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CHP FOR BUILDINGS – THE CHALLENGE OF DELIVERING VALUE TO THE COMMERCIAL SECTOR

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ABSTRACT

The commercial sector has historically not seen the same level of investment in Combined Cooling, Heating and Power (CHP) as the industrial sector. The average commercial building has smaller and more diverse energy requirements than would be expected at a typical industrial site. Consequently, even though the electrical requirements of the commercial and industrial sectors are very similar there is nine times more installed industrial CHP capacity than commercial CHP in the U.S. However, the advent of microturbines and increasing commercial viability of fuel cells promises generator sizes much more suitable for use in the commercial sector. There are many possible uses for the waste heat in a commercial building, depending upon geographic location, occupant requirements and the energy cost structures of both fuel and grid electricity. Possible waste heat technologies include absorption chillers, humidifiers, desiccant dehumidifiers, steam generators, hot water heating, space heating and thermal storage. Several of these could be combined with a generator to produce a commercial CHP for Buildings package. A well-designed and operated package should deliver energy and environmental savings as well as significant cost savings to the customer. Other potential value streams are improved indoor air quality, peak shaving to reduce demand charges, enhanced power reliability, tradable environmental credits or grid independence. This presentation is a broad discussion of the challenges that CHP faces when competing in the commercial sector and the technologies and strategies that will help overcome them.

INTRODUCTION

Commercial scale CHP focuses on applications where power generation and waste heat recovery is used on-site in a commercial building setting. In recent years several important factors in the energy industry have led to a growing interest in CHP systems focusing on the commercial sector. The restructuring of the electric industry, economic growth and the capacity limitations of the existing power grid have all raised concerns about the future cost and reliability of electricity. The advent of small-scale energy-efficient power generating equipment, such as microturbines and fuel cells, have made the transition to on-site generation more promising. The development of advanced heat recovery equipment that provides cooling, heating, or humidity control has made CHP systems more attractive.

The CHP initiative was started in March of 1999 by the U.S. Department of Energy (DOE) in cooperation with industry leaders representing manufacturers, utilities, building operators, research-and-development organizations, industry associations, energy-service companies, engineers, universities, and national laboratory personnel. In general, CHP seeks to improve the indoor environment, conserve resources, and reduce emission rates and improve reliability through energy-system integration. CHP also avoids power–line losses, recycles waste heat, and uses new, energy-efficient equipment that can lead to building energy systems that put to work 80% of the purchased fuel going into the system. In addition, it is estimated by the DOE that by increasing the market penetration of CHP systems to 50% of new commercial/institutional buildings and 10% of existing commercial and institutional buildings by 2020, the U.S. can reduce CO_2 emissions by 63 million metric tons per year, which corresponds to 50% of the total reduction target for greenhouse-gas emissions specified in the Kyoto Protocol. Additionally, CHP is likely to gain wider market acceptance due to the recommendations regarding CHP contained in the President's National Energy Policy (NEPDG, 2001).

The U.S. consumed almost 93 quadrillion BTUs (2.7×10^{10} MW-h) of energy in 1996. Of this total, commercial buildings accounted for over 15 quadrillion BTUs (4.4×10^{9} MW-h). This is equivalent to the amount of gasoline consumed in the U.S. in one year (DOE, 2001). In 1999, residential and commercial buildings consumed 36% of the nation's energy and utilized almost two-thirds of all the electricity generated. The growth of the economy, as well as the nation's rising population is leading to greater numbers of larger and more energy-intensive homes and commercial buildings, resulting in increased energy consumption in this sector (DOE, 2002).

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COMMERCIAL VS. INDUSTRIAL CHP

Currently, there are over 980 operating CHP facilities in the commercial sector (Onsite, 2000a) and over 1016 CHP facilities in the industrial sector (Onsite, 2000b). Nonetheless, as shown in Figure 1 total CHP capacity in the industrial sector is over 9 times that of the commercial sector.

