SIMULATION AND EVALUATION OF MARKETS FOR BUILDING COOLING HEATING AND POWER APPLICATIONS IN THE U.S.

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ABSTRACT

A two-level analysis was used to study the economic potential of implementing Building Cooling, Heating and Power (BCHP) technologies in the U.S. A simplified level allowed limiting the full evaluation to seven major metropolitan areas and seven typical service applications in three basic configurations. The more rigorous level of simulation involved studies of 147 cases and involved software developed at GTI. This software employed DOE21.E computational engine to generate 8760 hourly building load profiles. Also, calculated were the energy consumption and costs as based on the specific electric and gas rate structures and equipment characteristics.

The results rate the three types of systems, i.e. the power generation without heat recovery, (DG), power generation with heath recovery to heating and domestic hot water, (CHP), and power generation with heat recovery for heating, domestic hot water and absorption cooling, (BCHP).

INTRODUCTION

It has been long recognized that a combination of on-site power generation with recovery of heat rejected from such a system could have in many instances significant energy conservation impact(AGA/GRI, 1998). There are several concepts of technologies that fit that category of energy systems broadly described as Building Cooling, Heating and Power (BCHP) systems, and several possible applications. For this paper we selected to summarize and compare the energy conservation and economic potentials of three practical system types:

1. Engine-driven electric generators with engine heat recovered to assist in meeting building space cooling loads via an absorption chiller, and if any heat remained, building space heating and domestic hot water loads, (full BCHP);
2. Combined heat and power (CHP) systems, with heat recovered for space heating and domestic water heating;
3. Distributed generation (DG) systems, without heat recovery.

All of these configurations were examined as serving various types of commercial buildings across numerous regions of the United States representing diversity in weather, energy costs and market opportunity conditions.

The aim and goals of the original study was to establish the positive economic potential of BCHP systems in terms of annual energy savings and paybacks and thus to determine the:

- Best U.S. geographic markets for BCHP systems, and
- Best building application types.

To reach these goals it became obvious that covering the whole territory and range of applications would represent an immense and unmanageable magnitude of simulations in considering local energy cost rates, climate, and buildings function. The two-level approach was, therefore, adapted, where during the first phase the scope was reduced to a range of economically viable cases.

The preliminary selection of desirable locations and building functions included the following considerations:

1. Comparing of electric energy rates to find desirable locations(HEM Magazine, 2001), (U.S. DOE, 1997) (as an example see Figure 1);
2. Comparing the energy use intensity of existing buildings, by function, to determine the most intense energy users(U.S. DOE, 1995) (as an example see Figure 2 and 3);
3. Evaluating the balance of electrical and thermal needs to determine what markets can benefit most from BCHP application(U.S. DOE, 1995);
4. Determining the number of buildings, by their functions, size(U.S. DOE, 1995) and construction

trends[U.S. DOE, 1995), (U.S. Census Bureau, 1999] that exist in the individual locations, to focus on important markets, (see Figure 4).

As a result of this prescreening, ten states and four building application groups were selected for further analysis. Table 1 shows the selected states and building groups. The size of these buildings had to be assessed as well. That was done by using reference 1, Tables 8 and 9 of reference 4, and assumption that the distribution would equally apply to the selected states. The results are shown in Table 2.

Final process of screening yielded seven preferred applications (see Table 3) and seven metropolitan areas for detail evaluation. The seven metropolitan areas in descending order of desirability are New York, Boston, Chicago, Newark, San Diego, Miami, and Tampa.

SIMULATION AND EVALUATION

The final simulation was run to yield the economic evaluation of the previously defined BCHP, CHP, and DG systems. The above prescreening allowed limiting the final assessment to only the most desirable cases. For the 49 cases that were deemed most advantageous, hour-by-hour (8760 hr/yr) building load profiles have been generated. The final evaluation of three types of technologies, therefore, represents 147 applications. Their evaluation followed the steps of basic algorithm shown in Figure 5.

