FEDERAL ENERGY MANAGEMENT PROGRAM

DOE/EE-0234

Integrated Systems

Building high-efficiency heating, cooling, and power-generating facilities from gas-fired and electrically driven subsystems

Integrated systems bring together gas-fired and electrically driven equipment to provide heating, cooling, dehumidification, and electrical service to commercial and public buildings. The three principal configurations are (1) hybrid chiller plants incorporating gas-fired and electrically driven chillers, (2) desiccant dehumidifiers using waste heat from combustion of natural gas to regenerate the desiccant, and (3) combined heating, cooling, and power systems that include on-site electrical power generation with heating and cooling space conditioning and potable hot water production.

Energy-Saving Mechanism

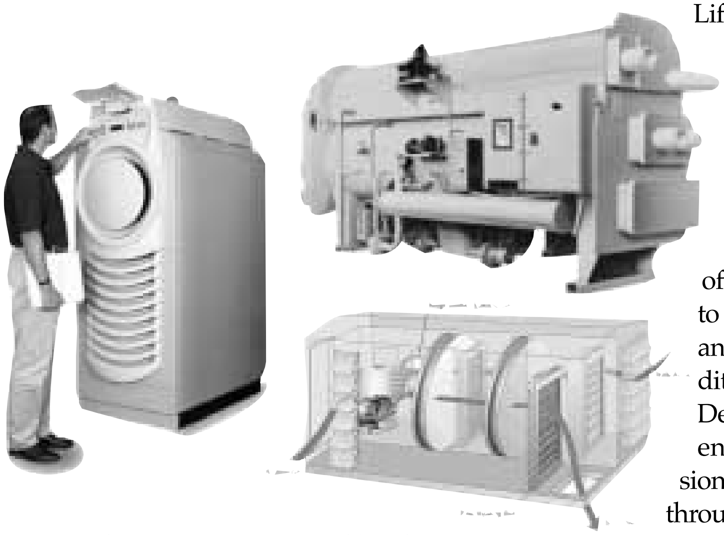
Principal energy savings are achieved through the use of waste heat from a combustion process to provide hot water or steam for other purposes. Additional benefits derive from reducing or eliminating use and costs of peak load electricity. On-site power generation can provide an overall energy savings through the elimination of transmission and distribution losses; primary benefit of on-site power generation remains elimination of utility peak demand charges and user control over power availability and reliability. Desiccant dehumidification using hydroscopic materials can be a more efficient process to remove moisture than conventional technologies that rely on overcooling and reheating ventilation air.

Application

A careful and rigorous analysis using hourly temperatures and loads is necessary in order to identify attractive applications of integrated systems. Circumstances can be favorable where there are high electric rates and low gas rates; special gas summertime or air-conditioning rates or rebates for installing gas air-conditioning equipment are helpful in achieving life-cycle cost savings.

There are several building types that can be attractive for integrated systems. These include buildings with high ventilation rates such as movie theaters and supermarkets because they have a much higher latent cooling load than most buildings and benefit more from desiccant dehumidification. Buildings with balanced electrical and thermal loads are attractive for on-site power generation or hybrid chiller plants because waste heat can be used for heating or hot water. Hospitals and hotels are good examples of these applications.

Life-cycle cost analysis should include site-specific installation costs and system performance using local weather and building loads. The efficiency and capacity of on-site power generation may degrade significantly with ambient temperature and altitude (some types of generators are much more sensitive to conditions than others); expectations and predictions based on design conditions can be extremely misleading. Desiccant systems must be carefully engineered, installed, and commissioned to avoid significant energy losses through increased fan and blower power and motors for wheel rotation.



Integrated systems offer improved building services and comfort.

Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

Prepared by the New Technology Demonstration Program

Technology Performance

There is very little performance history available to judge integrated systems. Hybrid chillers have been very successful as means of reducing summertime air-conditioning costs; most, however, are not run as truly integrated systems where both electric and gas chillers run simultaneously. Theoretically additional savings could be made by operating the chillers in a synergistic manner. Desiccant dehumidifiers are becoming a commercial success; regenerating desiccants using waste heat is rare and there is no performance history to report. On-site power generation is growing in popularity as electric demand charges rise and the electric grid becomes less dependable in the summer. Traditionally, waste heat has been recovered for space heating or hot water; there is very little history of waste heat use to drive absorption chillers or to regenerate desiccant dehumidifiers. There is also very little history concerning connecting on-site power generation with the utility grid; interconnection is a major issue and standards are needed to expedite licensing and power industry acceptance. New power generation technologies are being commercialized that could change the economics of on-site power generation. These include microturbines and fuel cells. There is no performance history of these technologies in integrated systems.

Case Study

A case study is presented for a hybrid chiller plant comparing two 400-ton centrifugal chillers with one 400-ton centrifugal and one 400-ton absorption chiller. The life-cycle cost of the hybrid chiller plant can be higher or lower than the electric chiller plant depending on gas utility incentives such as air-conditioning gas rates and equipment rebates.

Technology in Perspective

Developments in the integration of on-site power generation, heating, cooling, and dehumidification are moving rapidly as a result of the changing economics of commercial building electric rates. Many combinations of integrated systems will be demonstrated in the 2000 to 2003 time frame. Until then, applications other than hybrid chiller plants are on the leading edge of energy technology and have a high risk factor. Among the near-term developments will be wider commercialization of skid-mounted integrated systems built-up from pre-engineered modules, leading to significantly lower equipment costs, faster licensing of standardized systems, and reduced risks.

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Federal Technology Alert

Integrated Systems

Building high-efficiency heating, cooling, and power-generating facilities from gas-fired and electrically driven subsystems

Micro-Turbine Generator, Desiccant Dehumidifier, and Absorption Chiller

Abstract

Integrated systems employ gas-fired and electrically-driven equipment to provide heating and cooling for space-conditioning and hot water, dehumidification, and possibly on-site power generation. While similar systems can be used in industrial applications employing waste heat from manufacturing processes, they are not discussed in this report. There are at least three major aspects of integrated systems: (1) hybrid chilled water plants incorporating gas-fired and electric-driven chillers, (2) desiccant dehumidification systems using process waste heat to regenerate the desiccant, and (3) on-site power generation using waste heat for space conditioning, water heating, or heat actuated cooling. System energy efficiency is increased significantly in these applications when waste heat from one component of the integrated system is used by a second component (e.g., waste heat from power generation used to provide hot water for laundry facilities or for space heating, heat from engine-driven chiller used to regenerate desiccant in desiccant dehumidifier). Cost savings are possible by reducing electrical demand charges. Integrated systems are best suited to buildings with large cooling loads or buildings with balanced and simultaneous electrical and thermal loads. Equipment costs for integrated systems have been prohibitive for small applications, but reductions in the costs for microturbines or fuel cells and changing electric rate structures could make small-scale integrated systems more attractive.

The combinations of technologies (e.g., power generation, absorption chillers, natural gas engines, desiccant dehumidifiers) generally require additional training and experience of building engineering and maintenance personnel. Subsystems are introduced that are fundamentally different than conventional HVAC technologies; maintaining each individual component and balancing overall system operation requires new knowledge and skills

Many combinations of gas-fired and electrically driven heating, cooling, and power generation equipment are possible that provide higher system efficiencies, lower utility costs, or both. Dramatic energy savings occur in systems which take advantage of waste heat from power generation or engine-driven chillers. Hybrid chillers are an established technology for reducing operating costs that are becoming increasingly attractive under electrical deregulation. Integrated systems with desiccant dehumidification are fairly recent innovations and are proving attractive in some applications. Combined power generation, heating, and cooling is a new technology without an established performance record.

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About the Technology

"Integrated systems" combine electric and gas-fired equipment for building services in a synergistic manner to reduce overall system energy input or operating costs. Building services can include comfort space conditioning (both heating and cooling), water heating, dehumidification, and electrical power generation. Similar systems employing waste heat from manufacturing processes can be used in industrial applications, but they are not discussed in this report. The equipment to provide these services can be quite common and conventional (e.g., electric chillers, IC engine-generator sets) or new and innovative (e.g., fuel cells, microturbine generators). A partial list of equipment that can be used in integrated systems includes gas boilers, gas-fired absorption or engine-driven chillers, desiccant dehumidifiers, and electrically driven chillers as well as conventional engine-driven generators, microturbines, and fuel cells for on-site electrical power generation.

Some of the types of equipment that can be used in integrated systems may be unfamiliar to the reader:

- ***desiccant dehumidifiers*** use a rotating wheel or liquid spray to chemically remove water vapor from ventilation air and then subsequently use heated building exhaust air to remove moisture from the desiccant wheel or liquid.
- ***absorption chillers*** produce chilled water for air conditioning by a reversible chemical process of absorbing refrigerant vapor into a chemical solution at low temperature and using heat to desorb it at high temperature and pressure.
- ***fuel cells*** produce electricity through a chemical reaction of hydrogen and oxygen instead of the conventional combustion of fossil fuels.
- ***microturbine generators*** are small versions (25 to 300 kW) of turbine-generators on a scale suitable for producing electricity for single-building applications; multiple units can be used to achieve higher capacities for larger buildings.

System energy efficiency can be increased significantly in applications where waste heat from one component of the system can be used by a second piece of equipment. Additional benefits are possible by reducing electrical demand charges. Buildings with balanced, simultaneous electrical and thermal loads are good candidates for integrated systems as are buildings with large water heating loads. Equipment costs for integrated systems are generally prohibitive for small applications but may be advantageous in special circumstances or where waste heat is available.

The concept of integrated systems can be illustrated with a couple of examples. First, consider an office building cooled by a natural gas-fired absorption chiller with a desiccant dehumidifier. Moisture is removed from the air by using a desiccant wheel. The absorption chiller then provides sensible cooling and leftover waste heat from the combustion of natural gas used to power the chiller is used to "regenerate" the desiccant. Waste heat recovery and desiccant systems can also be combined with engine-driven chillers or on-site power generation to provide similar savings.

A second configuration for an integrated system would combine an absorption chiller with an electrically driven centrifugal chiller for air conditioning a large building. Traditionally one or two large, electrically driven chillers would be used in this application. Splitting the cooling load between two chillers, one using natural gas and the other using electricity, gives the building operator an additional tool in managing utility costs depending on the rate schedules for gas and electricity. Cooling plant operation is tailored to minimize costs considering demand charges, fuel costs, and system efficiencies. Either the gas chiller can be used, the electric chiller, or the two in tandem to provide the required cooling at the lowest cost. This configuration may or may not provide an overall reduction in energy consumption. An engine-driven chiller could also be used in tandem with an electrical chiller in this configuration.

Finally, a third configuration of an integrated system could combine on-site power generation with a hot water heat recovery system and an electrically driven centrifugal chiller. The overall system efficiency is improved dramatically by the heat recovery for potable hot water or building space heating. Depending on equipment requirements it may be possible to use waste heat from power generation to regenerate a desiccant for dehumidification or power an absorption chiller for additional air-conditioning capacity. The amount and temperature of waste heat available needs to be matched with the requirements of the desiccant or absorption equipment. In each instance, an integrated system consists of matching gas and electrically driven equipment to work together to provide building services.

