Zeven Element Design Institute PLC

15 May 2021

RE: ***KING COUNTY, WASHINGTON***
Analysis of Wastewater Energy Recovery Applications

The following pages contain a review of the potential impact through conceptual applications of SHARC wastewater energy recovery systems, applied in King County, WA. While I have based this analysis on the application of a SHARC 2 MW Unit at capacity, I have taken the liberty of using that as a baseline and estimating the potential impact of any SHARC model (0.3 to 4.0 MW) with similar load profiles yet adjusted for the related SHARC capacity. See Appendices for this information.

The results are quite interesting, with the average reduction in HVAC and Domestic Hot Water energy costs to the building owners in the range of 29 to 45%, while generating (conservatively) $2,500 to $4,000 per application in annual Thermal Energy Charges to the wastewater authority. Placed into the context of annual Thermal Charge Revenue per ton of the peak cooling load; the Office was approximately $6 to $7 per ton and the Mixed Use was approximately $5.50 to $9 per ton. Carbon emission reduction was approximately 34% for the Office and 71% for the Mixed-Use building.

I hope that this analysis will serve to be useful in your conversations.

Respectfully submitted:

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EXECUTIVE SUMMARY

Here is a tabular summary of the analysis:

PROJECT INFORMATION		
	OFFICE	***MIXED-USE***
Building Area	130,000 SF	185,000 SF
Building Location	Seattle, WA	Seattle, WA
Peak Cooling Load (tons)	457 tons	457 tons
Peak Heating and DHW Load (1,000 BTU per hour)	3,120 MBH	4,218 MBH
Estimated number of building occupants	650	555
Electric Rate: (kilowatt hour)	$0.0990/kWH	$0.0990/kWH
Natural Gas Cost: (million BTU)	$8.99/MMBTU	$8.99/MMBTU
Water Cost: (per 100 cubic feet)	$6.86/CCF	$6.86/CCF
Wastewater Cost: (per 100 cubic feet)	$6.00	$6.00
Cooling Tower Chemical Treatment: (per million BTU)	$0.71	$0.71
Thermal Energy Charge: (ton-hour)	$0.005/T-H	$0.005/T-H
Thermal Energy Charge: (million BTU)	$0.417/MMBTU	$0.417/MMBTU
ESTIMATED ANNUAL ENERGY & OPERATION COST		
	OFFICE	***MIXED-USE***
Boiler/Chiller/DHW – No Wastewater Energy Recovery	$69,556	$98,821
HR Chiller & SHARC Wastewater Energy Recovery	$49,666	$54,582
Est. Annual Energy Cost Reduction	$19,891 (-29%)	$44,239 (-45%)
Boiler/Chiller/DHW – No Wastewater Energy Recovery	$0.58/SF	$0.82/SF
HR Chiller & SHARC Wastewater Energy Recovery	$0.41/SF	$0.45/SF
ESTIMATED ANNUAL THERMAL ENERGY CHARGE		
	OFFICE	***MIXED-USE***
With internal energy recovery system (6 pipe HR Chiller)	$2,782	$2,522
Without internal energy recovery system	$3,159	$4,102
ESTIMATED IMPACT ON ANNUAL EMISSIONS (metric tons)		
	OFFICE	***MIXED-USE***
Boiler/Chiller/DHW – No Wastewater Energy Recovery	155 tons	391 tons
HR Chiller & SHARC Wastewater Energy Recovery	102 tons	112 tons
Est. Annual CO2 Emission Reduction	53 tons (-34%)	279 tons (-71%)

EXECUTIVE SUMMARY (Continued)

Here is an additional summary of the analysis:

ANNUAL COOLING TOWER WATER CONSUMPTION (gallons)		
	OFFICE	***MIXED-USE***
Boiler/Chiller/DHW – No Wastewater Energy Recovery	985,266 gallons	743,021 gallons
HR Chiller & SHARC Wastewater Energy Recovery	0 gallons	0 gallons
Est. Annual Water Consumption Reduction	985,266 gallons	743,021 gallons
COOLING/HEATING LOAD INFORMATION		
	OFFICE	***MIXED-USE***
Equivalent Full Load Cooling Hours	976 hours	736 hours
Equivalent Full Load Heating Hours	453 hours	1,748 hours
Potential Annual Internal Heat Recovery	11.9%	38.5 %
Peak Cooling Load	285 SF per ton	405 SF per ton
Peak Heating Load	24.0 BTUH per SF	22.8 BTUH per SF
Assumed Boiler Efficiency	80%	80%
Assumed Chiller and Heat Recovery Chiller Efficiency	14.0 EER	14.0 EER
Assumed SHARC Energy Consumption: (based on 12.5 HP)	9.33 kW	9.33 kW
Assumed Cooling Tower Efficiency: (tons per horsepower)	17 tons per HP	17 tons per HP
Assumed Cooling Tower Evaporation Consumption	3 GPM per 100 tons	3 GPM per 100 tons
Assumed Cooling Tower Blowdown Consumption	1 GPM per 100 tons	1 GPM per 100 tons

The above results demonstrate that the application of SHARC Wastewater Energy Recovery can provide significant energy (and water) cost savings as well as significant reductions in CO2 emissions.

In summary, building owners/occupants can reduce their operational cost by nominally 30 to 45%, while the wastewater authority can generate revenue on the order of $5.50 to $9.00 per peak cooling ton per year. So, for a 1,000 cooling ton peak load in this location, this could generate $5,500 to $9,000 in additional revenue per year with minimal initial invest from the wastewater authority (primarily metering expenses).

ASSUMPTIONS & APPROACH

Two (2) conceptual building applications were simulated; Office and Mixed Use (50% residential, 50% commercial). Typical time-of-use schedules were used for each building type. The commercial buildings were in general, assumed to be occupied 8 AM to 5 PM, while the residential followed an apartment-type schedule with high domestic hot water use in the morning and the evening.

As we were tasked to base the analysis on the SHARC Model 2 MW (569 Nominal Tons Capacity), we used this as the peak cooling (heat rejection) of the building (cooling load + compressor energy) and then used this to establish a building area (SF) to estimate the peak space heating capacity needed.

The buildings were then simulated for an entire year on an hourly basis (8,760 hours) using Trane TRACE 700 software. The weather was based on a Typical Meteorological Year (TMY3) based at Seattle Boeing Airfield. The number of people was estimated using ASHRAE Standard 62.1. This step generated the hourly thermal loads for both space cooling and space heating.

The buildings were assumed to have an effective internal energy recovery system that captures cooling loads that are simultaneous to heating loads and <u>first</u> recovers that energy <u>before</u> using the wastewater energy recovery system. This will significantly reduce the thermal demand upon the wastewater energy recovery system, which makes this the most conservative (low) estimate of potential Thermal Energy revenue. A typical embodiment of this type of system would be a 6-pipe heat recovery chiller with three (3) circuits connected to hot water, chilled water and a heat source/sink, which for this analysis is the SHARC Model 2 MW.