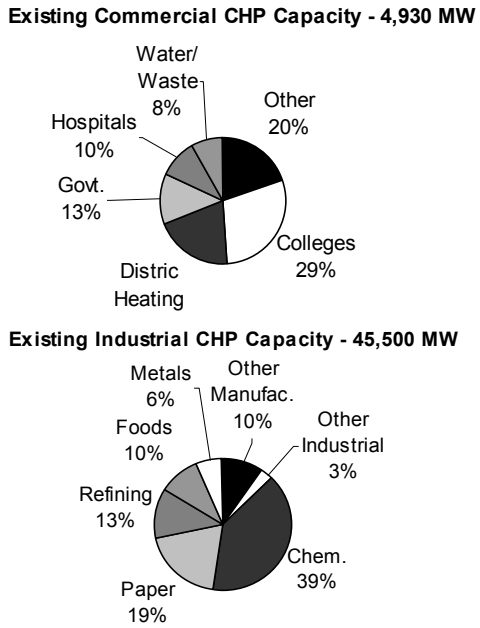

Figure 1: Existing CHP Capacity (1999)

Figure 2 characterizes CHP in terms of the prime mover for both the commercial and industrial sectors. In both sectors, the largest share of capacity (43% and 49% respectively) comes from combined cycle power plants, which consist of a combustion turbine and a heat recovery steam generator that drives either a backpressure or an extraction steam turbine. Combined cycle power plants are typically installed in facilities exceeding 5 MW in generation capacity. However, the majority of the electric load for commercial facilities falls under 1 MW in capacity.

The potential market for CHP in the commercial buildings sector is projected to be almost 17 GW in 2010, growing to over 35 GW by 2020 (RDC, 2001). Included in this market is a significant portion of CHP that incorporates absorption chillers (8.9 million tons, 31,300 MW-R), thermal storage (3.2 million tons, 11,254 MW-R), and engine driven chillers (2.4 million tons, 8440 MW-R).

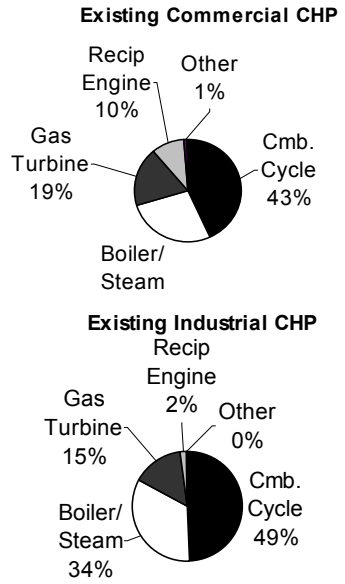

Figure 2: Existing CHP by Prime Mover

If the energy requirements of a typical commercial building are compared to that of the average industrial site there are three main differences: the total energy demand is smaller, the ratio of thermal to electric demand is much smaller and the energy requirements of the commercial site fluctuates more throughout both the day and the year. These three differences by themselves make commercial CHP quite a different proposition from CHP in the industrial sector.

Energy Demand

As the electric and thermal demand increases at a given site, economies of scale allow ever-greater generator efficiencies. Traditionally it has been very hard to achieve high efficiencies at a small scale. A recently commercialized technology, microturbines are prime movers that are currently approaching 30% LHV efficiency with a recuperated gas turbine power cycle. But while this efficiency is low in isolation, it is comparable to existing grid electricity supply and with the addition of CHP, 60-70% fuel utilization can be achieved. Looking into the future, ongoing development of stationary fuel cell technology promises high electrical efficiencies across a wide range of scales – from laptop batteries to central power plants. The major benefit, however, will probably be in the mid to low capacity plants where high efficiencies have traditionally been difficult to achieve. These two technologies are well poised to provide the small-scale power generation needs of commercial buildings.

Ratio of Thermal to Electric Load

A 30% efficient microturbine uses 30% of the fuel energy to produce electricity, while about 55% of this energy is produced as heat in the exhaust and 15% is lost due to the operation of power electronics and heat transfer through the

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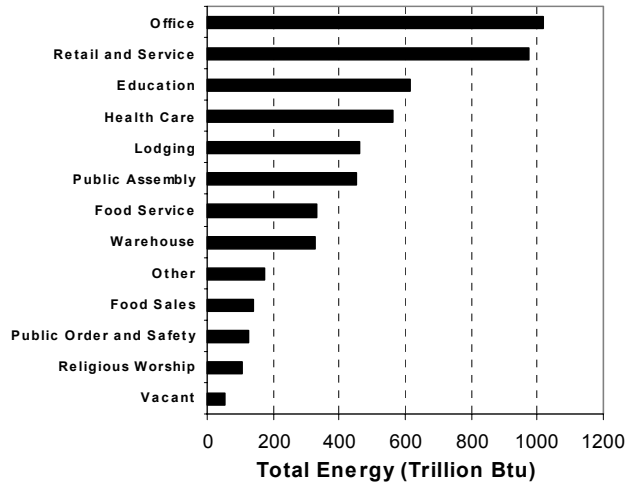
case of the equipment. The extent to which the waste heat can be utilized depends on the temperature required for the proposed heat recovery application, but an ideal site would have a heat load almost twice as high as the demand for electricity. This ratio of thermal to electric load is not present in most commercial buildings where the demand for electrical energy typically is equal to or even exceeds the thermal load. This is very different from the energy mix required by an industrial site where a large, continuous thermal load is commonly required for process heat. CHP applications in industry are typically sized to meet thermal loads and electricity is viewed as a high value byproduct that can be purchased from or sold to the grid.