Application Domain

The high initial cost of integrated systems has resulted in relatively few installations, but systems are being installed with increasing frequency to reduce electrical costs. There are hundreds of installations of hybrid chiller plants using absorption or engine-driven chillers in conjunction with electric chillers. While there are a great many installations of desiccant dehumidifiers with evaporative or compression cooling, there are few that employ waste heat to regenerate the desiccant. Finally, there are probably fewer than five installations of on-site power generation with waste heat actuated cooling operating in the United States. All known building combined cooling, heating, and power systems in the United States began operation in 1998 or later. There are a great number of Federal buildings where integrated systems could be employed in one configuration or another. Specific applications of what can be done depend on what equipment is commercially available.

Integrated systems have been built from custom designs using commercially available, independent "subsystems" rather than being marketed from standardized designs from an individual manufacturer or supplier. The list of possible subsystems include conventional electric-driven air-to-air vapor compression air conditioners and electric-driven chillers, gas-engine driven chillers, direct and indirect-fired absorption chillers, solid and liquid desiccant dehumidifiers, engine-generators, microturbine generators, and natural gas fuel cells. There are many well established manufacturers of the conventional electric air conditioners and chillers spanning the range of less than one ton to several thousand tons of cooling capacity.

There are at least nine manufacturers of desiccant dehumidification systems with drying capabilities covering the range from 3 to 670 lbs of water per hour and air flows of 300 to 84,000 cfm. This equipment spans the range of small to reasonably large building cooling loads; desiccant dehumidification has been used with success in quick service restaurants, movie theaters, supermarkets, and hospitals.

Combinations of equipment for hybrid chiller plants depend on the availability of absorption, engine-driven, and electric-driven chillers. Double-effect absorption chillers are available commercially from at least six manufacturers in the U.S. The cooling capacity of this equipment ranges in size from 20 to 1700 tons (70 to 6000 kW). Engine-driven chillers are available from at least seven manufacturers and range in capacity from 15 to 4000 tons (53 to 14,000 kW). HVAC manufacturers produce electric chillers in capacities from 2 to 10,000 tons (7 to 35,000 kW).

Integrated systems for combined cooling, heat, and power depend on the availability of conventional engine-generator sets, microturbines, or fuel cells for electric power generation. There are only two known manufacturers of microturbine electrical generators in the United States although several other companies are preparing products that will be available in 2000. There is only one commercial manufacturer of small capacity (200 kW) fuel cells. There are at least two manufacturers of pre-engineered skid-mounted integrated systems incorporating power generation with heat recovery and hot water, chilled water, or steam services.

Energy-Saving Mechanism

Energy savings from integrated systems is primarily the result of replacing purchased energy with recovered waste heat for potable hot water, comfort heating or cooling, or desiccant regeneration. Hybrid chiller plants generally provide significant savings in energy costs by replacing electricity use at peak load periods with natural gas, but they do not necessarily reduce overall energy consumption. Some reductions may be possible when the electric chiller is used concurrently with a gas absorption chiller in such a way as to maximize the gas chiller efficiency.

Desiccant dehumidification can yield direct energy savings as a more efficient means of providing sensible cooling than electric compression equipment. Desiccant dehumidifiers use a chemical process to remove moisture from the air that can require much less energy than conventional air conditioning systems. The "traditional" method of dehumidification relies on chilling the supply air below the dew point temperature so moisture condenses on the outside of heat exchanger tubes or fins. This process requires cooling the air below the level needed for comfort and subsequently reheating the air; the colder the air needs to be for dehumidification, the less efficient the cooling process is. Instead of blowing air across a cold heat exchanger to remove moisture, desiccant dehumidifiers blow across surfaces or through liquid sprays containing chemical compounds with lower vapor pressures than the supply air. The difference in vapor pressure causes water molecules to be adsorbed onto the surface of the desiccant or chemically combined with it.

Practical applications of desiccants in HVAC systems require that the moisture be removed from the desiccant so it can be reused. Some, but not all, desiccant materials can be regenerated at the temperatures of waste heat streams from on-site power generation or absorption and engine-driven chillers; other desiccant materials require electric or gas heaters to achieve the necessary regeneration temperatures. Figure 1 shows one configuration for incorporating a desiccant wheel into an integrated system.

Comparing the "traditional" dehumidification with desiccant systems, less energy is required to regenerate the desiccant to satisfy the latent cooling load (moisture removal) than is needed by a conventional air conditioner to chill the air stream below the dew point so water condenses on the evaporator. Desiccant dehumidifiers are particularly attractive in applications where there is a source of waste heat that is available to regenerate the desiccant.

While the chemical process described above requires less energy to dehumidify the air than the mechanical one, there are two factors that reduce the energy savings. First, as water is removed from the air using a desiccant, the air is heated in the process. Approximately 1000 Btu are added to the air for every pound of water removed. An additional cooling process has to be added to create a dehumidification/cooling system that provides the same level of comfort as the conventional mechanical systems. The cooling can be provided by a vapor compression system chilling the air just

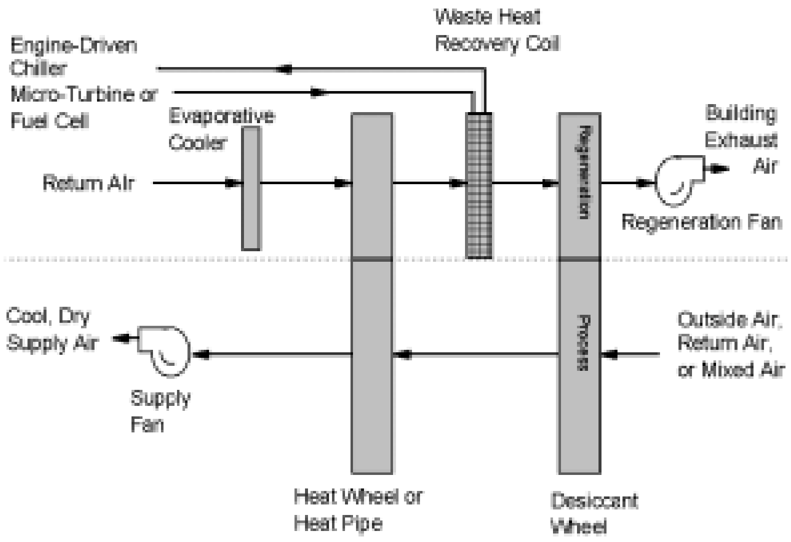

***Figure 1**. Two-wheeled desiccant dehumidifier.*

down to the temperature necessary for comfort or by an indirect evaporative cooling system. Evaporative cooling is the reverse of desiccant dehumidification; it cools air by adding water to it. An indirect system is used so that water is added to the building exhaust air and a heat exchanger is used to cool the building supply air.

There is also an increase in "peripheral" energy consumption for desiccant systems relative to conventional HVAC systems. Liquid desiccant dehumidifiers require energy for pumps that are not a part of conventional systems. Solid desiccant dehumidifiers employ honeycombed wheels that rotate through the supply air flow. The pressure drop across the desiccant wheel can be much greater than it is across the evaporator in a conventional system requiring higher blower power. The electric motor used to rotate the desiccant wheel also uses energy as may additional components added to the desiccant system to boost its efficiency.

The principal benefit in using chiller plants containing both gas and electrically driven equipment is to reduce electrical consumption, particularly at peak load periods. This can lead to large cost savings, but not necessarily energy savings. The hybrid chiller plant can be designed in a manner such that the electric chiller pre-cools the inlet water for the absorption chiller (or vice versa). This trades off the operation of one machine at less than optimal conditions in order to run the second machine at higher efficiency. There may be an overall net increase in efficiency for the combined machines as a result.

The energy savings in combined cooling, heating, and power are seen when looking at the entire "power cycle." Normally, the generation of electricity is done at a remote location and large amounts of heat are rejected to the air or nearby rivers, streams, or lakes. If the power plant is 35% efficient, then 65% of the energy content of the fuels is being rejected to the environment.

If a building requires electricity, heating, cooling, or hot water at the same time, energy is provided for each of these services separately. Combined cooling, heating, and power systems use engine-generator sets, microturbines, or fuel cells to generate power on-site. The primary energy savings come from recovery and use of waste heat from the power generating process (there can also be savings on the hottest days and highest cooling loads depending on the efficiency of the utility generators used at those times and electrical transmission losses). Hot water can be produced by the waste heat for space heating or domestic hot water uses (e.g., laundry, dish washing, bathing). Steam can be produced for space heating or to power absorption chillers for air conditioning or to regenerate a desiccant. Making use of the waste heat reduces the amount of energy that would have been required to provide these services and boosts system efficiencies to as high as 80%.

Other Benefits

All three major types of integrated systems provide additional benefits. Hybrid chiller systems provide the potential for significant cost savings by reducing electric demand charges. They give the building operators a capability of changing their source of energy during the day or through a season using the least expensive fuel as operating load and energy costs vary. While the "baseline" system may operate on electricity, the gas-fired system can be brought on line during peak loads to keep utility load charges at a minimum. Engine-driven chillers have the additional advantage of being able to modulate their cooling capacities by varying engine speed which increases part-load efficiency and follows the building load more closely without cycling on and off. Desiccant systems are recognized as providing intangible benefits by improving indoor air quality and comfort. Also, by operating strictly in the vapor phase of water, there is no opportunity for water to condense in the duct work providing an environment for mold and bacterial growth. In many remodel situations or retrofit applications, desiccant dehumidification or gas cooling can eliminate large expenses necessary to upgrade the building's electrical service. On-site power generation allows building operators to maintain electrical service during brownouts, rotating outages, or transmission failures on hot summer days when the regional electrical grid is overloaded.

Variations

By nomenclature alone, integrated systems include any combination of dissimilar subsystems designed or assembled in such a manner that they work in conjunction with each other at a higher efficiency or lower cost than they would operate individually. There are many variations within the subsystems themselves that can be used, so naturally there are a great many variations within integrated systems. Desiccant dehumidification can be performed using solid or liquid desiccants, with evaporative or compression cooling systems, or with thermal wheels to transfer heat between supply and exhaust air streams. On-site power can be generated using conventional IC engine-driven generators, microturbine generators, combustion gas turbine generators, fuel cells, wind-turbines, or photovoltaic generators. Gas-fired water chillers can be engine-driven or direct or indirect fired absorption cycles; they can be used alone or arranged with electric-driven chillers in hybrid plants in series, parallel, or side-stream configurations.

Data on on-site generating technologies is listed in Tables 1 and 2. Traditionally, reciprocating IC and diesel engine-generator sets have been used for emergency back-up power and on-site power generation. Combustion gas-turbines are also available for large installations, while microturbines are coming onto the market for small to medium sized applications. Fuel cells are being developed and capacities could be available covering the range from very small to large installations.

