DOE/EE-0239

Energy Efficiency Improvements Through the Use of Combined Heat and Power (CHP) in Buildings

Combined technology helps Federal energy managers meet mission critical energy needs

The Role of the Federal Energy Manager

It is hard to imagine, in today's computer age, what operations are not mission critical to the operation of our Federal Government. Therefore, today's Federal energy manager plays an important role in the nation's goal to generate energy efficiently and cost-effectively.

To accomplish this goal Federal energy managers must assure that their systems:

- supply mission critical operations,
- support the electric grid reliability efforts,
- reduce climate change gas emissions,
- conserve natural resources, and
- provide life-cycle cost-effectiveness.

System Integration

The Federal energy manager has a growing number of options to provide electric power and thermal energy (heating, cooling and humidity control) to buildings and processes throughout the Federal system.

This *Technology Focus* looks at integrating proven technologies (e.g., engines, gas turbines, boilers, absorption chillers, desiccant dehumidifiers, electric air conditioners) to maximize the use of recoverable thermal energy. It also provides a glimpse into the arena of emerging technologies (microturbines, fuel cells, etc.). FEMP's leadership is essential to achieve the nation's environmental, economic and security goals.

Combined Cooling, Heating and Power

Combined Heat and Power (CHP), also known as cogeneration, is a system that efficiently generates electricity (or shaft power) and uses the heat generated in the process to produce steam, hot water, and/or hot air for other useful purposes. DOE estimates about 7% of the total electrical power generation in this country is currently produced by CHP equipment. Industry working with DOE has examined broader utilization of the recoverable energy from on-site or near-site power generation for buildings and concludes that sensible cooling and humidity control provides additional energy savings and economic potential. This new approach is now called Buildings Cooling, Heating and Power "BCHP" technology, and an industry roadmap has been created (details can be found at www.bchp.org).

Meeting Executive Order 13123

Sustainable Design and Development for Federal Agencies

Sustainability is grounded in the knowledge that all of life is interdependent—that local actions may have global consequences. The basic objectives of sustainability are to:

- reduce the consumption of energy, land, and other nonrenewable resources, and
- minimize the waste of materials, water, and other limited resources.

Sec. 206. Source Energy

"The Federal Government shall strive to reduce total energy use and associated greenhouse gas and other air emissions, as measured at the source. To that end, agencies shall undertake life-cycle cost-effective projects in which source energy decreases, even if site energy use increases. In such cases, agencies will receive credit toward energy reduction goals through guidelines developed by DOE."

Sec. 403 (g) Highly Efficient Systems

"Agencies shall implement district energy systems, and other highly efficient systems, in new construction or retrofit projects when life cycle cost-effective. Agencies shall consider combined cooling, heat, and power when upgrading and assessing facility power needs and shall use combined cooling, heat, and power

Mission Critical Operations

"The 50-year-old grid was simply never designed to handle the volume and frequency of power trades that we're seeing today," said Kurt Yeager, president and CEO of EPRI® at an October 29, 1999, press conference. **"This trend is only expected to increase as competition becomes more widely adopted."**

Technology Focus

An update on technologies for energy and resource management

Prepared by the New Technology Demonstration Program

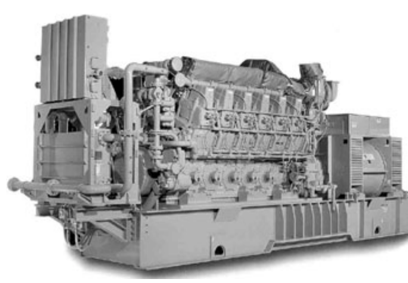
systems when life-cycle cost-effective. Agencies shall survey local natural resources to optimize use of available biomass, bioenergy, geothermal, or other naturally occurring energy sources."

Electrical Technologies

Engine/Generator Sets

Engine-driven generator sets use internal combustion engines to drive an electric generator in a single package. Typically, constant duty-cycle engines use spark ignition and burn natural gas as the primary fuel. Biofuels can also be used for fuel in place of petroleum and natural gas.

Current engine technology achieves efficiencies in the range of 30–40% [based on the fuel's lower heating value (LHV)], and emissions of NOx and CO, while higher than most other distributed technologies, have been reduced significantly in the last several years by exhaust catalysts and better design and control of the combustion process. Engines are generally low-cost, have proven reliability with proper maintenance, and have good load following characteristics and heat recovery potential. Historically engines have been used for standby generation, but they are also appropriate for peak power, or for BCHP in commercial and light industrial applications.