In a commercial CHP application the generator could be matched to the electric load or the exhaust heat matched to the thermal demand. Matching the electrical load will usually result in too much exhaust heat and matching the thermal load will result in a generator that can supply only a fraction of the site's electrical requirements. Some compromise between wasted exhaust heat and electrical undersupply could be reached but the least wasteful approach from a PEC standpoint would be to size to the thermal load. This is because electrical energy is transportable, meaning that it can be traded with the grid, whereas waste heat, if not utilized on site can only be dumped into the environment. The generator sizing can also be affected by the cost structure of onsite fuel compared to that of grid electricity – if the generator is efficient enough and the fuel is cheap enough then the generator could be sized larger, and the wastage of exhaust heat tolerated from an economic viewpoint.

An alternative approach is to try and increase the heat load onsite through the use of thermally activated technologies such as absorption machinery, steam generators, desiccant dehumidifiers or thermal storage. An excellent example is absorption where a traditionally electric load, cooling, can be displaced with a largely thermal energy supply. Chillers are typically the largest consumer of electricity during the summer months, and depending upon geographic location and building function, potentially annually as well.

Operating Hours

If a customer is making a large capital investment in a CHP system, they want to be able to run it continuously to maximize their return on investment. Many commercial buildings do not have both continuous and well-matched thermal and electric loads. An industrial CHP installation such as a refinery will usually be able to run for all 8760 hours in the year, whereas an office building operating for 10 hours a day, five days a week operates only 2600 hours per year. Additionally, the thermal and electric demand is likely to be highly seasonal. If the CHP system is using the waste heat for space cooling or heating then this will cut even further into the operational hours available to run the system and recover capital costs.



Source: EIA, 1995 Commercial Buildings Energy Consumption Survey.

Figure 3: Total Energy Consumption by Principal Building Activity

The two strategies are either to pick a building type (hospital, hotel, etc.) that has a large enough thermal demand in the form of water or space heating to run the system continuously, or else design the system to be diverse enough to supply more than one of the building's energy requirements. The first option will generally result in a system that only supplies part of the building's electrical demand and the second introduces the problems of controls and complexity.

DESIGNING CHP SYSTEMS FOR COMMERCIAL BUILDINGS

Commercial buildings are grouped by the Energy Information Administration into categories of principal building activity. These categories include office buildings, shopping malls, hospitals, churches, and many other types of buildings whose energy consumption are summarized in Figure 3. Based on total energy consumption, the largest of the categories is office buildings, followed by retail and service, education, and health care categories. A description of these categories and a discussion of suitable CHP systems that match each category are subsequently addressed.

Office buildings comprise the largest consumer of energy in commercial buildings representing 19% of the total energy consumption. Office buildings typically include buildings used for general office space, professional offices, and administrative offices. Figure 4 shows that lighting is the largest consumer of energy for office buildings (29%), while space heating and cooling combined accounts for 34% of the total energy consumption. In general, office buildings have a high electric demand, a high space heating demand, a low water heating demand and a moderate cooling demand. For