Microturbines are very promising equipment for on-site power generation, and they are attracting a lot of attention. Their use should be considered very carefully to avoid unwarranted expectations. First, microturbines employ internal heat recovery using recuperators to preheat the combustion air, as illustrated in Figure 2, which reduces the available thermal energy for an integrated application. Eliminating the recuperator to have exhaust heat for other uses reduces the generating efficiency by about 50%. Microturbine generating capacity is also sensitive to inlet air temperature and altitude; economic analyses must be performed using actual operating conditions rather than being based on microturbine design capacity. Among their advantages, microturbines have extremely low NO_x emissions and noise levels. They also have fewer moving parts, lower weight and smaller equipment footprint than conventional generation technologies and do not require cooling towers or radiators. They do require high pressure natural gas or a gas compressor; they are not able to start under large loads or follow large transients. Microturbines are well suited for base load applications but cycling mode will degrade component lifetimes; economic analyses in those applications need to factor in higher parts and maintenance costs resulting from frequent starts and stops. Further development work is being performed to improve the power electronics and gas compressors;

***Table 1**. Capacity, efficiency, and cost data for power generation systems.*

Power System	Capacity Range	Electrical Efficiency (HHV)	Capital Cost ($/kW)	Operating & Maintenance Cost ($/kWh)
Reciprocating Engine	20 kW to 20 MW	28% to 45%	$500 to $1400	$0.007 to $0.02
Microturbine	~25 to 300 kW	~20% to 33%	$600 to $1000	$0.003 to $0.01
Gas Turbine	500 kW to 150 MW	21% to 40%	$600 to $900	$0.003 to $0.008
Fuel Cell	5 kW to 3 MW	36% to 60%	$1900 to $3500	$0.005 to $0.10
Stirling Engine	~200 W to 100 kW	20% to 36%	$1000	not available
Rotary Engine	~5 kW and up	20% to 30%	not available	not available
Photovoltaic	1 kW to 1 MW	6% to 19%	$6600	$0.001 to $0.004
Wind Turbine	10 kW to 1 MW	25%	$1000	$0.01

Table 2. Advantages and disadvantages of technologies for on-site power generation.

Generating Technology	Advantages	Disadvantages/Problems
Microturbine Generators	• high reliability • compact and modular design • low maintenance and operating costs • low emissions and noise • ease of operation	• requires high pressure gas or gas compressor • not able to start under large load or follow large transients • power electronics need further development • may be life cycle problems with recuperator • performance sensitive to temperature and altitude
Reciprocating Engine-generator Sets	• runs well on part loads • suitable for start/stop operation • can be sized for lower electrical loads • follow electrical and thermal loads • insensitive to temperature and altitude	• emissions • noise • efficiency
Combustion Gas Turbine Generators	• reliable technology • high efficiency • low maintenance requirement • high quality heat: 20,000-25,000 lb/h 125 psig steam (5 MW plant)	• need to be run on constant load • not suitable for start/stop operation
Fuel Cells	• high efficiency • high output power quality • no moving parts • very low emissions • low noise	• poor ability for multiple starts • poor ability to follow large, rapid transients • high capital cost • availability • not a firmly established technology
Photovoltaic and Wind Generators	• pollution free	• dependent on availability of environmental resources

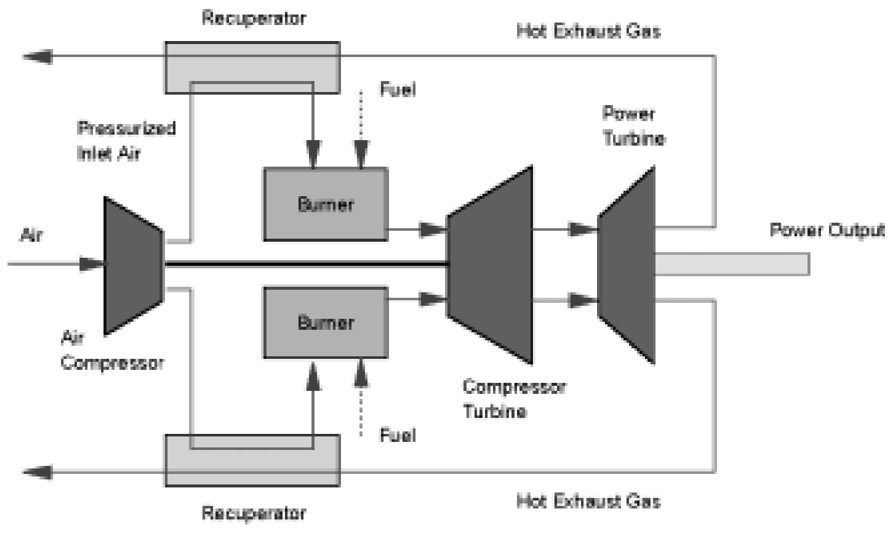

Figure 2. Schematic diagram of a microturbine generator.

there may be life-cycle problems with the recuperators.

Electric and gas-fired absorption or engine-driven chillers can be configured in several different manners in order to take best advantage of the characteristics of each machine. There is a very good, concise description of four common arrangements in *Cool Times* (1997):

- "Series: a series of connected chillers, as shown in Figure 3, can be used in high ΔT chiller plants. They are especially popular because this arrangement is capable of taking advantage of the high temperature preferences of absorption chillers and the low temperature capabilities of vapor compression chillers. The disadvantage

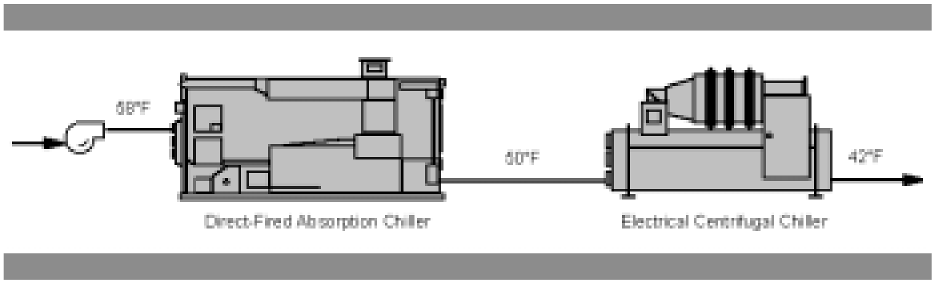

Figure 3. *Series configuration of gas and electric chillers.*

of this arrangement is the potential for high pressure drop in the system, resulting in higher pumping energy.

- **Parallel**: the parallel arrangement in Figure 4 is probably the most common arrangement in chilled water plants with two or more chillers. This arrangement is simple and reduces pressure drops and pumping power, but does not always have the flexibility to preferentially load a specific chiller to manage utility costs.
- **Sidestream**: the sidestream arrangement in Figure 5 is becoming more popular in hybrid chiller plants, especially plants with multiple electric chillers and a single peak shaving absorption or engine-driven chiller. This system provides the advantages of a series arrangement without the disadvantages of high pressure drops. The absorption (or engine-driven) chiller can operate in parallel with the electric chillers using the bypass line or it can operate in series to prechill the return water to the electric chillers and reduce their electrical load.
- **Ice**: hybrid chiller plants can also be used for ice or chilled water storage. The electric machine is used to produce ice during off-peak times while the absorber and ice storage system operate during peak electric demand periods. Engine-driven chillers can be used as back-up to make the ice at off-peak times because they can achieve the low temperatures required by ice storage systems.

The advantages and disadvantages of each configuration are discussed in more detail in publications by the American Gas Cooling Center (*Technology Transfer Workshop Workbook for Integrated System Design and Technology Transfer Workshop* (*TTW*)*: Integrated Systems Design*).

Combined cooling, heating, and power systems integrate power generation with chillers or compression air conditioners, desiccant dehumidification and cooling systems, and / or waste heat utilization for space conditioning or hot water generation. Such a system is illustrated in Figure 6. This shows a microturbine that generates electricity to power an electrically driven centrifugal chiller and to meet the other electrical loads of the building (e.g., fans and blowers, lighting). Steam or hot water from a heat recovery heat exchanger in the exhaust from the microturbine is used to power an indirect-fired absorption chiller, heat the building exhaust air to regenerate a desiccant wheel, and to provide building space heating. Chilled water from the chillers is also used to cool the ventilation air after it is dried by the desiccant wheel. Typically an integrated system would not include all of these subsystems, and in fact waste heat temperatures may be too low for many of them to be used effectively.