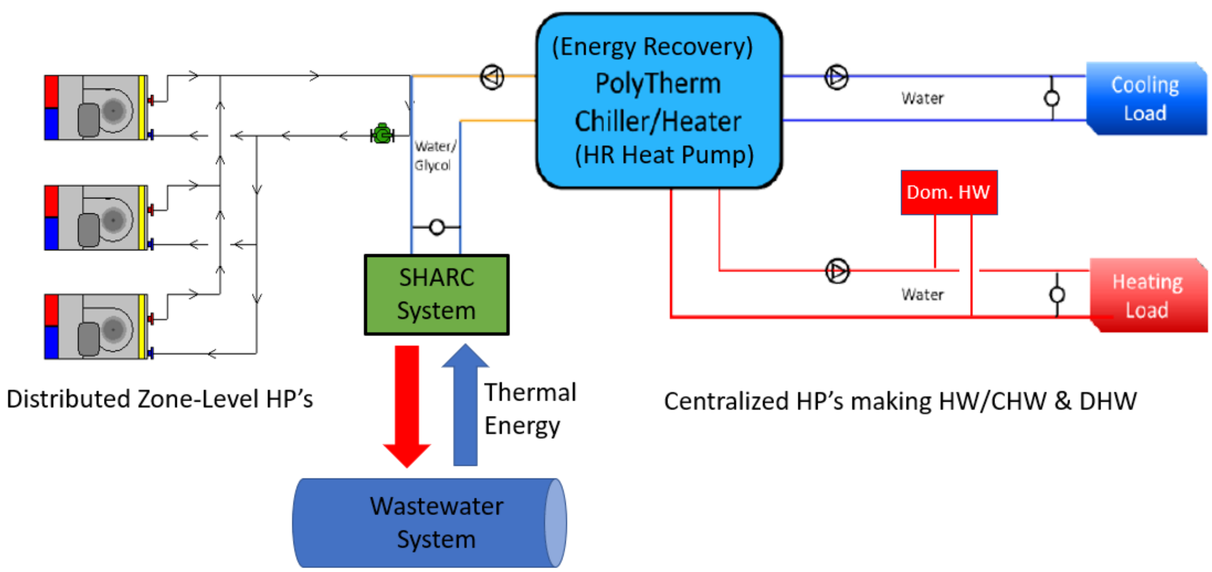

Figure 1 Example of a Building with Internal Energy Recovery

ASSUMPTIONS & APPROACH (Continued)

The Domestic Hot Water loads were based on ASHRAE consumption data and hourly load profiles in a spreadsheet analysis prepared by the author. These hourly heating loads were then combined with the thermal loads related to cooling and heating the building(s). This combined load data was then used as the basis of the next phases of analysis. The peak daily domestic hot water load per person was just over 1 gallon per day per person in an Office and 44 gallons per person per day in a Residential setting.

Cooling Tower Energy and Water-related calculations will vary widely with location, water chemistry, wastewater charges, etc. For this analysis:

- The cooling tower was assumed to meet ASHRAE 90.1 for energy consumption and was assumed to be an open tower (not closed circuit).
- Water (from the King County website) was assumed to cost $6.86 per 100 cubic feet and was assumed to be consumed by the cooling tower at a rate of 3 GPM per 100 tons.
- Wastewater was assumed to cost $47.37 per 100 cubic feet (King County website) and was generated at the rate of 1 GPM per 100 tons. This is from cooling tower blowdown.
- Cooling tower chemical treatment was assumed to cost $205 per day per 1,000 tons of peak cooling load.

Emission Reduction calculations were based on the CO_2 content of natural gas (146.25 pounds per Million BTU) and the average (for the state of Washington) CO_2 per kWH of 0.36 #/kWH (from the Energy Information Agency). This information was then converted to Metric Tons for the Summary.

SHARC Heat Exchanger energy consumption was based upon the electrical loads of the SHARC Solids-handling Pump, the Auger Pump, the Macerator and the HX Pump. Total of the listed above for this analysis was assumed to be 12.5 HP and to be in operation 100% of the time.

Note that these calculations DO NOT reflect the potential savings in boiler and cooling tower maintenance, related maintenance/operations staffing costs, or their replacement costs, or the costs to construct and maintain mechanical spaces to house them.

All the above information can (and will) vary from project to project and by location. Actual results are always different from estimates.

ANALYSIS

The following charts plot cooling loads (blue) and heating loads (red) for each hour of the year. Note that the Mixed-Use Building has a consistent heating load through the summer due to its much higher domestic hot water (DHW) consumption. First, Office, then Mixed-Use.