The initial steps in this process of systems modeling required rational yet manageable inputs. For that, electrical and thermal load profiles were developed using the GTI's Gas Cooling Guide employing DOE21.E simulation engine capable of generating detailed loads for typical building types and their locations. Results of these calculations were formatted into accessible load libraries, and later also used to develop the average/seasonal electric load profiles and respective charts helpful in refining generator control strategy (see an example in Figure 6).

In addition, configuration of the systems to be modeled was defined (see Figures 7, 8), and technology components characterized as to their performance.

Economic Evaluation

In performing this analysis the system model was exercised across a range of generator sizes up to the peak electric load of a building. It was also run with no electric generation and stand-by charges to establish an operating cost baseline, and consequently, operating cost savings (see typical example in Figure 9). These then formed the basis for optimizing the equipment size.

Sizing the equipment for the site and application was one of the most important yet difficult elements of the simulation. With the goal of providing the shortest payback, and admittedly without hard cost estimates, the optimum size of the matching equipment was only an approximation. The logic of this process can be followed in the graph of Figure 9. There, it could be seen that annual savings curves rise somewhat linearly to a certain electric capacity. This was found to be true for all the systems and applications studied. If the system costs were linear in size as well, the payback or return on investment would be totally indifferent to that capacity range. However, the system costs in $/kW are expected to be far from linear and will drop precipitously as the system grows. Therefore, the largest system that will produce the lowest payback will coincide with the electric capacity at which the annual savings starts to deviate downwards from the linear increase, the "break point."

It could be argued that this first approximation could have been used as an initial step of an iterative process of size optimization. The scope of the GTI evaluation did not allow for that approach. It should also be mentioned that the same logic was applied in sizing the CHP and DG systems.

An hour-by-hour simulation model was developed that, for each hour of the year:

1. Uses a specific realistic IC engine driven generator set, including part load performance of power generation and heat recovery, which follows the electric load. This generator operates whenever the load exceeds the generators minimum output and runs at full capacity whenever the load exceeds the capacity of the generator. No sell back of electricity to the utility is assumed. In addition, the generator may be free to run as needed or may be run only during peak power periods or during electric energy/demand peak hours only, as desired. For instance, because electricity for large commercial applications sells in Chicago for approximately 2 cents per kWh off peak, the generator availability was set for energy on peak hours (9 AM to 10 PM) for all evaluated cases.
2. Passes rejected/recovered heat from the engine-generator set to a single stage absorption chiller, if a cooling load is present,

then to the space heating load and the domestic hot water load. Heat remaining is rejected.

3. Sizes the absorption chiller to match the recoverable heat from the power generator at full load. Only a portion of the recoverable heat, at temperature higher than the minimum required to drive single absorption, is used to size and drive the chiller.
4. If thermally activated absorption cooling is used, the electric load is reset, and the calculation iterates until a solution is found for that hour. Realistic characteristics are used to model the absorption and the electric chiller rating point and part load performance.

Installed Cost Estimates

Costs of typical equipment and installation were estimated from various industrial sources (R. S. Means, Yazaki, Trane, and American Gas Cooling Center data book). Installed costs were totaled for the three different systems, i.e. DG, CHP, and BCHP across the range of 30-1000 kW. They were then reduced to generalized trend lines as shown in Figure 10. The decrease in costs in $/kW with the size is apparent. It should be remembered that the gathered estimates are conservative, as the costs will be reduced when highly prepackaged BCHP systems become available.

RESULTS AND CONCLUSIONS

Analyses described above yielded economic results ranging over the whole scale of practicality. As an example, cases of typical hotel applications are summarized in Table 4. Comparatively, economics of various systems and their applications are given in Figures 11, 12, and 13. In these figures all paybacks over 20 years have been eliminated and applications arranged in the order of desirability.