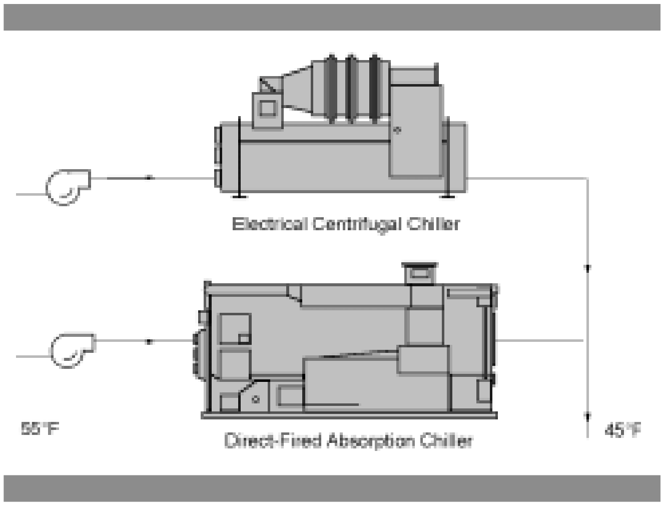

Figure 4. *Parallel configuration of gas and electric chillers.*

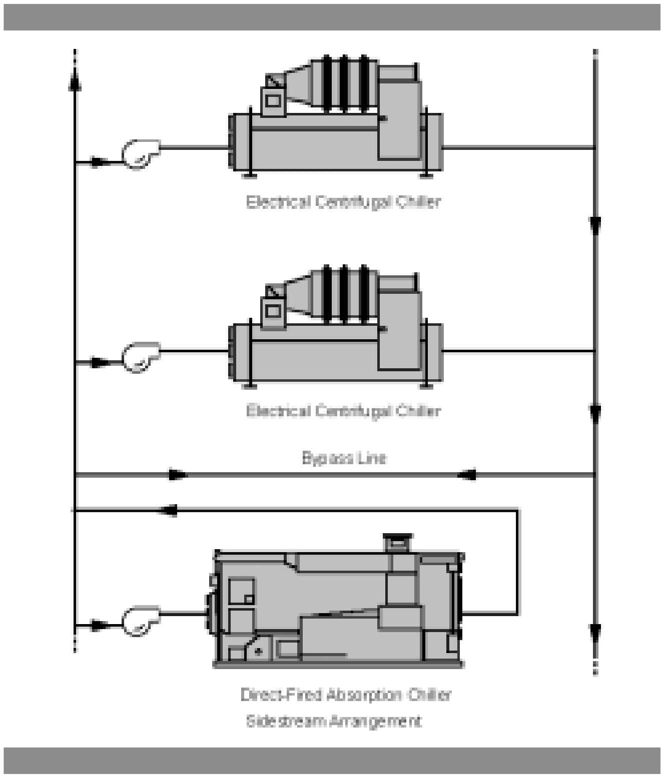

Figure 5. *Sidestream configuration of gas and electric chillers.*

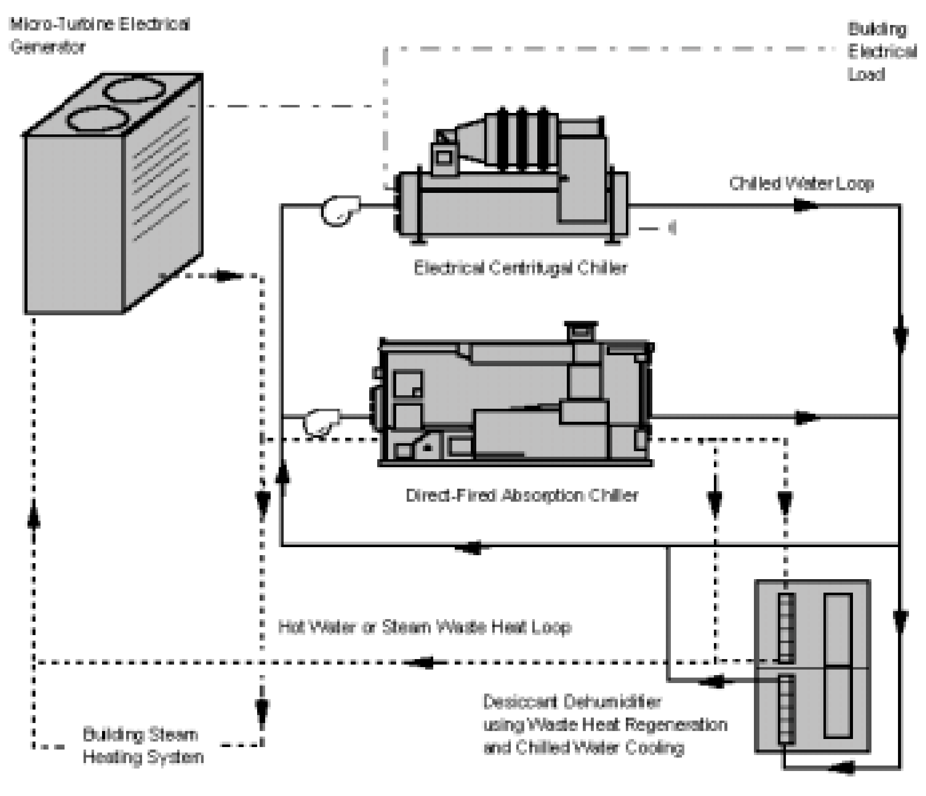

Figure 6. *Combined cooling, heating, and power system.*

Federal Sector Potential

Federal Technology Alerts target technologies that appear to have significant untapped Federal-sector potential and for which some installation experience exists. Integrated systems are recognized for their potential in reducing energy consumption, costs, and emissions.

Technology Screening Process

The new technologies presented in the *Federal Technology Alert* are identified primarily through direct submitals from Federal agencies to the Program's Interlaboratory Council (ILC). The ILC also identifies new technologies through trade journals, product expositions, trade associations, other research programs, and other interested parties. Based on these responses, the technologies are evaluated by the ILC in terms of Federal-sector potential energy savings, procurement, installation and maintenance costs. They are also categorized as either just coming to market or as technologies for which field data and experience exist. Integrated systems were judged to have notable potential and to be life-cycle cost-effective in the proper applications. Integrated systems were selected for the New Technology Demonstration Program by the ILC. Several other technologies are slated for future *Federal Technology Alerts*.

Estimated Savings and Market Potential

No estimate of nationwide energy savings is available for integrated systems. Discussions within the industry focus on the potential market for combined cooling, heating, and on-site power generation where an estimated 75 GW of capacity is economically justified. This potential market is divided primarily between buildings for education (27%), health care (24%), office buildings (21%), food sales and service (10%), and lodging (7%). The extent of cost-effective heat recovery and energy savings potential in these markets is not known.

Laboratory Perspective

Integrated systems have existed in the form of hybrid chiller plants since the 1970s, but they attracted increased attention in the 1990s because of deregulation of the electric industry. Increased demand charges, time-of-day rates, and real-time pricing of electricity change the economics of hybrid chiller plants significantly and make them attractive as a means of managing building energy costs. These systems have been demonstrated to be cost-effective in some gas and electric rate structures.

Integrated systems incorporating on-site power generation and desiccant dehumidification are relatively new technologies. Interest in using these systems is due to both electric utility deregulation and to technology advances in microturbine generators and desiccant materials. Concerns about "sick building syndrome" and indoor air quality are also leading to higher standards for ventilation rates resulting in increased latent cooling loads. Increased latent loads improve the economics of desiccant dehumidification and incorporation of desiccant dehumidification in integrated systems. Demonstration projects employing microturbines, advanced desiccant materials, and integrated systems employing these technologies together or in conjunction with gas-fired chillers were initiated in 1998 and 1999.

Application

Application Screening

Unfortunately there are no rules of thumb that help simplify the determination of where integrated gas and electric systems are practical. The decision is fundamentally the result of long-term gas and electric rates, electric demand charges, equipment costs, and building space conditioning loads. Summer air conditioning gas rates and/or utility rebates are virtually essential to achieve cost savings; discounts and rebates from equipment manufacturers help. Economics are probably unfavorable if none of these conditions exist.

Where to Apply

Integrated systems normally have higher initial costs and maintenance costs than conventional HVAC systems, by their very nature, and consequently are of interest primarily where there can be significant reductions in operating energy costs. Cost savings occur because of favorable gas to electrical price ratios, avoided electrical demand charges, one-time gas utility rebates or incentives to install gas-cooling equipment, and reductions in purchased energy through the use of waste heat from one of the components in the integrated system by another. The types of subsystems that are combined to form an integrated system will depend on the advantages and disadvantages of each as they pertain to the particular application.

Desiccant dehumidification systems may be cost-effective in several general instances depending on indoor requirements, building usage and occupancy, and ventilation or fresh air intake. Some of these are enumerated in the FTA *Two-Wheel Desiccant Dehumidification Systems* and include:

- level of indoor humidity; dehumidification cannot be achieved below 40°F dew point using conventional vapor compression equipment; this is rare in commercial and office building applications,
- high latent load fraction (>25%); latent loads are normally below 25% in office buildings but may be higher in supermarkets, movie theaters, schools, and auditoriums,
- fresh air intake; buildings with unusually high fresh air intake (>20%) such as those listed above, particularly in humid climates,
- demand and energy costs; high summertime demand charges and electrical rates coupled with low gas rates, and
- availability of free or inexpensive regeneration energy; sources of waste heat such as boilers, refrigeration condensers, engine-driven or absorption cooling systems, or fuel cells capable of providing air heated to 180° to 220°F.

Desiccant dehumidification can also be attractive in retrofit applications where additional cooling capacity is needed and site specific factors (e.g. upgrading building electrical service, available space) make increased electric chillers capacity expensive.

The advantages of hybrid chiller plants lie primarily in reductions of electrical demand charges, though there can be gains in chiller plant efficiencies through substitution of multiple smaller capacity chillers for a single large chiller with poor part load performance. Combinations of gas-fired absorption or engine-driven chillers with electrically driven chillers should be considered in equal or unequal capacities in applications where electrical peak rates and demand charges are high and gas prices are low. Special consideration should be given where low summertime gas rates or special air conditioning gas rates are available. Hybrid chiller plants can also be very attractive in retrofit applications where additional cooling capacity is required and use of electrically driven chillers by themselves would require an expensive upgrade of electrical service to the building.

Combined cooling, heating, and power can be cost-effective where electrical use rates and demand charges are high relative to gas rates. On-site power generation may be cost-effective through reduction in demand charges or peak rates for electrical consumption alone. It may not be cost-effective without the use of waste heat for space and/or water heating and "free" cooling from desiccant dehumidification systems or absorption chillers. The data in Table 3 can be used with information from preceding tables to scope out the components

Table 3*. Approximate sizing of electrical load and building types.*

Magnitude of Electrical Load	Type of Application
• >1 MW	• large high-rise office buildings • largest hospitals • largest hotels • large shopping malls
• 200 kW to 1 MW	• hospitals (200 to 300 beds) • large hotels (750 rooms) • office buildings (200,000 ft^2) • schools (125,000 ft^2) • large retail buildings
• 50 to 200 kW	• office buildings (50,000 ft^2) • average hotel (75,000 ft^2, 125 rooms) • multi-family residences (100 units)
• 10 to 50 kW	• fast food restaurant (4,000 ft^2) • small office building (10,000 ft^2) • multi-family residences (<25 units)
• ~10 kW peak load • 0.50 to 1.5 kW average load • 0.10 kW base load common • little coincidence of electrical and thermal loads	• single-family residence

of an integrated system for a particular building as a step in generating some cost estimates. A detailed, hourly simulation of electrical and thermal loads using actual building data and utility rates with typical weather data is necessary to evaluate the savings generated through waste heat recovery. Waste heat is valuable for space heating or cooling purposes only if it is available when heating or cooling is required.

What to Avoid

Careful design and matching of components is required for integrated systems, particularly combined cooling, heating, and power. Microturbines and fuel cells are more appropriate for on-site power generation than other engine-driven generators because of their low emissions and projected low maintenance costs.

Communication and planning with electric utilities and government air quality agencies may be necessary to avoid delays or obstacles to installing and licensing an integrated system. Stringent state or local regulations may restrict the use of some gas-fired chillers. Licensing delays may arise for systems employing on-site power generation because of air quality standards that were written to regulate emissions of nitrogen and sulphur compounds from large utility operated power plants based on emissions per unit electrical production (g/kW_e). Regulations may not directly recognize the benefits of on-site power generation with waste heat recovery where emissions can be viewed in terms of mass per unit useful energy (g/kW_e+kW_t). Good preparation and communication with the governing authorities can reduce or eliminate licensing problems. It is also necessary to coordinate with local utilities and electric distribution companies. A significant amount of time and effort may be required to resolve issues concerning interconnection with the local utility grid. Electrical utilities may also impose exit fees on users installing gas-fired air conditioning or power generation equipment because of the costs incurred by the utility from abandoned capacity. Anticipation of future plans for use of gas-fired equipment, and communication of those intentions to electrical utilities can be effective in reducing or eliminating exit fees.