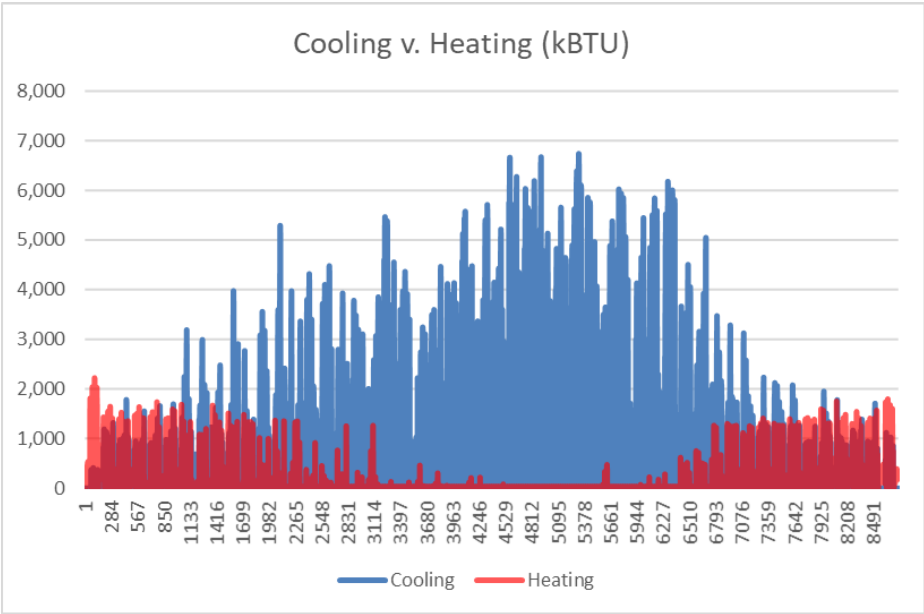

Figure 2 Office Building Hourly Cooling/Heating/DHW Loads

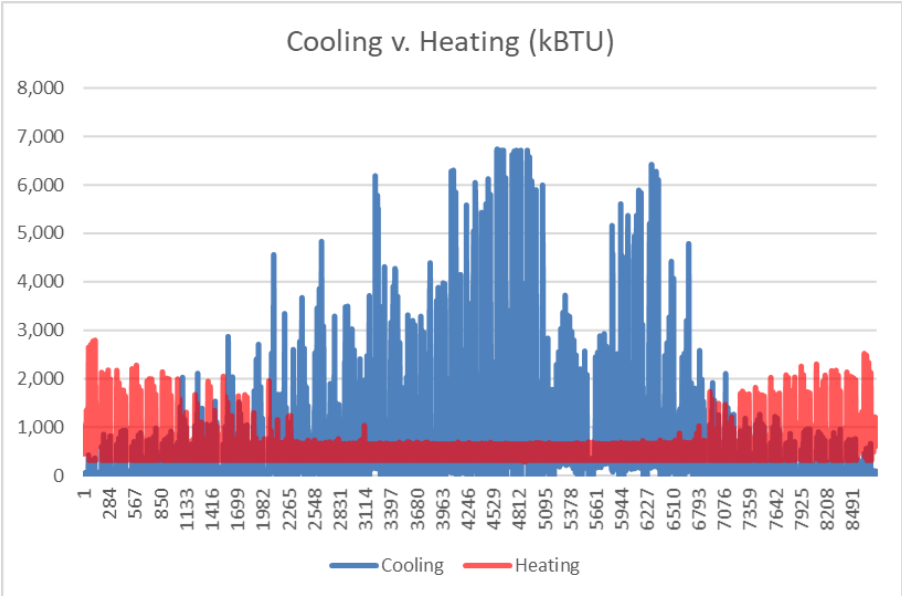

Figure 3 Mixed-Use Building Hourly Cooling/Heating/DHW Loads

ANALYSIS (Continued)