The study yielded number of valuable findings and conclusions that are described in detail in this report. The most important of them are:

1. The essential element in finding the best possible payback for DG, CHP, and BCHP systems was assuring that the size of the system was optimized with respect to the size of the load. A system that was too small or too large for the load increased payback sharply.
2. The optimum size for BCHP Systems was significantly smaller than for DG Systems. In many cases, the difference in optimum size was sufficiently large that the first cost of the optimum BCHP System was lower than for the optimum DG System.
3. In all cases, the optimum electric generating capacity of all of the DG, CHP, and BCHP Systems was substantially lower than the peak electric demand, and was generally in the 40%-60% of the electric demand range.
4. The selection of the proper market segment is at least as important as the location and local utility rates under which a DG/CHP/BCHP system operate. In the same city, operating under the same utility rates, paybacks varied as much as 400% depending on the nature of the load, that is whether the load was a hospital, a school, and so on.
5. In every case examined, operation of the DG, CHP, and BCHP Systems produced lower paybacks when the system was operated through the on-peak energy periods and shut down during lower nighttime and weekend rate periods.
6. In all analyzed locations low nighttime power rates barred the operation of CHP Systems even when the heat recovery was fully accounted for. This meant that CHP systems could not be credited with reducing the heat equipment capacity needed by the building.
7. In general, much better paybacks were developed for larger commercial loads due to the escalating costs of these systems for smaller loads. Smaller loads considered were small supermarkets and sit-down restaurants. Future interest in BCHP systems for supermarkets should be focused toward the larger end of the supermarket segment.
8. In the economics of this study, the systems were not credited in any way for their ability to serve as back-up generators. For buildings that do require that capability and can use gas engines in that role, the credit against DG/CHP/BCHP System first cost, in the $350-400 kW range could reduce the paybacks shown in this paper by as much as 40%.

The main conclusion of this study was that by using simulation tools it is possible to identify economically feasible location and application of advanced energy systems for commercial buildings. However, economics of successful BCHP applications are very strongly influenced by the total of local energy rates. Higher ratios of electric to gas energy prices will shorten the BCHP system payback. However, it is impossible to make a useful economic prediction based just on the energy price ratio. A detailed analysis of each separate case, including evaluation of applicable on-site power generation standby charges, is necessary. Such standby charges can vary significantly among utilities.

It is also important to remember that the results of the presented detailed economic modeling are based on using an IC-engine driven generator with heat recovery for heating/domestic hot water and single-stage absorption chillers. Using different power generation technology (microturbine, fuel cell) or heat recovery technology (desiccant dehumidification, direct-fired absorption) will produce different economic results.

REFERENCES

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U.S. Department of Energy, Energy Information Administration, Tables 3, 8, 9, 10 “A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures.”

U.S. Department of Energy, Energy Information Administration Website, State Energy Data Report 1997, released September 1999, Table D4, Table 5.

