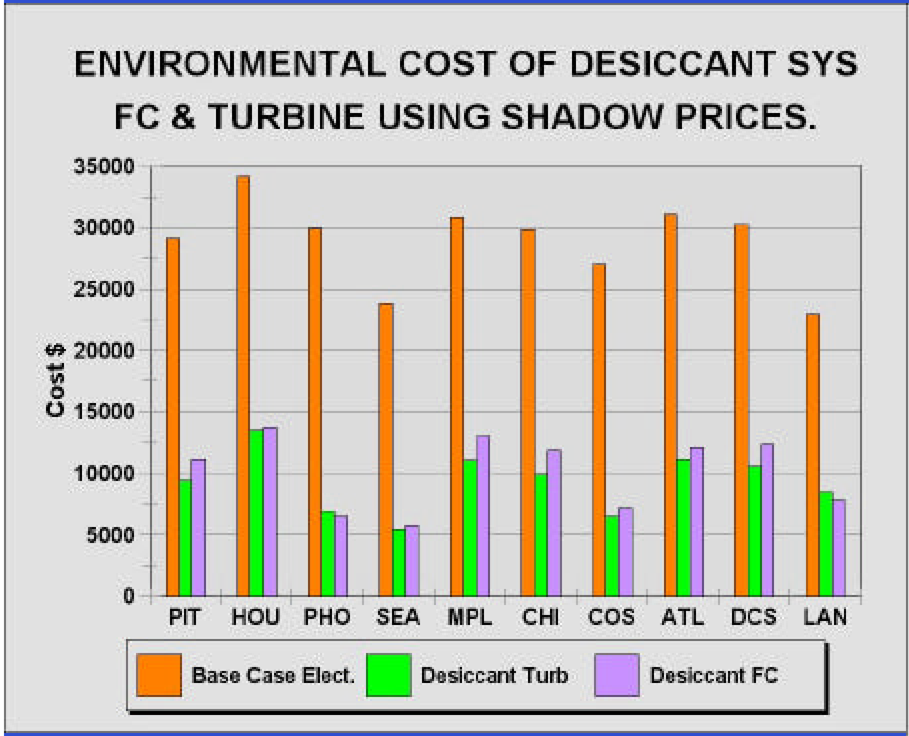
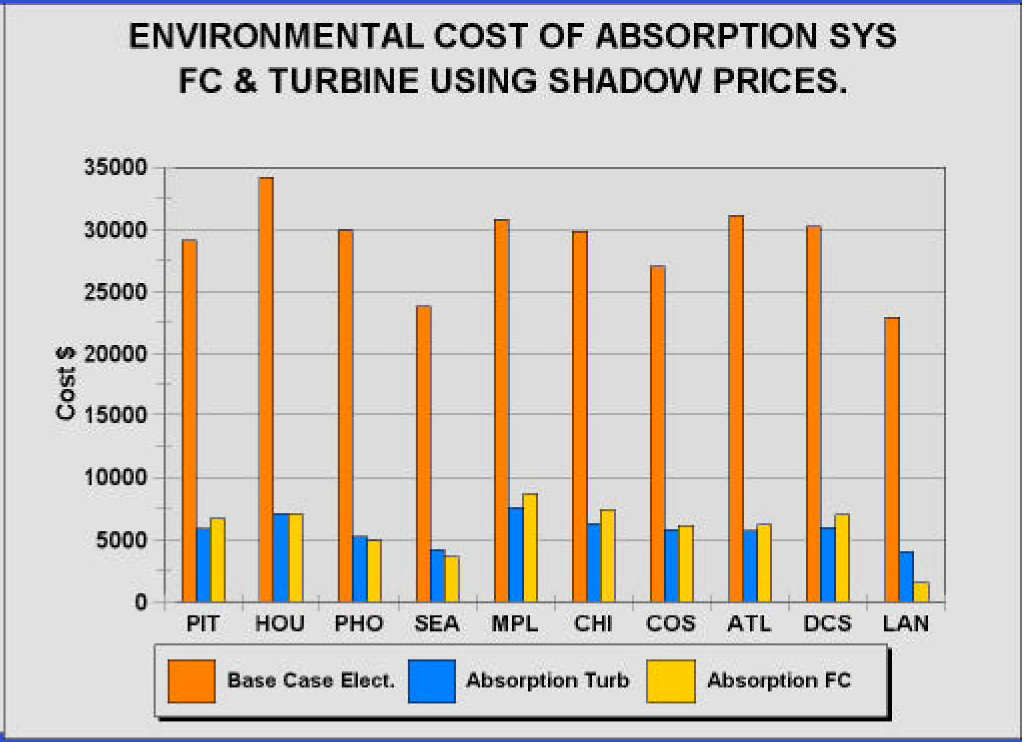
Comparison of Environmental Costs





Summary and Conclusions

- In most climates, the heat from fuel cells provide about 25% of the total thermal energy requirements.
- The utilization of heat produced by fuel cell is between 75% and 92% for various cities. The rejection of fuel cell heat is small.
- For the microturbine generation, the system provides from 50% to 98% of the total thermal energy. The utilization of heat produced is from 50% to 80%.

Summary and Conclusions (cont'd)

- More heat is wasted or rejected for turbine systems than for fuel cell system.
- On a monthly basis the utilization of heat is low in swing months.
- In cooling dominated climates, more heat is rejected, primarily in winter months.
- In the desiccant system, the temperature of the exhaust air is quite high and can be used for heat recovery for service hot water, saves approximately $50,000 per year.

Summary and Conclusions (cont.)

- The use of desiccant system allows the operation without “wet cooling coil,” “drain pans,” and cooling towers, thereby reducing molds and air quality issues.
  - Most desiccants are also a bacteriacide which greatly improves indoor air quality and may help prevent “sick building syndrome”.
- No reheat energy is required for desiccant cooling systems.
- Thermal based cooling allows the use of multiple fuels as heat sources.

Summary and Conclusions (cont'd)

- The operating cost based on energy alone, suggests that absorption systems have the lowest cost. However,
  - Absorption systems require larger cooling towers, thus increased maintenance
  - Require reheat energy for labs
  - Part load efficiency may be lower

Summary and conclusions (cont'd)

- For desiccant cooling system, the operating cost based on energy, is still lower than base electric/gas system specifically:
  - No cooling towers are required
  - Heat can be recovered from the exhaust
  - Uses lower grade energy - heat

Summary and Conclusions (cont'd)

- Fuel cell and natural gas systems significantly help air quality, especially in distressed air quality areas
  - Very significant societal benefits are available from disturbed generation, based on shadow pricing of pollutants.
- Carefully designed distributed generation systems may reduce the total cost of building by not requiring large UPS, batteries, and other equipment.
- The thermal and electric loads must be optimized for every application.

Further Study

- Evaluate the distributed generation system coupled to variations of desiccant cooling.
  - Cooling and reheat
  - Total recovery with conventional cooling and reheat
  - Total recovery and free heat with dual wheel approach
  - Heat regenerated based cooling and recovery, wheel hybrid

Further study (cont'd)

- Study desiccant based systems, with detailed calculations for energy distribution costs due to pressure drops in conventional system
- Couple a refrigerant-based heat pipe systems with desiccant cooling for energy recovery
- Evaluate the improved air quality bacteriacidal benefits of desiccant systems for lab air supply
- Study of the integration of high temperature fuel cells with building thermal systems

Thank You!