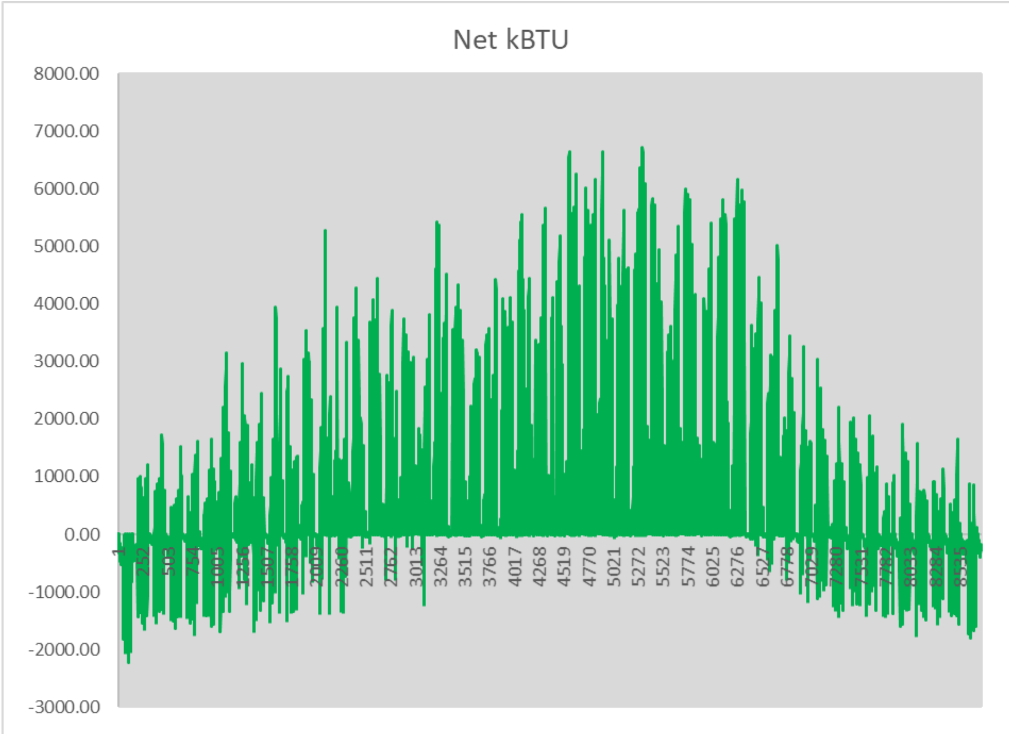

Figure 4 Office Building Hourly Plot of Net Cooling/Heating/DHW Loads

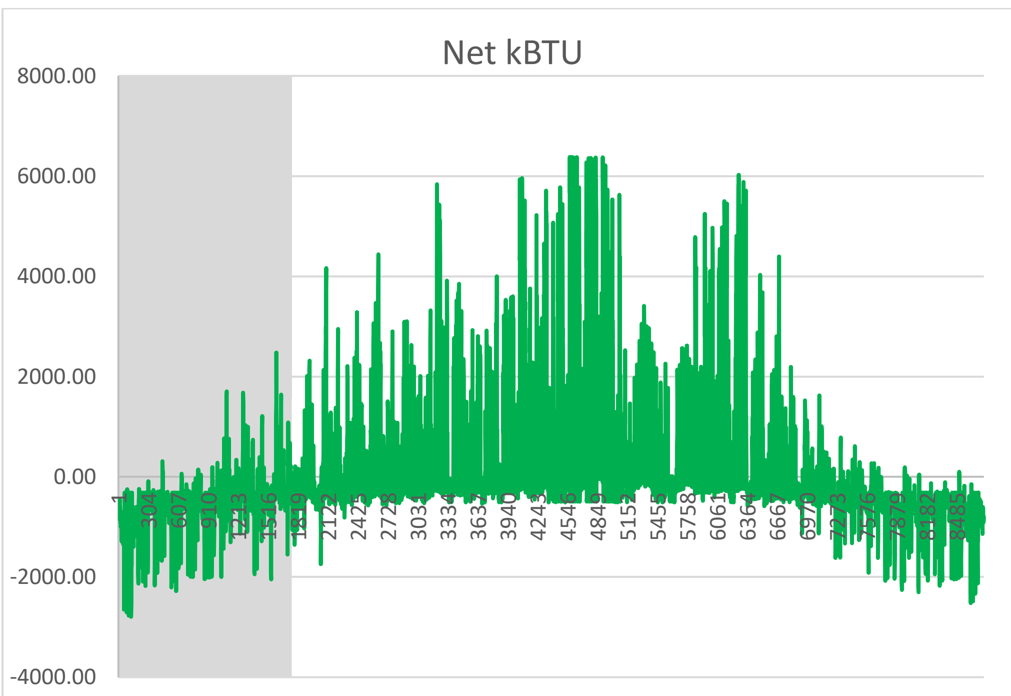

Figure 5 Mixed-Use Building Hourly Plot of Net Cooling/Heating/DHW Loads

ANALYSIS (Continued)

The Domestic Hot Water Demand Schedule has a significant influence on the net cooling/heating loads. Note