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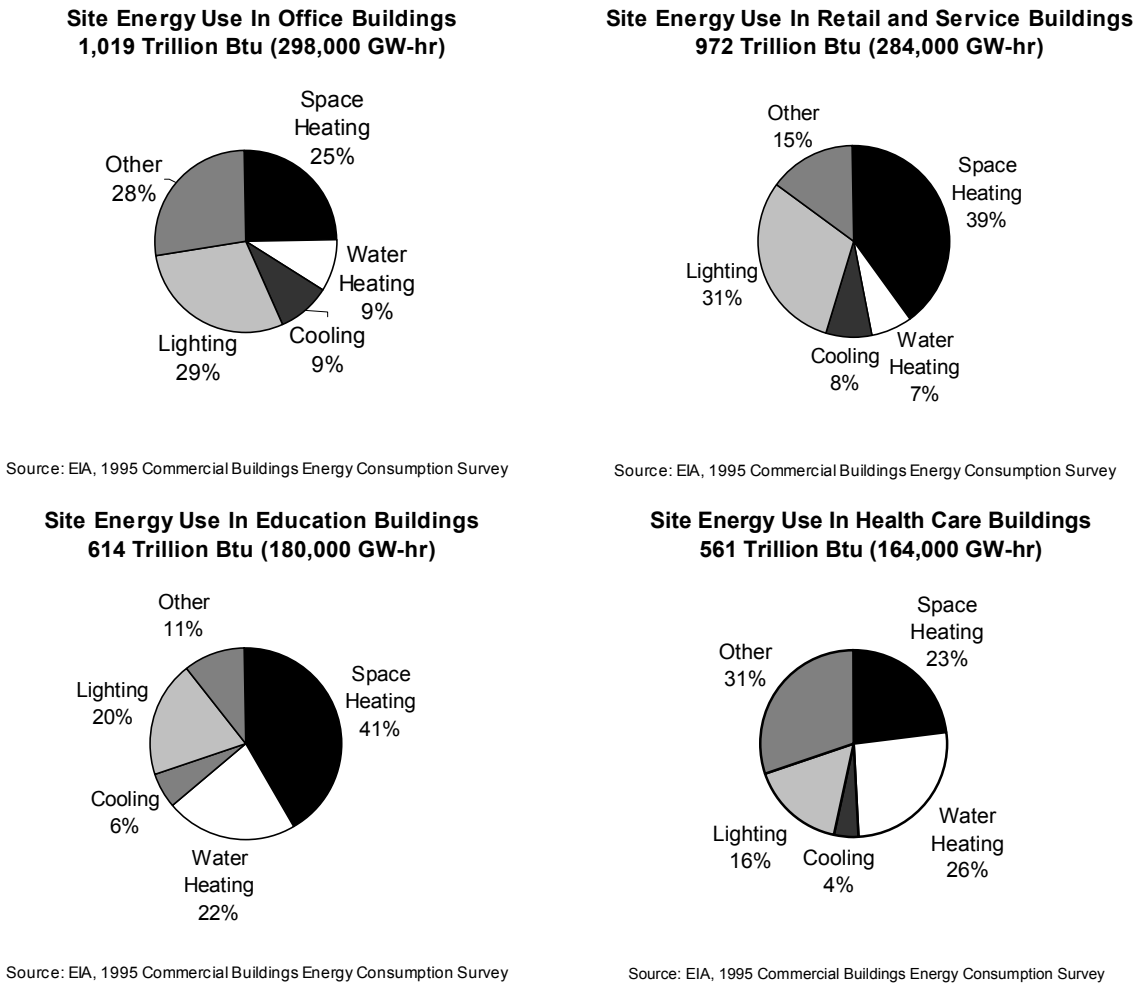

Figure 4: Site Energy Use by Principal Building Activity

this category, on-site power generation along with waste heat utilization in the form of either space heating or cooling would be a reasonable combination. A CHP system that would take care of most of the requirements for this type of application, is a recuperated microturbine integrated with either a hydronic heat recovery system for space heating or a single effect absorption chiller for space cooling.

The retail and service building category is the second largest consumer of energy and represents 15% of the total energy consumption in commercial buildings. Retail and service buildings include service buildings such as dry cleaners, car washes, gas stations, service centers, and post offices. Educational buildings represent the third largest category for total energy consumed and represents 12% of commercial buildings' total energy consumption. For both the retail and service buildings and the educational buildings categories, space heating is the largest consumer of energy. When combined, space heating and cooling represent almost half of the total energy consumption for both categories. In general, retail and service buildings and educational buildings have a very high space heating demand, a high electric demand, a moderate water heating demand, and a low to moderate cooling demand. In this case, CHP systems that apply heat recovery for space heating would be most beneficial. A system well matched for this type of application, would be a recuperated microturbine integrated with a hydronic heat recovery system for space heating.

The health care buildings category is the fourth largest for total energy consumption and represents 11% of the total for all commercial buildings. Buildings in this category include both inpatient and outpatient health care buildings such as hospitals, psychiatric facilities, rehabilitation centers, dental clinics, emergency walk-in clinics, and veterinary clinics. In this category, water heating is the largest consumer of energy followed by space heating. Since hospitals are used around the clock, they have a much higher occupancy and subsequently a more continuous energy demand as compared to other commercial buildings. Because of this, hospitals are better able to take advantage of CHP benefits from high operating hours. An example CHP system that is well suited for hospitals is a

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recuperated turbine with hydronic heat recovery for water or space heating.