Equipment Integration

Desiccant dehumidifiers can be integrated into conventional vapor compression air conditioning systems in order to handle the latent cooling load, but they have greater potential when teamed with gas-fired cooling equipment or with on-site power generators. Desiccant wheels or liquid desiccants need to be regenerated with heat which removes or desorbs the moisture from the desiccant so it can be vented to the outside air. Typically electric heaters, heat reclaim coils, steam coils, or gas burners are used to provide the heat of regeneration. Each of these processes incur a fuel cost. Waste heat may be a source of "free" energy to perform this job. Regeneration temperatures vary depending on desiccant materials, airflow velocities, and rotational speeds of the desiccant wheel. While some materials can be regenerated at about 140°F (E-Source p. 6.5.2) most require temperatures of 190° to 230°F. Waste heat from a power generator or from an absorption or engine-driven chiller may be able to provide the heat of regeneration without any additional energy cost. Temperature and heat requirements need to be matched between the desiccant equipment and the source of waste heat; waste heat "availability" is summarized in Table 4, and waste heat requirements

***Table 4**. Heat recovery, maintenance schedule, and emission data for electric generating systems.*

Power System	Maximum Heat Recovery Temperature (°F)	Heat Recovery (Btu/h per kW)	Expected Time Between Overhaul (operating hours)	NO_x Emissions (ppm)
Reciprocating Engine	~200°F water jacket 750° to 930°F exhaust	~4000 to 10,000	25,000+	20
Microturbine	~500°F	~4000 to 12,000	40,000+	<1
Gas Turbine	930° to 1100°F	not available	not available	not available
Fuel Cell	140° to 180°F (PEM) 390°F (PAFC) 1100° to 1400°F (SOFC) ~1100°F (MCFxC)	~3500 to 4000	40,000+	~1
Stirling Engine	~160°F to 200°F	~6000 to 12,000	up to ~60,000+	not available
Rotary Engine	~300°F water jacket ~1600°F exhaust	not available	not available	not available

PEM: proton exchange membrane fuel cell, PAFC: phosphoric acid fuel cell, SOFC: solid oxide fuel cell, MCFC: molten carbonate fuel cell for absorption and desiccant systems are listed in Table 5.

Engine-driven chillers can be integrated with desiccant dehumidifiers or absorption chillers. Waste heat can be recovered from the cooling water or the exhaust gases from engine-driven chillers as hot water at temperatures of up to 230°F or as low-pressure steam. The heat can be used to regenerate desiccant wheels or to drive indirect-fired absorption chillers. Temperatures are a closer match for desiccant regeneration or single-effect absorption chillers than they are for double-effect absorption chillers. End-use temperature requirements may limit the use of waste heat to preheating to reduce some of the energy input required by desiccants or absorption chillers. Figure 7 shows data for recoverable waste heat from commercially available engine-driven chillers as 1000's of Btu/h per ton of chiller capacity. While there is broad scatter in the data for small capacity chillers, the recoverable waste heat is fairly constant at approximately 2750 Btu/h per ton for chillers above 500 tons capacity (E-Source 1997, Table 10-5, p. 10.4.2).

Finally, waste heat from a microturbine, generator, or a fuel cell can be used for hot water or space heating, powering an absorption chiller, or regenerating a desiccant. Waste heat temperatures from microturbines appear well suited for use with indirect-fired absorption equipment, but these numbers need to be considered carefully in consultation with microturbine manufacturers. Microturbines use pressurized natural gas, air compressors, and recuperators in order to achieve high operating efficiencies. As illustrated in Figure 2, inlet air is compressed, preheated in the recuperator cooling the exhaust gases, and then mixed with natural gas in the burner. This process boosts the power conversion efficiency of the microturbine from 15 to 17% to an overall efficiency as high as 33% (Kreider 2000), but reduces the temperature of the exhaust air and amount of waste heat available for use with an absorption chiller or desiccant dehumidifier.

***Table 5**. Waste heat energy requirements.*

Equipment	Requirements	Effect
Single-Effect Absorption Chiller	240-270°F steam, 9-12 psig	one ton cooling per 17,000-18,500 Btu/h input
Double-Effect Absorption Chiller	370°F steam, 115 psig	one ton cooling per 10,000 Btu/h input
Desiccant Dehumidifier	180-230°F hot air	one lb H2O removed per 3700 Btu input

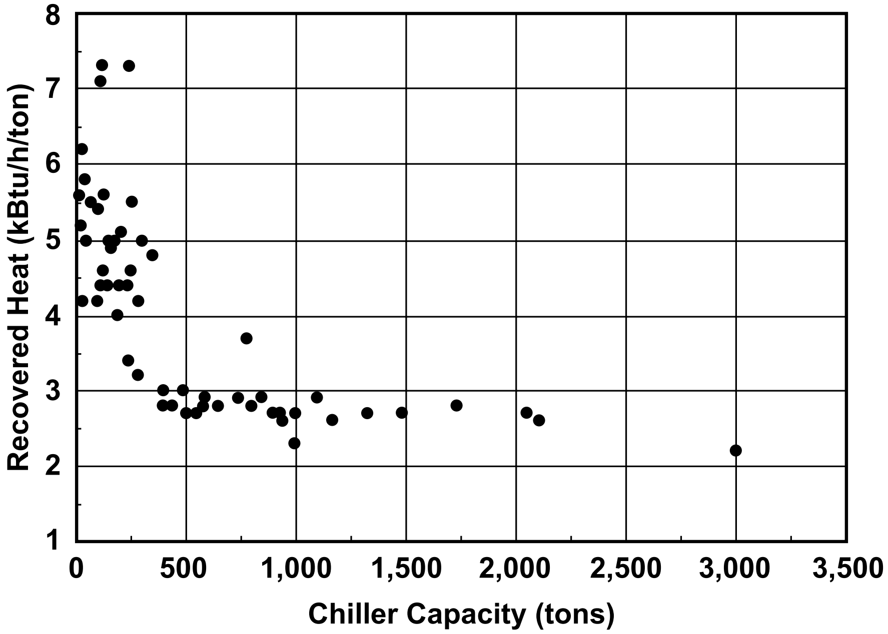

***Figure 7**. Recoverable waste heat from engine-driven chillers.*

Maintenance Impact

Solid desiccant dehumidification systems require periodic maintenance to ensure that the desiccant and thermal wheels are clean and rotating smoothly. Dirt and dust reduce the effectiveness of the desiccant and worn seals allow hot air and moisture to leak from the exit air stream to the supply air, reducing system effectiveness. Periodic maintenance includes:

- changing filters and vacuuming the desiccant wheel every two months,
- inspecting and repairing contact seals, wheel drive assemblies, wheel support bearings, fans, and fan belts regularly.

The desiccant wheel itself needs very little maintenance if the filters are cleaned and replaced on schedule; wheel life should be 10,000 to 100,000 hours (10 to 15 years) under normal use. Contact seals have an expected life of five years (FTA 1997, p. 16).

Absorption chillers may require maintenance procedures that are unfamiliar to chiller plant personnel. This schedule includes:

- daily check of burner and controls, flue pressure, fuel leaks (direct-fired chillers), chilled water loop and cooling tower operation,
- seasonal maintenance includes checking for vacuum leaks, checking the purge pump, the electrical systems, controls, and burner (indirect-fired chillers).

Solution and refrigerant pump motors, bearings, and seals require periodic repair or replacement (E Source 1997). Samples of refrigerant solution should be drawn according to manufacturer schedules and procedures and sent to an outside laboratory to be checked for the presence of non-condensibles and concentration of corrosion inhibitors.

Engine-driven chillers require regular maintenance of the engine in addition to the normal maintenance required by electric motor driven chillers. These include:

- daily check of oil level, oil filter ΔP, discharge temperature, condenser and cooler tube ΔTs, inlet and outlet temperatures, and operating pressures,
- a weekly check of the refrigerant charge,
- quarterly tests of the oil and checks of the mounting screws,
- semi-annual replacement of the oil filter and oil return system, and
- an annual oil change, pressure test of the refrigeration system, and cleaning of condenser tubes and water strainers.

Engine top-end overhauls by trained personnel are recommended somewhere between 12,000 and 30,000 operating hours and complete engine overhauls anywhere between 15,000 and 60,000 operating hours, depending on operating conditions.

Microturbine electrical generators were introduced as commercial products in the United States in the fall of 1999, so there is not a great deal of operating experience with them. One manufacturer requires regular service at prescribed intervals to maintain their product warrantee.

These include:

- every 8000 hours of operation replace the engine air filter, clean the electronics air filter, inspect the internal fuel filter, and replace the external fuel filter,
- every 16,000 hours, also replace the turbine exhaust thermocouple, ignitor, and the fuel injectors.

The gas compressor also requires service every 3000 to 16,000 hours, depending on the gas supply pressure.

Finally, the controls of integrated systems are more complicated than are those of HVAC systems without combined and inter-related operation of components. Initial system commissioning is necessary to ensure that system performance is up to design specifications; periodic recommissioning and adjustment is required to keep equipment operating at that level.

Costs

Desiccant dehumidification systems are sized on their air flow requirements, cubic feet per minute or cfm; costs are typically given in terms of dollars per cfm. Equipment costs range from $5/cfm for large commercial units down to $8/cfm for units of less than 1000 cfm for residential applications (FTA 1997). Installation costs depend heavily on site specific factors and are not generalized here.

Equipment costs for chiller plants varies with type of chiller (i.e. electrically-driven, absorption, engine-driven) and chiller capacity. Approximate equipment costs are listed in Table 6 (Arnold 1998, Garland 1999). These data do not include the cost of cooling towers and installation; cooling tower costs vary depending on site specific conditions and range from $50 to $100 per ton of heat rejected (E-Source 1999). The gas-fired absorption and engine-driven chillers will require larger cooling tower capacities than electrically-driven chillers, because of the higher peak load heat rejection requirements.

Conventional engine-generators, turbine generators, fuel cells, and recently introduced microturbine generators can be used for power generation in combined cooling, heating, and power systems. Equipment parameters for engine-generators, turbine generators, and fuel cells are listed in Table 1. Microturbines were introduced by one manufacturer in October 1999 and are scheduled for introduction by another in late 1999 or early 2000. Cost data on these systems are preliminary; projected future prices of $300/kW may be possible because of the economies of scale in mass production. These costs also do not include installation expenses, which vary with local factors and can be significant.

***Table 6**. Approximate cost of water chillers (1998 $/ton capacity).*

Chiller Type	Small (<500 tons)	Medium (500-1000 tons)	Large (1000-1500 tons)
Electrically Driven	$300	$278	<$278
Engine-Driven	$600-$650	$525-$550	$460
Single-Effect Absorption	$285	$210	$195
Double-Effect Absorption	$600	$525-$550	$460

Utility Incentives and Support

Natural gas utilities frequently sponsor customer incentive programs including rebates for installing gas cooling equipment and summertime gas air conditioning rates. The availability of these programs changes over time and it is necessary to contact local gas suppliers to identify the availability of utility incentive programs for natural gas air conditioning and on-site power generation.