that the Office consumption profile (shown first) peaks mid-day, whereas the Mixed-Use consumption profile (shown second) peaks in the morning and again later in the day. The Office consumption was assumed to be zero (0) on the weekends.

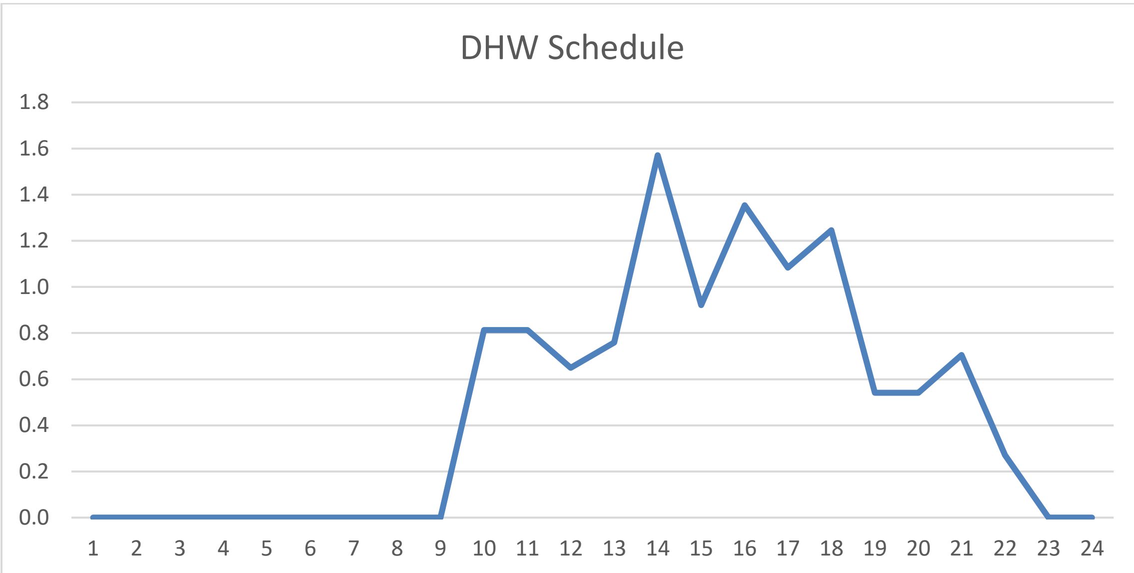

Figure 6 Office Building Hot Water Daily Demand Profile (ASHRAE)