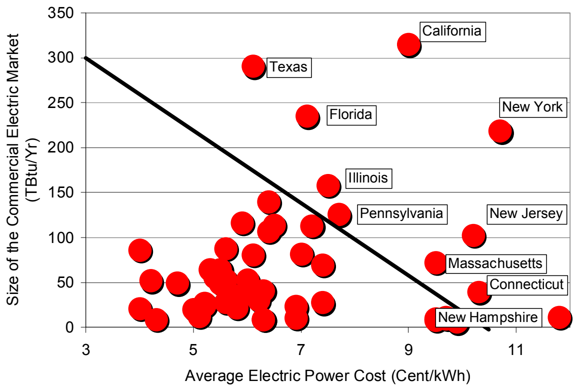

Figure 1 – State-by-State Average Power Cost vs. Size of Commercial Market

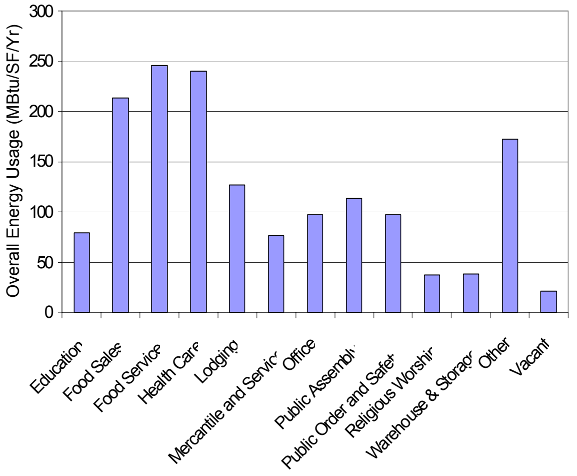

Figure 2 – Overall Energy Usage Intensity (Site Based) for Existing Buildings

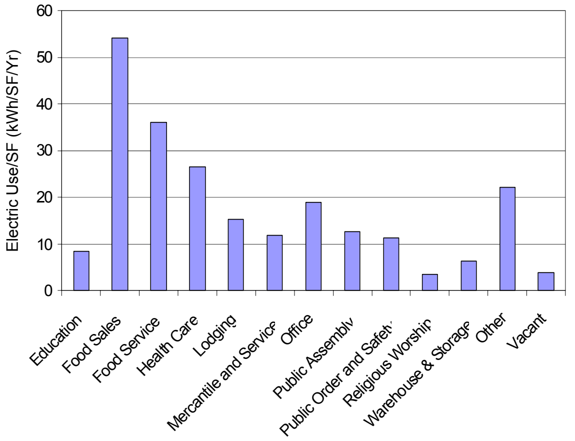

Figure 3 – National Average Electric Usage Intensity for Existing Buildings by Function