Technology Performance

Field Experience

Maritz Inc. operates a multi-building campus in suburban St. Louis, Missouri, including 1.3 million ft^2 of office and warehouse space spread over 300 acres. Each building houses its own equipment room, generally with two chillers individually sized to handle the design cooling load. Maritz has opted for dual chillers in order to provide redundancy to ensure uninterrupted building services. They have been changing over to hybrid plants combining absorption and electric driven chillers to reduce peak electric demand charges. Leonard Bilheimer explains that in 1988 Maritz chose to replace an electric chiller during the process of remodeling a building with a 200-ton direct-fired double-effect absorption chiller, in part to avoid a costly upgrade of building electrical service. He had to overcome his initial feelings left over from some unpleasant experiences with old single-effect absorption chillers, but he's become an enthusiastic proponent of modern direct-fired absorption chiller/heaters. Since 1988 Maritz has installed double-effect absorption chillers in two additional buildings and Bilheimer looks forward to more conversions to gas/electric chiller plants as opportunities arise. Maritz has been very successful at leveling their gas load year-round and at shaving electrical peak demand. Chiller plant operation and routine testing and maintenance of both electric and gas chillers are performed by an in-house staff with only rare need for contracted replacement of heat exchanger tubes by outside firms. Maritz rarely operates the gas and electric chillers simultaneously, though they do have limited experience in doing so. While they monitor operating costs, they have not tracked energy savings per se.

Both combined cooling, heating, and power systems and desiccant regeneration with waste heat are such new applications that there is no field experience to report on these systems.

Case Study: Hybrid Chiller Plant

Facility Description

In order to compare conventional electric-driven chiller plants and hybrid chiller plants, consider a nine story office building in Atlanta, Georgia. The exterior walls are primarily glass, there is 370,000 ft^2 of floor space, the lighting load averages 1.5 W/ft^2 and electrical plug loads 1.0 W/ft^2. The building is occupied by up to 190 people on a schedule with high occupancy between 8:00 a.m. and 5:00 p.m. on weekdays with low occupancy on evenings and weekends. Computer simulations using the Gas Cooling Guide from the Gas Research Institute are used with chiller equipment manufacturer's data to calculate monthly electrical demand and consumption.

Existing Technology Description

The baseline technology for heating and air conditioning is two 400-ton electrically driven centrifugal chillers with a small boiler to provide space heating. The cost of each of the chillers is \$132,000 and the cost of the cooling tower is \$71,092; annual maintenance and operating costs (e.g., cooling water chemical treatment, makeup water) are estimated to be \$36,000. The expected equipment lifetime is 25 years. The cost assumptions are listed in Table 7.

New Technology Equipment Selection

The alternative technology considered in this application is a 400-ton electrically driven centrifugal chiller operated in parallel with a 400-ton direct-fired, double-effect absorption chiller. The absorption chiller is the lead chiller in peak and mid-peak periods with the electrical chiller being used as necessary to meet the load. The cost of the electrical chiller is \$132,000 and the absorption chiller \$240,000; the cost of the cooling tower is \$88,046 (larger than electrically driven baseline because of higher reject heat requirement). Annual operating and maintenance costs are \$39,600. The expected lifetime is 25 years.

***Table 7**. All-electrical and hybrid chiller plant cost comparison.*

Cost Item	All-Electric Baseline Chiller Plant	Hybrid Gas & Electric Chiller Plant
Equipment		
a. Electric Chiller(s)	\$264,000	\$132,000
b. Absorption Chiller		\$240,000
c. Cooling Tower	\$71,092	\$88,046
Total	**\$335,092**	**\$460,046**
Non-Energy O&M Costs		
a. Electric Chiller(s)	\$36,000 per year	\$18,000 per year
b. Absorption Chiller	\$0 per year	\$21,600 per year
Total	**\$36,000 per year**	**\$39,600 per year**

Saving Potential

Information about changes in peak electrical demand is needed to evaluate the cost savings of integrated systems as well as data for gas and electrical consumption. Computer simulations are necessary to estimate these values. In this case, the Gas Cooling Guide calculated the annual energy consumption for the baseline all-electric chiller plant in Atlanta as 4,446,900 kWh electricity and 19,970 therms of natural gas. The average energy consumption for the hybrid plant is 4,081,104 kWh of electricity and 102,960 therms of natural gas. The peak electrical demand is reduced approximately 16% each month; monthly peak demand and monthly demand charges are shown in Table 8. Over the lifetime of the equipment, the hybrid chiller plant would have electrical consumption 9,145,504 kWh lower than that of the all-electric plant, while natural gas use would be 2,074,750 therms higher.

Life-Cycle Cost

The life-cycle cost analysis depends heavily on energy costs and any utility rebates that are available for gas air conditioning or for improved electrical load factors. Commercial electric rates schedules of 3.65¢ per kWh and demand charges of $15.12 per kW in summer and $9.31 per kW in winter are used for this analysis. Natural gas rates are $0.488 per therm in the summer and $0.513 per therm in the winter; these correspond to an annual average rate of $0.511 per therm. Demand charges are $172,550 per year for the all-electric chiller plant and $143,420 for the hybrid chiller plant, for a net savings of $29,131 per year. The initial and recurring costs for these two chiller plants are summarized in Table 9. These data show that the hybrid chiller plant has significantly higher equipment costs than the baseline all-electric chiller plant with slightly higher non-energy operating and maintenance costs.

A life-cycle cost comparison of the hybrid and electric chiller plants is also shown in Table 9 for four different sets of assumptions for utility rate structures. The second and third columns of Table 9 contain the costs for the baseline electric chiller plant and the hybrid plant using equal capacity electrically driven and absorption chillers and the rate structure described in the preceding paragraph.

***Table 8**. Electricity demand and demand charges for electric and hybrid chiller plants.*

	Peak Electric Demand (kW)			Demand Charges		
Month	**Electric Chiller Plant**	**Hybrid Chiller Plant**	**Demand Reductions**	**Electric Chiller Plant**	**Hybrid Chiller Plant**	**Net Savings**
January	1,287	1,080	207	$12,749	$10,514	$2,235
February	1,304	1,097	207	$12,937	$10,702	$2,235
March	1,337	1,107	230	$13,286	$10,802	$2,484
April	1,460	1,243	217	$14,618	$12,278	$2,340
May	1,532	1,280	252	$15,397	$12,674	$2,723
June	1,567	1,317	250	$15,773	$13,070	$2,703
July	1,628	1,360	268	$16,428	$13,538	$2,890
August	1,600	1,340	260	$16,130	$12,746	$2,808
September	1,530	1,287	243	$15,374	$12,746	$2,628
October	1,517	1,277	240	$15,230	$12,638	$2,592
November	1,293	1,090	203	$12,818	$10,622	$2,196
December	1,200	1,080	120	$11,810	$10,514	$1,296
Total				**$172,551**	**$143,420**	**$29,131**

The fourth, fifth, and sixth columns contain cost data for the hybrid chiller plant assuming a special gas air conditioning rate (24.9¢ per therm), a gas utility rebate of $250 per ton, and the gas air-conditioning rate and the rebate. This data shows negative savings for the equipment costs, operating and maintenance costs, and also for the energy costs between the base case and the hybrid chiller plant. The utility rebate and gas air conditioning rate decrease the life-cycle costs of the hybrid systems significantly and can yield two to seven year paybacks, as shown in the columns on the right of Table 9.

The Technology In Perspective

There are at least three different sides to integrated systems. Those employing hybrid gas-fired and electrically driven chiller plants represent demonstrated combinations of proven technologies. Further development of system controls will occur in order to manage energy costs more effectively as utilities are deregulated, but hybrid systems are already proven effective means of controlling peak electrical demand charges. Desiccant dehumidification systems are commercially available, but there is not much experience in incorporating waste heat utilization to regenerate the desiccant. The U.S. Department of Energy is currently sponsoring field tests of dual wheel desiccant systems that are providing valuable insights on system performance, and design and installation problems. Lessons learned from these projects will benefit both stand-alone desiccant systems and the use of desiccant wheels in integrated systems. Combined cooling, heating, and power is a fairly young technology with extremely few installations nationwide in 1999. It is a major area of interest for building

Table 9. *Life-cycle costs for hybrid chiller plants.*

Cost Item	Baseline Electric Chiller Plant	Hybrid Chiller Plant	Hybrid Chiller Plant with Gas A/C Rate	Hybrid Chiller Plant with Utility Rebate	Hybrid Chiller Plant with Rebate and Gas A/C Rate
Equipment					
electric chiller(s)	$264,000	$132,000	$132,000	$132,000	$132,000
absorption chiller	—	$240,000	$240,000	$140,000	$140,000
cooling tower	$71,092	$88,046	$88,046	$88,046	$88,046
Total	**$335,092**	**$460,046**	**$460,046**	**$360,04**	**$360,046**
Operating and Maintenance	$567,791	$624,571	$624,571	$624,571	$624,571
Energy Costs					
electricity (use)	$2,339,753	$2,147,281	$2,147,281	$2,147,281	$2,147,281
electricity (demand)	$2,487,319	$2,067,393	$2,067,393	$2,067,393	$2,067,393
gas	$156,916	$809,014	$394,216	$809,014	$394,216
Total	**$4,983,988**	**$5,023,688**	**$4,608,890**	**$5,023,688**	**$4,608,890**
Savings/Investments					
p.v. non-investment savings	—	-$96,480	$318,318	-$96,480	$318,318
increased total investment	—	$124,954	$124,954	$24,954	$24,954
net savings	—	-$221,434	$193,364	-$121,434	$293,364
Life-Cycle Cost					
epuipment	$335,092	$460,046	$460,046	$360,046	$360,046
O&M	$567,791	$624,571	$624,571	$624,571	$624,571
energy	$4,983,988	$5,023,688	$4,608,890	$5,023,688	$4,608,890
Total	$5,886,871	**$6,108,305**	**$5,693,507**	**$6,008,305**	**$5,593,507**
Savings-to-Investment Ratio	—	N/A	2.55	N/A	12.76
Adjusted Internal Rate of Return	—	N/A	8.07%	N/A	15.26%
Payback					
simple	—	never	6 years	never	2 years
discounted	—	never	7 years	never	2 years

energy R&D, and while it promises great rewards, projects in this area should be approached carefully with attention to system controls, component synergisms, energy costs, and local utility and air quality regulations and standards.

The Technology's Development

Integrated systems, to date, have been custom designed on a case-by-case basis by engineers familiar with components (e.g., chillers, power generators, dehumidifiers) from separate manufacturers. While such special attention allows the designers to take best advantage of unique factors for each application (e.g., latent cooling load, utility rates or rebates), it also kept costs high. Chillers, desiccant wheels, and electric generators have been developed separate from their use in integrated systems. Double-effect absorption chillers were introduced in the 1980s representing a quantum step up in efficiency and reliability from the old single-effect chillers. Electrically driven centrifugal, screw, and reciprocating chillers changed dramatically in the 1990s as manufacturers took the opportunity to redesign machines as CFCs were phased out so that new machines have significantly higher efficiencies and lower refrigerant emissions than old models. IC and diesel engine generators were developed to mature, efficient products. Desiccant systems were also developed and were becoming widely used in niche applications (e.g., supermarkets, theaters, hospitals) in the 1990s. Microturbines with high efficiency, low emissions and maintenance costs, and low noise are becoming available. Rarely, though, were these components put together into an integrated gas and electric system.