CHALLENGES AND OPPORTUNITIES

Primary Energy Consumption Savings

CHP can be used to make significant savings in Primary Energy Consumption (PEC) – the quantity of fossil fuels consumed in supplying a service. The use of grid electricity actually results in the consumption of three times the delivered quantity of energy, due to power plant inefficiencies and transmission and distribution losses. It is relatively easy to make the comparison between grid electricity and traditional CHP (Combined Heat and Power) applications. Even with generators of relatively low efficiency, recovering waste heat from the exhaust almost always reduces the PEC of supplying heat and power to the site. In this application the concept of first law efficiency (heat absorbed/heat supplied) can be used to compare different systems for energy efficiency, because any heat utilized from the exhaust of the generator directly displaces the consumption of heating fuel.

In a commercial installation using desiccants and absorption technology the energy savings calculations are not as obvious. Energy utilization (First Law) by itself is no longer sufficient to assess the performance of the system. An additional aspect is the higher availability of electrical energy when compared to the same quantity of energy in the form of hot water or hot air. Take absorption chilling as an example. 1 kW of electrical energy in a state of the art electrical chiller can produce almost 5 kW of cooling, whereas 1 kW of exhaust heat or steam used in an absorption chiller can produce up to 1.4 kW of cooling. In this situation, for the end application of cooling, electrical energy could be said to have 2.8 times (4/1.4) the availability of waste heat. Each system utilizes the same quantity of energy, but the output from both is very different in scale.

CHP Application	Losses in Generator [%]	Exhaust Heat Utilized [%]	Parasitic Electrical Power in CHP	Non-CHP alternative
Displacing Grid Electricity	14% of PEC	0%	N/A	> Grid efficiency of 30%
Displacing Grid Electric Heating and Grid Electricity	14% of PEC	80%	Negligible pump work	> 95% efficient electric heating > Grid efficiency of 30%
Displacing Natural Gas Heating and Grid Electricity	14% of PEC	80%	Negligible pump work	> 85% efficient natural gas combustion > Grid efficiency of 30%
Displacing Electric Chilling and Grid Electricity (with absorption COP of 1.4)	14% of PEC	50%	10% of cooling capacity for absorption pump work	> Electric chiller with COP of 5 running on grid electricity > Grid efficiency of 30%

Note: Losses in generator represent heat loss through the generator casings and other effects that reduce the quantity of waste heat seen in the exhaust

Table 1: Summary of Analysis Assumptions

As the temperature of a given heat source decreases the usefulness or exergy of the energy provided by it decreases as well. Thermodynamically, electric energy has a much higher exergy than exhaust gases, but this number by itself this does not completely describe the relative availability of the electrical and thermal outputs of a commercial CHP system. Displacing electric chilling with absorption equipment in the building will create additional thermal demand but the importance of the electric efficiency of the prime mover should not be underestimated. While there is no absolute measure of the value of commercial CHP that takes into account both thermodynamic performance and building energy characteristics, comparisons between some typical CHP systems can be made.

PEC Savings Through Waste Heat Recovery

In this section the PEC savings obtained from recovering waste heat are examined for a variety of existing thermal loads – electric, gas and the supply of heat to absorption machinery. The analysis does not attempt to cover every detail of the interaction between the electrical generator and the waste heat recovery but addresses the major contributions to overall system performance. Some basic assumptions are made as detailed in Table 1.

The comparison that is being made is the difference in PEC of supplying electricity and heat or electricity and cooling from traditional sources compared to that consumed using CHP equipment. The PEC of electric heat, gas heat or electric chilling is a straightforward calculation once the delivered efficiency of grid electricity is known. The average efficiency of thermal power plants in the US in 1999 was estimated to be 32.5% by the EIA (EIA, 1999). If transmission and distribution (T&D) losses of between 5-10% are accounted for, the overall electrical efficiency of delivered electrical energy is reduced to approximately 30% in terms of PEC. The assumption of 30% grid efficiency is common to all cases.

The PEC in the CHP case is always the energy in the fuel delivered to the prime mover. The electric energy and thermal energy is then utilized as described by the assumptions in Table 1. The absorption chilling case is the most complicated comparison to make and the energy flows and conversions are shown in Figure 5 for the case of a 60kW prime mover with 30% efficiency and an absorption chiller with a COP of 0.7. The delivered service in both cases is 52 kW of electric power (60 kW – 8 kW consumed by the chiller) and 70 kW of cooling.

The PEC saving in the case displayed in Figure 5 is 10% when compared to the grid electric equivalent. The results obtained from varying the efficiency of the prime mover for the three CHP alternatives analyzed, as well as for a generator with no heat recovery, are displayed in Figure 6.