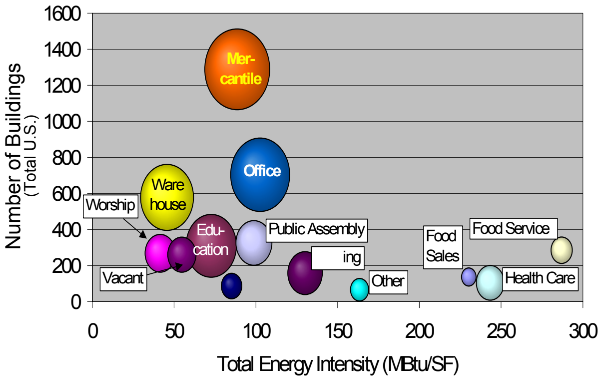

Figure 4 – Overall View of the Market

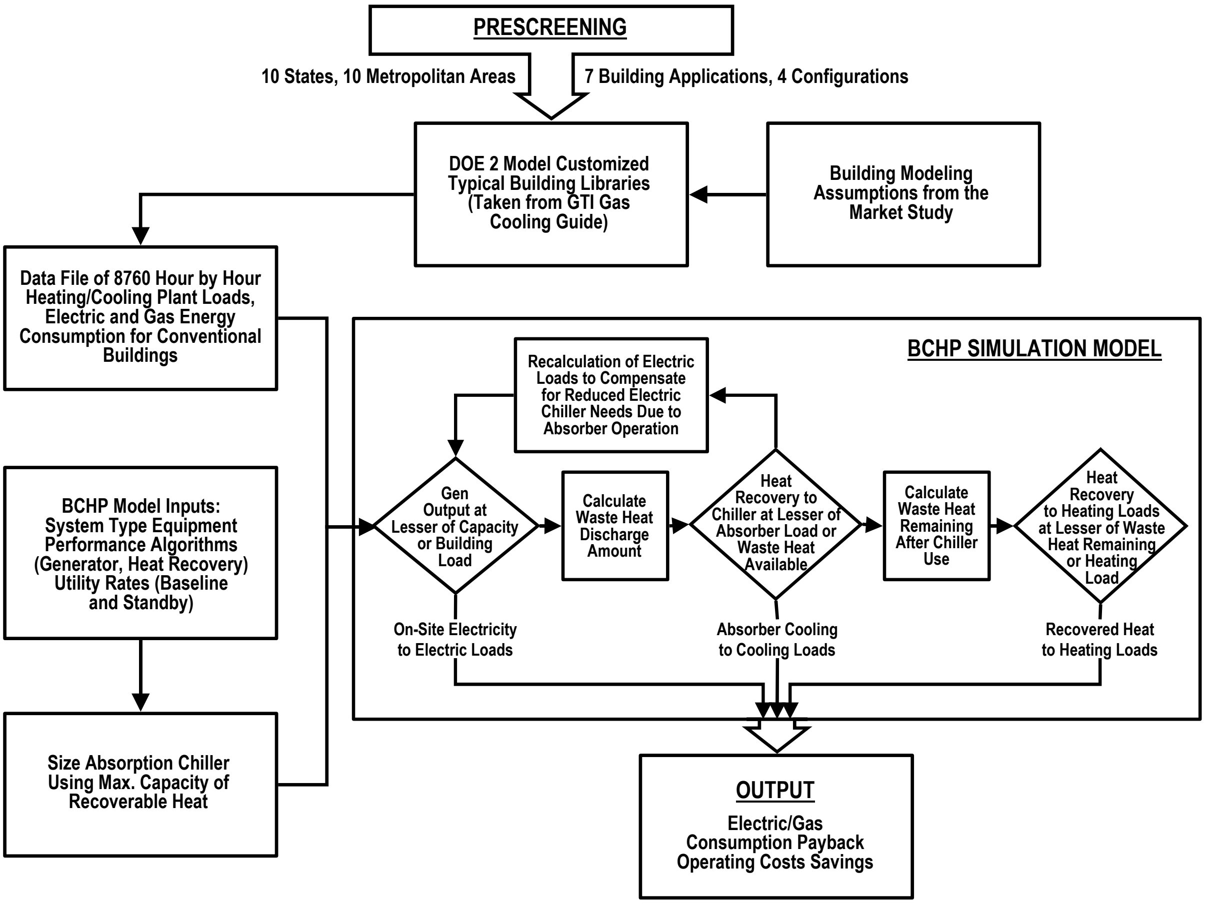

Figure 5 – Overall Logic Flow Used in the Model

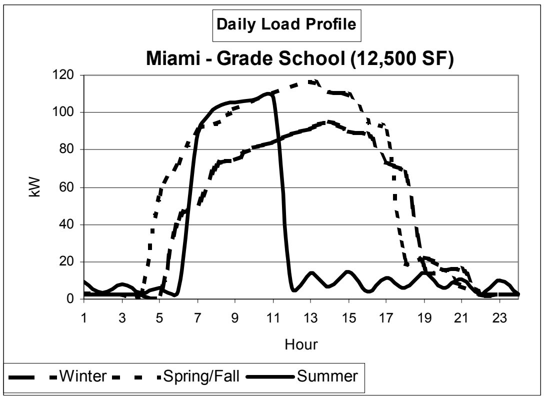

Figure 6 – Average Hourly Electric Load Profiles for Typical Summer, Winter, or Spring/Fall for a 10,000 SF Grade School with Half-Day Summer Operation