Technology Outlook

Look for developments in "packaged" integrated systems from a single vendor that incorporate multiple functions on a single skid so that architects and designers only need to be concerned about matching the building's requirements with a piece of equipment that provides the necessary services. Making pre-engineered, "off-the-shelf" systems will reduce design and installation costs to the point that integrated systems will be considered by more people in more instances.

There will be some further development of components for integrated systems. Much of the equipment needed for integrated systems comes from mature technologies. These include:

- IC and diesel engine-driven generators,
- electrically driven and engine-driven chillers, and
- single- and double-effect absorption chillers.

While dual-wheel desiccant dehumidifiers are commercially available, the technology is also undergoing significant developments to improve performance and reduce operating costs. Small gas-turbine driven generators appropriate for single building applications, particularly 30 and 75 kW microturbines, are new products and future developments may increase performance or reduce costs. Major developments may come in the areas of controls for integrated systems to manage energy costs effectively.

Manufacturers

The number of manufacturers of components for integrated systems is extensive. The list provided below includes manufacturers of chillers, desiccant dehumidifiers, and on-site power generation equipment. Efforts were made to identify all manufacturers of equipment for integrated systems, but this listing does not purport to be complete.

Absorption Equipment

American Yazaki Corp.
13740 Omega Road
Dallas, TX 75244
Ph: 972-385-8725
Fax: 972-385-1324

Broad
1 World Trade Center, Suite 7929
New York, NY 10048
Ph: 212-775-0665
Fax: 212-775-1936

Carrier Corp.
P.O. Box 4808
Syracuse, NY 13221
Contact: Doug Rector
Ph: 315-432-7152
Fax: 315-433-4985

Dunham-Bush Inc.
101 Burgess Road
Harrisonburg, VA 22801
Ph: 540-434-0711
Fax: 540-432-6486
e-mail: smassien@shentel.com

McQuay International
Chiller Products Group
P.O. Box 2510
Staunton, VA 24402
Contact: Dave Wiggins
Ph: 540-248-9557

Robur Corporation
2300 Lynch Road
Evansville, IN 47711-2951
Ph: 812-424-1800
Fax: 812-423-1847

The Trane Company
3600 Pammel Creek Road
La Crosse, WI 54601-7599
Ph: 608-787-3914

York International Corp.
P.O. Box 1592-361R
York, PA 17405-1592
Ph: 717-771-6359
Fax: 714-772-6820

Electric-Driven Chillers

Advantage Engineering, Inc.
525 East Stop 18 Road
Greenwood, IN 46142
Ph: 317-887-0729
fax: 317-881-1277

Carrier Corp.
P.O. Box 4808
Syracuse, NY 13221-4808
Contact: Jim Parsnow
Ph: 315-433-4376
Fax: 315-432-7836
e-mail: jim.parsnow@carrier.utc.com

Dunham-Bush
101 Burgess Road
Harrisonburg, VA 22801
Contact: Brian Davis
Ph: 540-434-0711
Fax: 540-434-4595
e-mail: dbmkt@shentel.net

McQuay International
P.O. Box 2510
Stanton, VA 24402
Contact: Jay Eldridge (water-cooled)
Ph: 540-248-9639
Fax: 540-248-9412
e-mail:
eldridge.george@online.mcquay.com
or
Contact: Ric Tharp (air cooled)
Ph: 540-248-9684
Fax: 540-248-9412
e-mail:
tharp.richard@online.mcquay.com

The Trane Company
3600 Pammel Creek Road
La Crosse, WI 54601-7599
Contact: Sher Peterson
Ph: 608-787-3084
Fax: 608-787-2204
e-mail: speterson@trane.com

York International Corp.
P.O. Box 1592-361P
York, PA 17405-1592
Contact: Bob Schmitt
Ph: 717-771-6356
Fax: 717-771-6820

Engine-Driven Chillers

Alterdyne Energy Systems
8050 Armour Street
San Diego, CA 92111
Contact: Joe Browning
Ph: 619-565-2131
Fax: 619-279-4296

Carrier Corporation
Carrier Parkway
P.O. Box 4808
Building TR-1
Syracuse, NY 13221
Ph: 315-432-7011
Fax: 315-433-4985

Chillco Inc.
1971 Abbott Road
P.O. Box 16
Buffalo, NY 14218
Ph: 716-822-0208
Fax: 716-822-0266
e-mail: chillcoinc@aol.com

GASAIR, Inc.
P.O. Box 5348
Kingwood, TX 77325
Ph: 713-360-0893
Fax: 713-360-7567

HEP, Inc.
2896 West Telegraph Road
Fillmore, CA 93015
Ph: 805-524-5880

Industrial Heat Recovery Equipment (IHRE)
850 West Bradley Avenue
El Cajon, CA 92020
Contact: David Williams
Ph: 800-423-1333
Fax: 619-596-3080

Napps Technology Corporation
P.O. Box 1509
Longview, TX 75606
Ph: 903-984-2112
Fax: 903-984-1633

Powerchill
Cummins Southwest, Inc.
Power Systems Division
2222 N. 23rd Drive
P.O. Box 6688
Phoenix, AZ 85005-6688
Ph: 602-257-5984
Fax: 602-258-1010

Tecogen
45 First Avenue
P.O. Box 8995
Waltham, MA 02254-8995
Ph: 617-622-1400
Fax: 617-622-1025

Trane Company
3600 Pammel Creek Road
La Crosse, WI 54601-7599
Ph: 608-787-3914
Fax: 608-787-4100

Trico Energy Systems, Inc.
Two Appletree Square, Suite 335
Bloomington, MN 55425
Ph: 612-854-1690
Fax: 612-854-6657

York International Corp.
P.O. Box 1592-361R
York, PA 17405-1592
Ph: 717-771-7514
Fax: 717-771-6820

Desiccant Dehumidifiers

Advanced Thermal Technologies, Inc.
12900 Automobile Blvd.
Clearwater, FL 34622
Ph: 813-571-1888
Fax: 813-571-2242

Airflow Company
Dryomatic General Products Group
295 Bailes Lane
Frederick, MD 21701-3136
Contact: Richard M. Wolcott
Ph: 301-695-6500
Fax: 301-631-0396

Comfort Enterprises Co.
P.O. Box 11148
1812 Colonial Village Lane
Lancaster, PA 17605-1148
Ph: 717-394-8208 (ext. 206)
Fax: 717-394-0612

Engelhard / ICC
441 North Fifth Street
Philadelphia, PA 19123
Ph: 215-625-0700 (ext. 130)
Fax: 215-592-8299

Fresh Air Solutions
330 S. Warminster Rd.
Hatboro, PA 19040
(215) 740-0624

Kathabar Inc.
P.O. Box 791
New Brunswick, NJ 08903-0791
Ph: 908-356-6000
Fax: 908-356-0643

Munters Corporation
Cargocaire Division
79 Monroe Street
P.O. Box 640
Amesbury, MA 01913-0640
Ph: 508-388-0600 / 800-843-5360
Fax: 908-356-0643
e-mail: cargo@munters.com

Munters Corporation
DryCool Division
16900 Jordan Road
Selma, TX 78154
Ph: 210-651-5018 / 800-229-8557
Fax: 210-651-9085

Octagon Air Systems
1724 Koppers Road
Conley, GA 30017
Ph: 404-608-8881
Fax: 404-608-0880

Seasons ● 4 Inc.
4500 Industrial Access Road
Douglasville, GA 30134
Ph: 770-489-0716
Fax: 770-489-2938

Fuel Cells

Analytic Power Corporation
268 Summer Street
Boston, MA 02210
Contact: David Bloomfield
Ph: 617-542-6352
Fax: 617-695-3272

Ballard Power Systems, Inc.
980 West First Street, Unit 107
North Vancouver, BC V7P 3N4
Canada
Contact: Keith Prater
Ph: 604-986-9367
Fax: 604-986-3262

Energy Partners
Suite 102, Technology Center
West Palm Beach, FL 33407
Contact: Teresa Gomez
Ph: 407-688-0500
Fax: 407-688-9610

Fuel Cell Corporation of America
811 Route 51 South
Large, PA 15025
Contact: Charles Rose
Ph: 412-382-7124
Fax: 412-382-5509

H Power Corporation
60 Montgomery Street
Belleview, NJ 07109
Contact: Arthur Kaufman
Ph: 201-450-4400
Fax: 201-450-9850
e-mail: moreinfo@hpower.com

ONSI Corporation
195 Governor's Highway
P.O. Box 1148
South Windsor, CT 06074
Contact: Greg Sandelli
Ph: 203-727-2348
Fax: 203-727-2319

Microturbine Generators

Allison Engine Company, Inc.
2001 S. Tibbs Avenue
Indianapolis, IN 46206-0420

Capstone Turbine Corporation
6430 Independence Avenue
Woodland Hills, California 91367
Ph: 877-282-8965
e-mail: info@capstoneturbine.com

Elliott Energy Systems
10485 Bush Drive North
Jacksonville, FL 32218-5601
Contact: Rich Sanders
Ph: 904-757-7600
Fax: 904-767-7604

Honeywell Power Systems.
8725 Pan American Freeway
Albuquerque, New Mexico 87113
Integrated Power Systems International
P.O. Box 92384
Rochester, New York 14692
Ph: 800-959-4724
Fax: 716-359-9061
e-mail: RCIPOWER@worldnet.att.net

Northern Research and Engineering Corporation
39 Olympia Avenue
Woburn, MA 01801-2073
Ph: 781-935-9050
Fax 781-935-9052

SatCon Technology
161 First Street
Cambridge, MA 02142-1221
Contact: Ed Godere
Ph: 617-349-0884
Fax: 617-661-3373

Turbec AB,
Malmö, Sweden

TRD Corporation
7471 Tyler Boulevard
Mentor, OH 44060
Contact: Charles Heinrich
Ph: 216-946-2838
Fax: 216-946-2838

Reciprocating Engine-Generators

Caterpiller Inc. Information Center
P.O. Box 10097
Peoria, IL 61612

Cummins Southwest, Inc.
2222 North 23rd Drive
Phoenix, AZ 85009
Contact: Kirby Brown
Ph: 602-257-5984
Fax: 602-258-1010

Deutz MWM
33 Christa McAuliffe Boulevard
Plymouth, MA 02360
Contact: Eugene Morrill
Ph: 508-746-5500
Fax: 508-746-1630

Intelligen Energy Systems, Inc.
98 South Street
Hopkinton, MA 01748
Contact: Frank Fulton
Ph: 508-435-9007
Fax: 508-435-9160

Jenbacher Energiesysteme Ltd.
1502 Providence Highway, Suite #2
Norwood, MA 02062
Contact: Kimberley Cotter
Ph: 617-255-5886
Fax: 617-255-5887

Kohler Company Power Systems
Kohler Co. Generator Division
444 Highland Drive
Kohler, WI 53044
Ph: 414-565-3381
Fax: 414-459-1646