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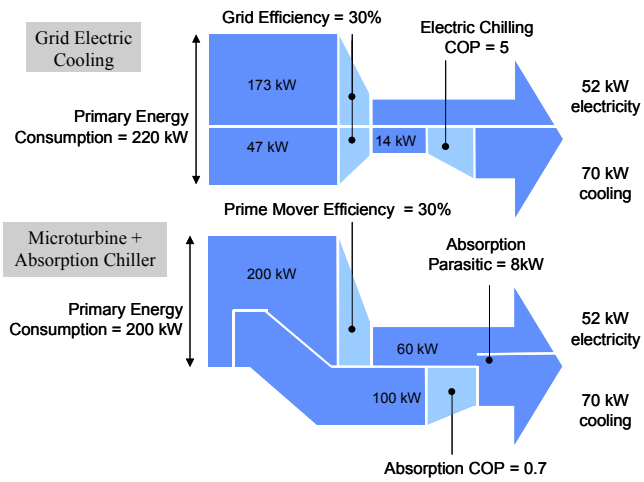

Figure 5: Energy Flows and Conversion in a Grid Electric System and One Utilizing CHP Cooling

The results displayed in Figure 6 show the large differences in PEC that are achievable through different CHP techniques. It is clear that displacing electric heating with the waste heat in the generator exhaust achieves the highest PEC savings of any CHP strategy. This is a result of the low overall efficiency of combusting fossil fuels to generate heat, converting this heat to mechanical work, then to electric energy and then transmitting it to the consumer where it is converted to heat again. The savings that are achieved by displacing electric heat are almost totally insensitive to prime mover efficiency. This effect can be explained by considering that if the prime mover is made 1 kW more efficient, this displaces about 3.3 kW of PEC, whereas if the efficiency were not increased, most of this would be seen in the exhaust as heat where it would displace about 3 kW of PEC as well. At the other extreme is a prime mover without heat recovery where the savings are entirely dependant upon efficiency.

Of all of the CHP applications, absorption chilling shows the greatest sensitivity to prime mover efficiency. Absorption chilling can only make small improvements in PEC when compared to a prime mover with no heat recovery for three main reasons: low COP of absorption machinery, parasitic electrical loads and low utilization of exhaust waste heat. The low utilization (50%) of exhaust heat is due to the small temperature difference between exhaust gases and the high stage generator of a double effect absorption chiller, reducing heat transfer into the chiller. Waste heat utilization would be much higher, (around 70%) if a single-effect absorption chiller were used since the generator temperature is lower and the temperature difference driving heat transfer is higher, but the net effect of this on energy savings is to reduce savings only slightly from that theoretically achieved by a double effect chiller since the COP of a single effect chiller is only 0.7. However, given the additional capital cost of a double effect chiller and the trend towards ever lower exhaust temperatures as the efficiency of modern prime movers increases, it is less likely that in commercial buildings in the US that the marginal increase in energy savings obtained from using double effect chillers over single effect can justify the use of double effect absorption chillers in waste heat recovery applications.

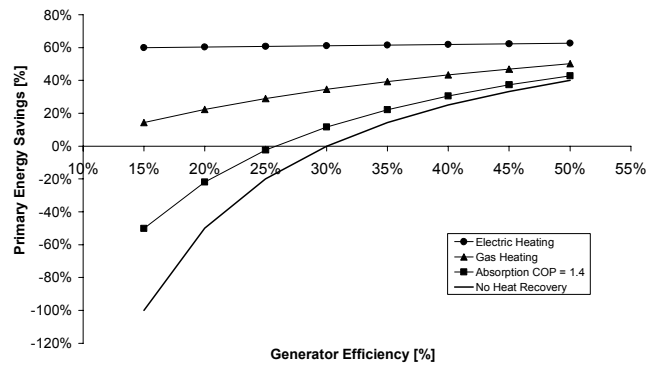

Figure 6: Primary Energy Savings of CHP Applications Compared to Grid Electric Equivalents and On-site Combustion

The other trend visible in Figure 6 is the decreasing value of any form of waste heat recovery as generator efficiency improves. This does not imply that the absolute energy or cost savings will not be substantial; a 1% improvement in efficiency at a 300 MW coal plant is worth about $2 million in saved energy annually. However in a CHP application where a 50% efficient generator displaces gas heat, 80% of the PEC savings could be achieved from operating the generator by itself. Additionally, a 50% efficient prime mover, especially at the scale required by many commercial applications not only produces a lower fraction of its PEC as waste heat, but will usually produce lower grade heat as well. For example, the exhaust from Proton Exchange Membrane fuel cells is usually below 100°C and this significantly decreases the exergy of their waste heat. Other types of fuel cells can however produce much higher-grade heat. It should be noted that the analysis in Figure 6 also assumes that regardless of efficiency the exhaust temperature necessary to run the waste heat utilizing equipment (notably absorption chillers) can be achieved. This may not be the case for all types of prime mover but the trends displayed of the decreasing relative value of waste heat recovery are still widely applicable when capital investment in waste heat recovery equipment and installation costs are considered.