Courtesy of Caterpillar

***Figure 1**. Engine-generator set.*

Microturbines

Microturbines are small, high-speed (up to 100,000 rpm) electric generator systems that include the turbine, compressor, and generator on a single shaft or with a separate generator shaft, and the power electronics for delivering AC power. Microturbines have only one or two moving parts and are air-cooled. Some systems use air bearings requiring no lubricating oil. Natural gas-fueled microturbines require fuel pressures in the 75 to 100 psig range and these units may require on-board fuel gas compressors, which are available as a standard option.

Courtesy of Capstone Turbine

***Figure 2**. Nominal 30-kW microturbine.*

Microturbines emit low levels of noise (approximately 70 dB at 10 feet), and noise can be further reduced through readily available, inexpensive control technologies.

Microturbines are currently available in nominal 30, 45, 75 and 100 kW sizes (larger sizes up to 350 kW are being developed), and individual units can be packaged together to serve larger loads. Microturbines are capable of producing power at 20–30% efficiency (LHV). Research and development efforts to use advanced ceramics technologies target 40% efficiency for the next generation of products.

Current designs are offered for grid parallel, standalone (black start capable) and can separate from the grid and restart in standalone mode when the grid goes down.

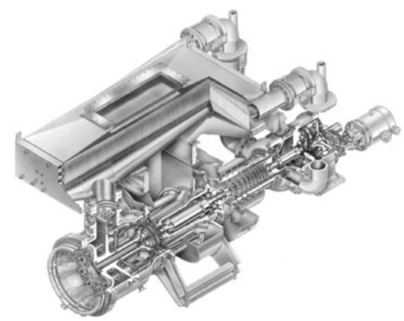
Courtesy of Honeywell Power Systems

***Figure 3**. Nominal 75-kW microturbine.*

Combustion Turbines

Combustion turbines range in size from 600 kW to several hundred megawatts; however, BCHP-type systems would typically encompass the range of 600 kW to 30 MW. Combustion turbines can burn a wide range of fuels and are capable of dual-fuel operation and have operating efficiencies in the range of 24–35% (LHV).

Gas-fired turbines require natural gas to be supplied at fairly high pressures; therefore, a fuel booster compressor is needed on most local distribution lines. Combustion turbines rapidly adjust to changes in load and to produce high temperature waste.



Courtesy of Solar Turbines

***Figure 4**. 4,200-kW advanced combustion turbine.*

Fuel Cells

Fuel cells are an exciting technology that convert hydrogen-rich fuels, such as natural gas, into electricity and heat through an extremely quiet and environmentally clean process. Fuel cells generate electricity through an electrochemical process in which the energy stored in the fuel is converted directly to electricity. There are three main components that govern the operation of fuel cells: a Hydrogen Reformer that extracts hydrogen from a fuel source, a Fuel Cell Stack where the hydrogen fuel generates DC power in an electro-chemical reaction, and an Inverter that converts DC outputs to AC power.

Phosphoric acid fuel cells (PAFCs) have already entered the commercial marketplace with over 200 units sold worldwide; solid oxide fuel cell (SOFCs) and molten carbonate fuel cells (MCFCs) are undergoing full-scale demonstration and are projected to enter the market by 2002; proton exchange membrane fuel cell (PEM) units are in development and testing.

Courtesy of International Fuel Cells

***Figure 5**. 200-kW phosphoric acid fuel cells.*

Thermal Technologies

Heating

Heat recovery from power-generating equipment is well known. Essentially four types of heat exchangers are used: air-to-air, air-to-fluid, fluid-to-air, and fluid-to-fluid.

Design consideration must be given to the coincidence of electric and thermal load requirements, which will determine the amount of thermal storage required (if any) and the proper heat recovery system.

Absorption Chillers

The absorption cycle uses a condenser and evaporator just like vapor compression systems, but replaces the motor and compressor assembly with a thermal fluid compressor (absorber, generator and small fluid pump) to transfer low-temperature energy to high-temperature heat rejection. The absorption cycle uses thermal energy (natural gas, waste heat or solar energy), not electricity, to create chilled water.

The cooling cycle begins in the evaporator where the refrigerant (which is water) is sprayed over tubes containing chilled water that is circulated through the building as a cooling medium. The evaporator operates under a vacuum, which permits the refrigerant (water) to boil at a low temperature and remove heat from the chiller water. The refrigerant vapor migrates to the absorber where it is absorbed into a concentrated solution of lithium bromide (LiBr). The combined LiBr/water solution is pumped to the generator where heat is added by natural gas combustion or another heat source to vaporize the refrigerant (water) from the absorbent (LiBr). The concentrated LiBr returns through intermediate heat exchangers to the absorber to repeat its cycle. The refrigerant enters the condenser where it is liquefied and returned to the evaporator to repeat the process.