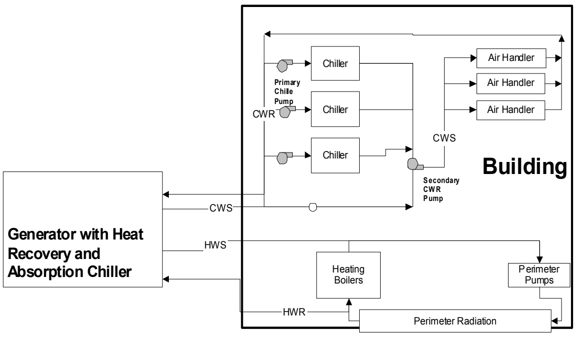

Figure 7 – Model's Visualization of BCHP in Large Building

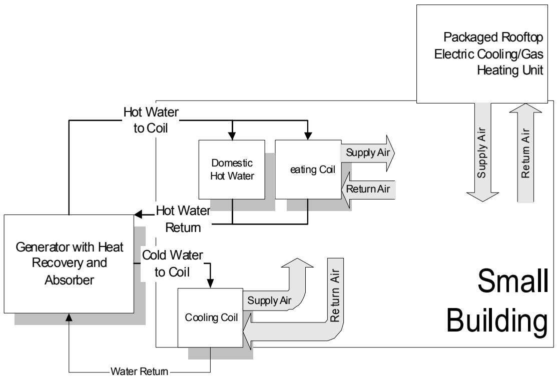

Figure 8 – Model's Visualization of BCHP in a Smaller Building

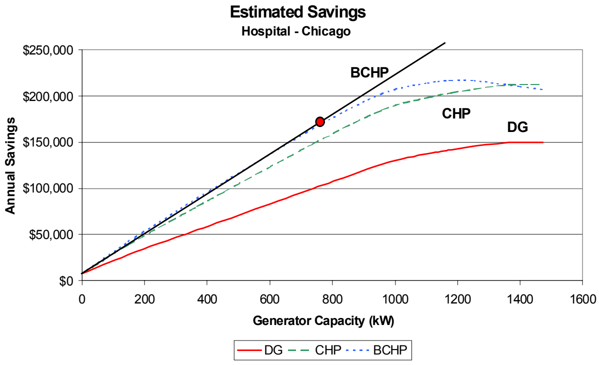

Figure 9 – One Way to Approximate the Optimum Equipment Capacity

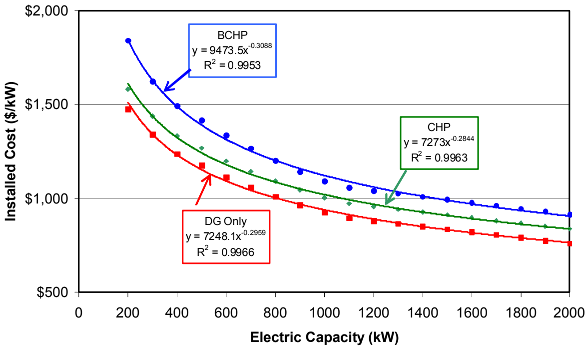

Figure 10 – Plot of First Cost into Trend Lines with Correlations

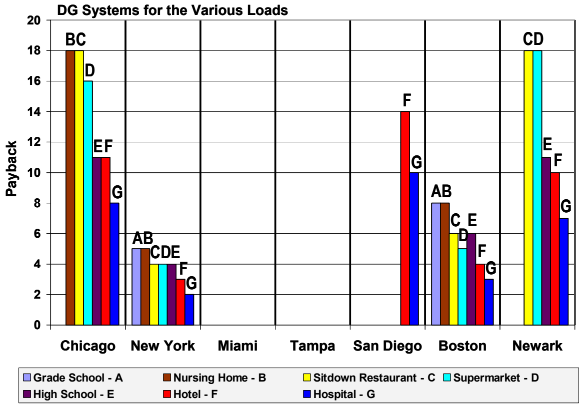

Figure 11 – The Desirability of Cities for Generation Only Systems (payback in years)

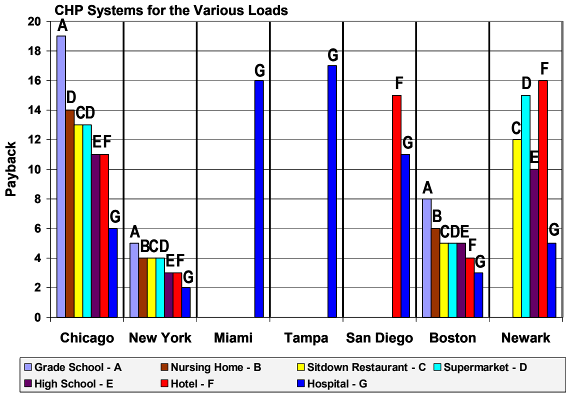

Figure 12 – The Desirability of Cities for CHP Systems (payback in years)

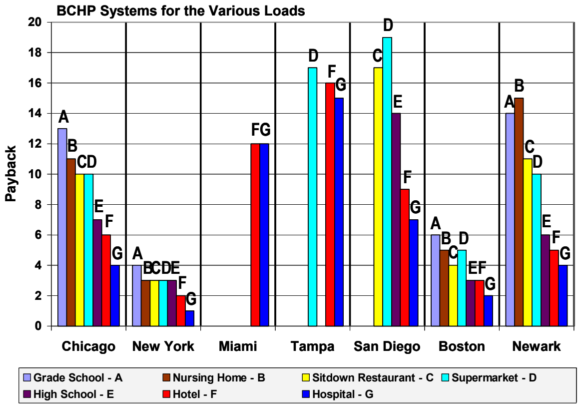

Figure 13 – The Desirability of Cities for BCHP Systems (payback in years)