Installation Complexity

Grid interconnect issues contribute to the complexity of CHP installations. Although the Institute of Electronic and Electrical Engineers (IEEE) is examining interconnection standards to facilitate safe and easy connection of CHP to the grid, currently there is no national uniform technical standard for grid interconnection. Typically, grid interconnection is controlled by the utilities and varies from state to state so CHP installations at one facility may not be the same for another. In addition, interconnect often requires individual interconnect studies and custom engineering to be performed prior to commencing the installation. The disagreements over interconnection requirements have in the past resulted in delays, and additional costs (Brent, 2001). Moreover, manufacturers

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have not been able to realize economy of scale cost reductions from plug and play interconnection because each interconnect is different from the next. Uniform interconnection standards will reduce interconnection costs while providing the safety and reliability required by grid owners and encouraging the deployment of clean, efficient and reliable generation.

Additional Opportunities

Since power costs fluctuate hour-by-hour depending on demand and generation availability, there are seasonal and daily time-of-use rate categories such as on-peak, off-peak, or shoulder rates. Customers who peak shave, or use on-site power generating equipment during relatively high-cost on-peak periods, can reduce operating costs significantly. Additionally, costly utility demand charges can be reduced as well. HVAC systems may not provide sufficient humidity control or meet the building's need for outside air. CHP systems that incorporate desiccant dehumidifiers can provide better humidity control over conventional systems and reduce the potential for mold and bacteria growth. CHP equipment is a potential source of highly reliable power for sensitive facilities, such as data centers or telecommunication facilities. They also provide a source of emergency or standby power that reduces demand on the electric grid and can prevent billions of dollars in economic losses from power interruptions (Dunn, 2000).

THE CHP INTEGRATION TEST CENTER – A CASE STUDY

The Chesapeake Building on the campus of a Maryland University houses the CHP Integration Test Center, which was established to explore the integration of advanced power generating equipment with waste heat activated technologies. The 52,000 ft^2 (4831 m^2) building was designed to be a platform for conducting research on advanced energy efficient and environmentally friendly building technology. Figure 7 shows the typical summer electric load for this commercial office building as well as the contribution of a proposed CHP system – not the system that is actually installed. This proposed system provides a base load of 150 kW to the building using a recuperated microturbine, which takes care of the typical electric requirements for commercial office buildings (57% of total load, See Figure 4) and satisfies most of the cooling requirements with a 40-ton (140 kW) single effect absorption chiller. If a desiccant dehumidifier is added to the system, further improvements in indoor air quality are gained by providing humidity control. In all, this system takes care of roughly 80% of the total building load.

CHALLENGES AT THE TEST CENTER

Some of the challenges of integrating thermally activated technology into a commercial building are more apparent after a summer of recording data at the Chesapeake Building where an absorption chiller and a solid desiccant unit using waste heat from a microturbine displace electric chilling and sub-cooling for space cooling and dehumidification. The energy flows and comparison to its grid electric counterpart is identical to that displayed in Figure 5, except that the efficiency of the microturbine is 27%, resulting in theoretical PEC savings of 8%. While reductions in primary energy consumption are not easily measured onsite, the average reduction in electrical power consumption for cooling can be a good measure of the effectiveness of a CHP cooling system and results from the test building after two summers of data collection are displayed in Figure 8 across a range of outdoor air enthalpies. Enthalpy was chosen as the basis for comparison because it includes the effect of increasing humidity as well as temperature on cooling load.