Courtesy of York International

***Figure 6**. Single-effect absorption chiller.*

Absorption systems are classified by single, double or triple "effect" referring to the number of generators in the given system and respective efficiency levels.

Courtesy of The Trane Company

***Figure 7**. Direct-fired double-effect absorption chiller.*

Single-effect absorption chillers ideally fit BCHP applications providing low-cost chilled water using low-quality heat (9 to 12 psig steam or 190 to 270 ºF hot water). Double-effect chillers increase efficiency using 65 to 115 psig steam, and 300 to 370 ºF hot water or can be co-fired with hot air (e.g., direct gas turbine exhaust).

Absorption chillers may economically increase the capacity of combustion turbines by cooling turbine inlet air and using turbine exhaust to power the cycle. Combustion turbine output will typically increase by 10% to 18% for every 20°F of reduction in inlet air temperature.

Desiccant Dehumidification

A desiccant material naturally attracts moisture. The material becomes saturated as moisture is adsorbed; but when heated, the desiccant dries out—or regenerates—and can be used again.

In a dehumidifier, the desiccant removes moisture from the air: this in turn, releases heat and raises the air temperature. Heat-recovery devices then cool the air, and cooling devices such as cooling coils of a conventional air conditioner provide final, sensible cooling.

Courtesy of SEMCO

***Figure 8**. Desiccant/enthalpy dehumidifier.*

In most systems, a wheel containing desiccant material continuously dehumidifies outside and/or recirculated air entering the cooling unit. The desiccant is then regenerated by thermal energy supplied by natural gas or waste heat. A desiccant system can also supplement a conventional air-conditioning system. The desiccant removes the humidity load while the evaporator of the air conditioner lowers the air temperature.

Since desiccants are thermally activated, they are also ideal for integration with on-site power applications.

BCHP Technology Success

The cognizant Federal energy manager knows that the success of BCHP technology focuses on two key elements:

- optimizing the recovery of thermal energy from on-site power generation, and
- cost-effective integration of thermal recovery/use systems.

BCHP Project Success

Proper planning by the Federal energy manager, like in most capital projects, will help assure success.

Implementing BCHP technologies within Federal Government facilities depends upon identifying the best uses of BCHP and assuming an appropriate investment timeframe.

Undertaking a BCHP project should be viewed as an investment, in terms of planning, implementation, and operation.

A good approach to any project is to understand the thermal load requirements of the facility and try to match the load with recovered energy. This will then size the amount of electricity that can be optimally produced.

The proper planning of all key aspects of a medium- to large-scale successful BCHP project, including legal, financial, regulatory, environmental, engineering, and training issues, requires that the project schedule match the expected benefits from full BCHP implementation.

The financial benefits from a BCHP project will depend upon the amount of the purchased thermal and electric power that the BCHP system is replacing and the mission critical nature of the project.

Larger Federal building sites, including military bases, multi-building medical centers, national laboratory complexes, and training/research centers, have the largest purchased fuel and electric power requirements. Therefore, these larger Federal facilities will reap the greatest financial benefit from applying BCHP technology.

BCHP Information

www.eren.doe.gov/der

www.uschpa.org

www.bchp.org

www.districtenergy.org

www.oit.doe.gov/chpchallenge/

BCHP Benefits to Federal Facilities

Leading the way for broad implementation of BCHP integrated systems, Federal facilities can have a significant impact toward a sustainable energy future. BCHP and other distributed energy resources offer:

- deferral of new transmission and distribution (T&D) capital investments,
- reduction of T&D electrical line losses,
- economic source of energy-efficient thermal energy,
- significant reductions in CO_2 emissions,
- cost-effective source of new peak demand power,
- improved power quality and reliability (voltage support, source of reactive power, and power factor correction),
- reduction in energy ($/kWh) and electric demand ($/kW) charges,
- source of emergency or standby power, and
- potential source of high-reliability power for sensitive facilities when coupled with uninterruptible power supply (UPS) systems.

References

FEMP "Combined Heat and Power: A Federal Manager's Resource Guide," March 2000. Available online at: www.eren.doe.gov/femp/resources.html)

DER Taskforce and Industry "BCHP Initiative Roadmap." Available online at: www.bchp.org/about.html

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