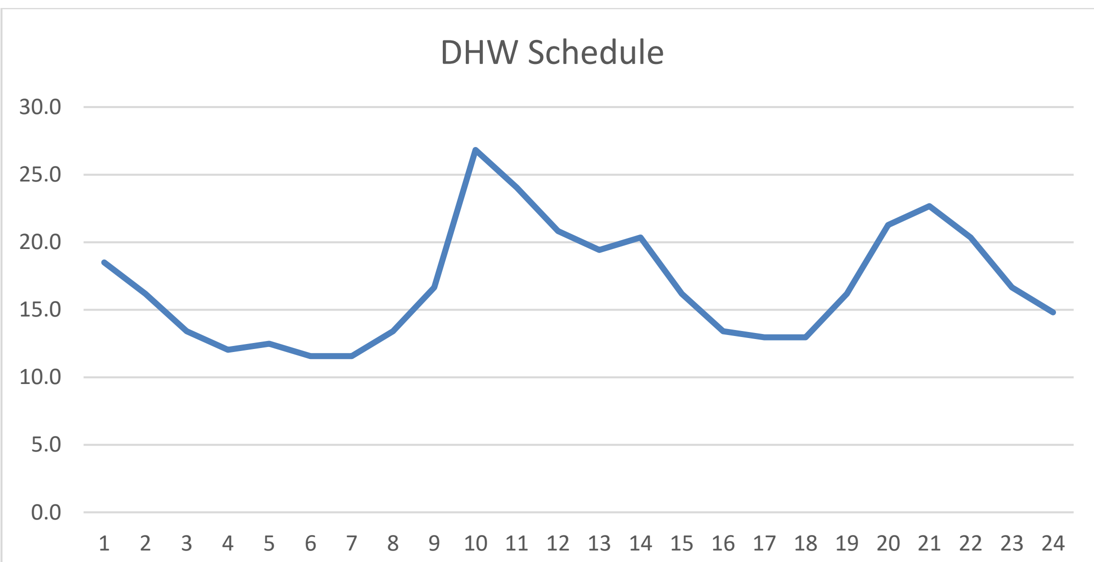

Figure 7Mixed-Use Building Hot Water Daily Demand Profile (ASHRAE)

APPENDICES

Comparison of different SHARC models – Office Building:

SHARC Comparison (Base case is 2.0 MW)		**Office Building Seattle. WA**			***Estimated Annual Thermal Charges w/ Building Energy Recovery***	***Estimated Annual Thermal Charges w/o Building Energy Recovery***
Model (MW) Peak Capacity (MW)	*SHARC Peak Capacity (Tons)*	*Boiler/Chiller Estimated Annual Energy & Op Cost*	*SHARC Estimated Annual Energy & Op Cost*	*Estimated Savings*		
0.3 MW	71 Tons	$ 8,696	$ 6,209	$ 2,487	$ 348	$395
0.5 MW	141 Tons	$ 17,270	$ 12,331	$ 4,939	$ 691	$784
1.0 MW	284 Tons	$ 34,772	$ 24,829	$ 9,944	$ 1,391	$1,579
1.5 MW	427 Tons	$ 52,164	$ 37,247	$ 14,917	$ 2,087	$2,369
2.0 MW	569 Tons	$ 69,556	$ 49,666	$ 19,891	$ 2,782	$3,159
2.5 MW	711 Tons	$ 86,936	$ 62,076	$ 24,861	$ 3,478	$3,949
3.0 MW	853 Tons	$ 104,328	$ 74,494	$ 29,834	$4,173	$4,739
3.5 MW	995 Tons	$ 121,721	$ 86,913	$ 34,808	$4,869	$5,529
4.0 MW	1,137 Tons	$ 139,101	$ 99,323	$ 39,778	$5,564	$6,318