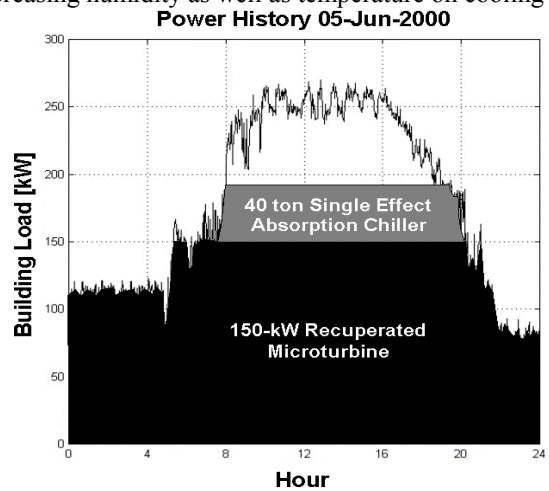

Figure 7: Typical Building Load

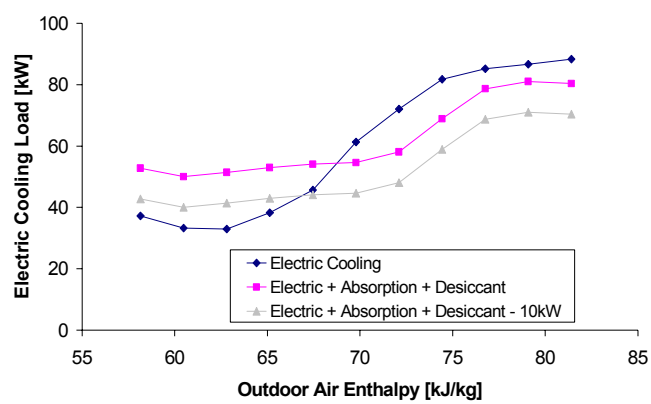

Figure 8: Average Electric Cooling Load from Collected Data at the Chesapeake Building over the Summer of 2000 and 2001

At low outdoor air enthalpy the combination system (CHP cooling) requires more electrical power than its electric counterpart, but once the outdoor air enthalpy is above 68 kJ/kg the CHP cooling requires, on average, less electricity. Outdoor air conditions are above this level for only approximately 30% of office hours in Maryland. This is the result of a combination of effects: auxiliary electric consumption, part load operation and the operation of the desiccant unit.

The CHP cooling systems has a relatively large auxiliary electric load, 8 kW for the absorption chiller, 8 kW in the desiccant unit, 3 kW for a high temperature fan between the microturbine and absorption chiller; totaling 19 kW. This is

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similar to the difference in power consumption exhibited at low outdoor air enthalpy in Figure 8. Reductions in auxiliary power consumption are certainly one of the most obvious targets for future energy savings. Figure 8 shows the likely result of the same analysis when auxiliary power is reduced by 50%, or 10kW. This would result in electrical savings across a wider range of outdoor air enthalpies.

Part load operation is complicated by three separate capacity control techniques: varying the amount of heat utilized by the absorption chiller, both compressor staging and hot gas bypass in the electric roof top unit (RTU), as well as the absence of effective capacity control in the desiccant unit. The controller in the RTU is hunting for supply air set point, the controller in the absorption chiller is looking only at the temperature drop across the retrofitted chilled water coil in the RTU and the desiccant controller is only concerned with humidity, not temperature. The effect of the three separate targets is particularly noticeable when the cooling load is slightly larger than the absorption chiller can provide in isolation. It is at these enthalpy levels where the worst conflict occurs. At high outdoor enthalpy, by contrast, all three pieces of equipment operate quite effectively together.

The last contribution to lowered effectiveness at low outdoor enthalpy is the operation of the desiccant. The relatively high power consumption (8kW) of the unit is justified in terms of energy savings only at very high humidity levels. However, the controller has not been programmed to save energy – only to control humidity independently of temperature. Humidity control using a desiccant running on waste heat can save energy but not when operated across all the outdoor air conditions where cooling is required. Deciding upon the combination of outdoor air conditions and chiller operation where the use of a waste heat activated desiccant is beneficial is a key control issue.

The importance of developing the relatively sophisticated controls necessary to operate these three items of equipment together to achieve their common goal of energy and cost savings should not be underestimated. While control is distributed rather than centralized it is challenging to make savings across all the outdoor air conditions where cooling is required.

CONCLUSIONS

Currently there is less existing CHP capacity installed in the commercial sector than in the industrial sector, even though the electrical power requirements of both sectors are almost equivalent. This is due to the technical difficulty of achieving high electrical efficiencies in generators of a scale appropriate to many commercial sites and the economic issue of low annual operating hours as well as large daily and seasonal fluctuations in energy requirements. The opportunities for commercial CHP should become larger as equipment is developed with higher and higher electrical efficiencies. Commercial CHP systems are likely to be more complex than their industrial counterparts and need to be engineered for the building type that they are to be installed in. Nonetheless, a wide pool of electrical generators and heat recovery equipment can be drawn from to build up the most appropriate system for the building and its geographic location. The benefit from some of these items of equipment may not be directly seen in energy cost savings – indoor air quality, humidity control and power reliability are a few of these additional benefits. Designed wisely, small-scale commercial CHP systems should be capable of delivering the benefits of systems currently only seen in sites much larger in scale to the sector of the market where much of the identified potential currently exists.

ACKNOWLEDGMENTS

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