Onan Corporation
1400 73rd Avenue NE
Minneapolis, MN 55432
Ph: 612-574-5000
Fax: 612-574-8090

Tecogen, Inc.
P.O. Box 8995
Waltham, MA 02254-8995
Contact: Jeff Glick
Ph: 617-622-1400
Fax: 617-622-1252

Wärtsilä Diesel Inc.
201 Defense Highway, Suite 100
Annapolis, MD 21401
Contact: Mack Shelor
Ph: 410-573-2100
Fax: 410-573-2200

Waukesha Power Systems
Waukesha Engine Division
Dresser Industries, Inc.
1220 South Prairie Avenue
Waukesha, WI 53188
Ph: 414-549-2925
Fax: 414-549-2989

Stirling Engine-Generators

Stirling Technology Company
4208 West Clearwater Avenue
Kennewick, WA 99336
Contact: Maurice White
Ph: 509-735-4700 ext 105
Fax: 509-736-3660

Stirling Thermal Motors, Inc.
275 Metty Drive
Ann Arbor, MI 48103-9444
Contact: Lennart Johansonn
Ph: 313-995-1755
Fax: 313-995-0610

Sunpower, Inc.
6 Byard Street
Athens, OH 45701-2702
Contact: William Beale
Ph: 614-594-2221
Fax: 614-593-7531

Tamin Enterprises
311 Grove Street
Half Moon Bay, CA 94019-2005
Contact: Don Isaac, Jr.
Ph: 415-726-2338
Fax: 415-726-7342
e-mail: info@tamin.com

Rotary Engine-Generators

Alturdyne Power Systems
8050 Armout Street
San Diego, CA 92111
Ph: 619-565-2131

Moller International
1222 Research Park Drive
Davis, CA 95616
Contact: Ren Tubergen
Ph: 916-756-5086
Fax: 916-756-5179

Rotary Power International, Inc.
Industrial Products
P.O. Box 128
Woodridge, NJ 07075-0128
Contact: Jack Kasmer
Ph: 201-470-7095
Fax: 201-779-5595

Combustion Gas Turbine-Generators

ABB Alstom Power
P.O. Box 1
Waterside South
Lincoln LN5 7FD
United Kingdom
Ph: 01522 584000
Fax: 01522 584900

GE Power Systems
Evendale, Ohio
http://www.gepower.com

Solar Turbines Incorporated
Harbor Drive Facility
2200 Pacific Highway
San Diego, CA 92101
Ph: 619-544-5000
Fax: 619-544-2849

Combined Cooling, Heating, and Power

Thermax Ltd. Novi Office
40440 Grand River Avenue
Novi, MI 48375
Ph: 248-474-3050
Fax: 248-474-5790

W‰rtsil‰ Diesel Inc.
201 Defense Highway, Suite 100
Annapolis, MD 21401
Contact: Mack Shelor
Ph: 410-573-2100
Fax: 410-573-2200□

Who is Using the Technology

Federal Sites

Federal Energy Regulatory Commission
Union Center Plaza
Washington, DC

Non-Federal Sites

Hybrid Chiller Plants

Fairview Southdale Hospital
6401 France Avenue South
Minneapolis, MN
Ph: 612-924-5000

Hackensack University Medical Center
30 Prospect Avenue
Hackensack, NJ 07601
Contact: Wojciech Mickowski

Independent School District 622
Oakdale, Minnesota
Contact: John Brady
Armstrong, Torseth, Skold, and Rydeen

Maritz, Inc.
St. Louis, MO
Contact: Leonard Bilheimer
Ph: (314) 827-1311

Morton Plant Hospital
323 Jeffords St
Clearwater, FL 33756
Ph: 727-462-7000

Philadelphia Marriott
1201 Market Street
Philadelphia, PA 19107
Ph: 215-625-2900
Fax: 215-625-6000

Norfolk International Airport
2200 Norview Ave
Norfolk, VA
Ph: 757-857-3351

St. Elizabeth's Hospital
1431 N Claremont Ave
Chicago, IL 60622
Ph: 773-278-2000
Contact: Richard Gilligan

Combined Cooling, Heating, Power

University of Maryland
CEEE
College Park, MD 20742-3035
Contact: Predrag Popovic
Ph: 301-403-4410
Fax: 301-403-4409

Desiccant Dehumidification with Waste Heat Regeneration

Energy Resource Center
2250 Park Pl
El Segundo, CA
Ph: 310- 643-9016

For Further Information

AGCC 1996. *Natural Gas Cooling Equipment Guide*, American Gas Cooling Center, 1515 Wilson Boulevard, Arlington, VA 22209, Fourth Edition, April 1996.

AGCC 1999. *Technology Transfer Workshop Workbook for Integrated System Design*, American Gas Cooling Center, 400 N. Capitol Street, N.W., Washington, DC 20001, 202-824-7141, March.

AGCC *Technology Transfer Workshop* (TTW): *Integrated Systems Design*, American Gas Cooling Center, 400 N. Capitol Street, N.W., Washington, DC 20001, 202-824-7141.

Arnold, Roger and Bahnfleth, William 1996. *Peak Shaving Using Natural Gas Engine-Driven Chillers*, Heating/Piping/Air Conditioning, September 1998, pp. 51-59.

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FTA 1997. *Federal Technology Alerts*: Two-Wheel Desiccant Dehumidification System, http://www.pnl.gov/fta/8_tdd.htm, April 1997

FTA 1995. *Federal Technology Alerts*: *Natural Gas Fuel Cells*, http://www.pnl.gov/fta/5_nat.htm#man, November 1995.

Harriman, Lewis G., *The Basics of Commercial Desiccant Systems*, Heating / Piping / Air Conditioning, July 1994, pp. 77-85.

Kreider, J. and Curtiss, P., 2000. *Distributed Electrical Generation Technologies and Methods for Their Economic Assessment*, ASHRAE Transactions 2000, V. 106, Pt. 1.

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Appendixes

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Appendix A

Glossary

absorption chiller	water chiller based on absorption of refrigerant vapor into a liquid solution, pumping of solution to elevated pressure, and desorption of refrigerant vapor through addition of heat; direct-fired chillers employ natural gas burners, indirect-fired chillers use steam or hot water from a boiler, heat recovery heat exchanger, or generator exhaust gas; single-, double-, and triple-effect chillers employ multiple stages of desorption and internal use of waste heat to boost efficiency
demand charge	charges for the use of electricity based on the maximum power requirement, electrical demand, during a specified period of time, typically a month ($/kW)
desiccant	a solid or liquid material with an affinity for absorbing water molecules
engine-generator	electrical generator using a reciprocating, Stirling, or rotary engine
enthalpy wheel	heat exchanger rotating through building supply and exhaust air flows to transfer energy from one air stream to the other
evaporative cooling	lowering the temperature of air through the evaporation from a water spray or wetted membrane; direct evaporative cooling adds water to the supply air while indirect evaporative cooling adds water to the exhaust air and incorporates a heat pipe or thermal wheel for indirect cooling of the supply air
fuel cell	device for producing electricity using a chemical process rather than conventional combustion processes with steam generators
heat wheel	heat exchanger rotating through building supply and exhaust air flows to transfer heat from one air stream to another
latent cooling load	amount of cooling required to reduce humidity of air in conditioned space to specified level for comfort
microturbine power generator	turbine-engine driven electrical generator with output power of 25 to 300 kW
real time pricing	charges for electrical demand and consumption based on instantaneous cost of production and distribution as opposed to fixed rates or fixed time-of-day rates
sensible cooling load	amount of cooling required to reduce the temperature of air in the conditioned space to a specified level for comfort
therm	a unit of energy used to measure natural gas; 10^5 Btus, 1.055×10^8 joules, approx. 97.5 ft^3
thermal wheel	heat exchanger rotating between two air flows to transfer heat from one to the other
ton or refrigeration ton	quantity of cooling available from melting 2000 pounds of ice; 12,000 Btu/h or 3.1413 kW
vapor compression air conditioning	cooling system based on mechanical compression of a gaseous refrigerant to a high pressure, and heat transfer with changes of state (i.e., liquid and vapor) to produce useful heating or cooling
waste heat	portion of the energy input to a mechanical process which is rejected to the environment

Appendix B

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$\mathrm{LCC} = \mathrm{PV(IC)} + \mathrm{PV(EC)} + \mathrm{PV(OM)} + \mathrm{PV(REP)}$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$\mathrm{NPV} = \mathrm{PV}(\mathrm{EC}_0) - \mathrm{PV}(\mathrm{EC}_1)) + \mathrm{PV}(\mathrm{OM}_0) - \mathrm{PV}(\mathrm{OM}_1)) + \mathrm{PV}(\mathrm{REP}_0) - \mathrm{PV}(\mathrm{REP}_1)) - \mathrm{PV(IC)}$$

or

$$\mathrm{NPV} = \mathrm{PV(ECS)} + \mathrm{PV(OMS)} + \mathrm{PV(REPS)} - \mathrm{PV(IC)}$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the break-even energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$\mathrm{PV(LEC*EUS)} = \mathrm{PV(OMS)} + \mathrm{PV(REPS)} - \mathrm{PV(IC)}$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$\mathrm{SIR} = (\mathrm{PV(ECS)} + \mathrm{PV(OMS)} + \mathrm{PV(REPS)})/\mathrm{PV(IC)}.$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

About FEMP's New Technology Demonstration Program

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in Federal buildings be reduced by 35% from 1985 levels by the year 2010. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of energy-efficient and renewable technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort FEMP is sponsoring a series of publications that are designed to disseminate information on new and emerging technologies. New Technology Demonstration Program publications comprise three separate series:

Federal Technology Alerts—longer summary reports that provide details on energy-efficient, water-conserving, and renewable-energy technologies that have been selected for further study for possible implementation in the Federal sector. Additional information on Federal Technology Alerts (FTAs) is provided in the next column.

Technology Installation Reviews—concise reports describing a new technology and providing case study results, typically from another demonstration program or pilot project.

Technology Focuses—brief information on new, energy-efficient, environmentally friendly technologies of potential interest to the Federal sector.

More on FTAs

Federal Technology Alerts, our signature reports, provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the FTAs have already entered the market and have some experience but are not in general use in the Federal sector.

The goal of the FTAs is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

The information in the FTAs typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of manufacturers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the FTAs to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal-sector savings, the FTAs do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Nor do the FTAs attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the FTAs as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the FTAs to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $8 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), Executive Order 12902 in 1994, and Executive Order 13123 in 1999.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

Log on to FEMP's New Technology Demonstration Program Website

http://www.eren.doe.gov/femp/prodtech/newtechdemo.html

You will find links to

- An overview of the New Technology Demonstration Program
- Information on the program's technology demonstrations
- Downloadable versions of program publications in Adobe Portable Document Formats (pdf)
- A list of new technology projects underway
- Get on the program's regular mailing list for new products when they become available
- How Federal agencies may submit requests for the program to assess new and emerging technologies

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