Table 1 – Initial Screening Based Best Markets for BCHP

Location	Application
California	Food Sales
New York	Food Service
New Jersey	Health Care
Texas	Lodging
Florida	
Illinois	
Pennsylvania	
Massachusetts	
Connecticut	
New Hampshire	

Table 2 – BCHP Market Sub-Segments Identified

Application	Sub-Division	Number of Buildings (National)	Basis	Rational
Food Sales	Supermarkets, other stores	137,000	All	Need for Power Back-up for food preservations makes this an attractive market for any on-site power system
Food Service	Quick Service	210,000	<5000 SF	5,000 SF Safely exceeds – **Eliminated**
	Larger Sit-Down	52,000	>5,000 SF	Size of Quick Service Bldg.
Health Care	Medical Office/Clinics	57,000	<5,000 SF	Too small a building size for Practical BCHP – **Eliminated**
	Nursing Homes and Small Medical Centers	21,000	10,000 to 50,000 SF	Need for Power Back-up makes this an attractive market for any on-site power system
	Hospitals	5,000	>100,000 SF	Need for Power Back-up makes this an attractive market for any on-site power system
Lodging	Motels	143,000	<50,000 SF	Too small a building size for Practical BCHP – **Eliminated**
	Large Hotels	15,000	>50,000 SF	Generally exceeds 100 Rooms – Inclined to Be High Rise Hotel with Central Plants
Educational	Larger Facilities – Generally Secondary or High Schools	87,000	>25,000 SF	Exceed 50 typical rooms, inclined to be secondary schools with more year around operation and pools/ gym showers providing a more constant thermal load.
Educational	Grade Schools	222,000	<25,000 SF	Require large make-up air

Table 3 – The Applications Specifics for the Simulations and the Number of Buildings in the United States

Target Application	Hospital	Nursing Home	Sitdown Restaurant	Supermarket	Hotel	High School	Grade School
Average Size in SF	300,000	22,000	7,500	7,500	131,000	71,000	12,500
No of Buildings in the U.S.	5,000	21,000	52,000	29,000	15,000	87,000	222,000
HVAC Base Case Equipment	Centrifugal	Rooftop	Rooftop	Rooftop	Electric Screw	Electric Screw	Rooftop
Max RH Control Setpoint*	70%	70%	70%	55%	70%	70%	70%

*Note: RH means Relative Humidity

Table 4 – Economic Simulation Output for a Typical Hotel

	Hotel Load					
	DG		CHP		BCHP	
	Gen Size	Savings	Gen Size	Savings	Gen Size	Savings
	(kW)	*(per Yr)*	*(kW)*	*(per Yr)*	*(kW)*	*(per Yr)*
Chicago	425	$45,000	425	$50,000	350	$70,000
New York	280	$150,000	280	$160,000	220	$175,000
Miami	500	$25,000	500	$28,000	460	$44,000
Tampa	150	$7,500	150	$12,000	400	$30,000
San Diego	450	$38,000	450	$39,000	350	$48,000
Boston	300	$100,000	300	$115,000	220	$120,000
Newark	350	$46,000	950	$60,000	220	$65,000

	Hotel Load					
	DG		CHP		BCHP	
	System Cost	Payback	System Cost	Payback	System Cost	Payback
	($)	*(Years)*	*($)*	*(Years)*	*($)*	*(Years)*
Chicago	$513,886	11.42	$552,826	11.06	$448,225	6.40
New York	$383,056	2.55	$410,110	2.56	$323,235	1.85
Miami	$576,186	23.05	$621,007	22.18	$543,333	12.35
Tampa	$246,833	32.91	$262,376	21.86	$492,412	16.41
San Diego	$534,989	14.08	$575,907	14.77	$448,225	9.34
Boston	$402,123	4.02	$430,865	3.75	$323,235	2.69
Newark	$448,225	9.74	$983,043	16.38	$323,235	4.97