SHARC Comparison (Base case is 2.0 MW)		**Office Building Seattle. WA**		***Estimated Annual Thermal Charges w/ Building Energy Recovery ($/peak Cooling Ton)***	***Estimated Annual Thermal Charges w/o Building Energy Recovery ($/peak Cooling Ton)***
Model (MW)	*Approx. Building Size (SF)*	*Approx. Building Peak Cooling Load (tons)*	*Approx. Building Peak Heating Load (MBH)*		
0.3 MW	16,253 SF	57 Tons	390 MBH	$6.09	$6.92
0.5 MW	32,277 SF	113 Tons	775 MBH	$6.09	$6.92
1.0 MW	64,989 SF	228 Tons	1,560 MBH	$6.09	$6.92
1.5 MW	97,494 SF	342 Tons	2,340 MBH	$6.09	$6.92
2.0 MW	130,000 SF	457 Tons	3,120 MBH	$6.09	$6.92
2.5 MW	162,483 SF	571 Tons	3,900 MBH	$6.09	$6.92
3.0 MW	194,989 SF	685 Tons	4,680 MBH	$6.09	$6.92
3.5 MW	227,494 SF	799 Tons	5,460 MBH	$6.09	$6.92
4.0 MW	259,977 SF	913 Tons	6,239 MBH	$6.09	$6.92

APPENDICES (Continued)

Comparison of different SHARC models – Mixed-Use Building:

SHARC Comparison (Base case is 2.0 MW)		**Mixed-Use Building, Seattle. WA**			***Estimated Annual Thermal Charges w/ Building Energy Recovery***	***Estimated Annual Thermal Charges w/o Building Energy Recovery***
Model (MW) Peak Capacity (MW)	*SHARC Peak Capacity (Tons)*	*Boiler/Chiller Estimated Annual Energy & Op Cost*	*SHARC Estimated Annual Energy & Op Cost*	*Estimated Savings*		
0.3 MW	71 Tons	$12,355	$6,824	$5,531	$315	$513
0.5 MW	141 Tons	$24,536	$13,552	$10,984	$626	$1,018
1.0 MW	284 Tons	$49,402	$27,286	$22,116	$1,261	$2,050
1.5 MW	427 Tons	$74,111	$40,934	$33,177	$1,892	$3,076
2.0 MW	569 Tons	$98,821	$54,582	$44,239	$2,522	$4,102
2.5 MW	711 Tons	$123,513	$68,220	$55,293	$3,153	$5,127
3.0 MW	853 Tons	$148,222	$81,868	$66,355	$3,783	$6,152
3.5 MW	995 Tons	$172,932	$95,515	$77,416	$4,414	$7,178
4.0 MW	1,137 Tons	$197,624	$109,154	$88,470	$5,044	$8,203

SHARC Comparison (Base case is 2.0 MW)			**Mixed-Use Building, Seattle. WA**	***Estimated Annual Thermal Charges w/ Building Energy Recovery ($/peak Cooling Ton)***	***Estimated Annual Thermal Charges w/o Building Energy Recovery ($/peak Cooling Ton)***
Model (MW)	*Approx. Building Size (SF)*	*Approx. Building Peak Cooling Load (tons)*	*Approx. Building Peak Heating Load (MBH)*		
0.3 MW	23,129 SF	57 Tons	527 MBH	$5.52	$8.98
0.5 MW	45,933 SF	113 Tons	1,047 MBH	$5.52	$8.98
1.0 MW	92,484 SF	228 Tons	2,109 MBH	$5.52	$8.98
1.5 MW	138,742 SF	342 Tons	3,163 MBH	$5.52	$8.98
2.0 MW	185,000 SF	457 Tons	4,218 MBH	$5.52	$8.98
2.5 MW	231,226 SF	571 Tons	5,272 MBH	$5.52	$8.98
3.0 MW	277,484 SF	685 Tons	6,327 MBH	$5.52	$8.98
3.5 MW	323,742 SF	799 Tons	7,381 MBH	$5.52	$8.98
4.0 MW	369,967 SF	913 Tons	8,435 MBH	$5.52	$8.98