

9. BUILDING COOLING, HEATING AND POWER GENERATION SYSTEMS

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Recommendation

Consider an integrated cooling, heating and power generation system for buildings with both significant cooling loads and heating loads. Appropriate heating loads are usually domestic hot water or swimming pools. Building cooling, heating and power (BCHP) systems are most cost effective for facilities operated continuously such as hotels, hospitals or high-rise residential buildings.

Description

The term BCHP covers a range of system types and is sometimes defined as *Building Combined Heating and Power* and other times as *Building Cooling, Heating and Power*. The common elements are usually electricity generation and recovery of waste heat from the generation process (also called *cogeneration*). The “optional” element is space cooling — either using the waste heat to feed absorption cooling equipment or using the electricity to run an electric chiller. A variation on BCHP systems actually has no generator; it uses an engine-driven chiller for cooling and recovers the waste heat from the engine for water heating. BCHP systems include at least two of the following components:

- **Power Components.** Turbines, engines, fuel cells or micro-turbines.
- **Cooling Components.** Engine-driven chillers, electric chillers, and/or absorption chillers.
- **Heating Components.** Domestic water heating, pool heating, desiccant regenerators, and/or reheat for humidity control.

In Hawaii, the waste heat is most often used to produce domestic hot water for hotels, hospitals or high-rise residential buildings. In

some cases, it is also used for swimming pool heating. For dehumidification applications, the waste heat from the power generation can be used for reheat in conventional mechanical cooling systems, or can be used to regenerate desiccants in desiccant-based cooling systems. See the Dehumidification Guidelines.

There are many possible BCHP system configurations. Table 9-1 illustrates some basic options. In each case, a fuel is consumed as input and the system produces electricity, hot water and/or chilled water.

Table 9-1. Basic BCHP configurations.

System Description	System Configuration
<p>Engine-driven generator produces electricity, and heat from the engine jacket and exhaust is recovered for water heating. As an alternative, a turbine or microturbine could be used in place of the engine.</p>	
<p>An absorption chiller is added to the first system to produce chilled water using the recovered heat.</p>	
<p>An engine-driven compressor (chiller) produces cold water and heat from the engine jacket and exhaust is recovered for water heating. No electricity is produced in this configuration.</p>	
<p>A less common configuration includes a fuel cell that produces electricity as well as heat that can be recovered for hot water. The fuel cell runs on hydrogen, so propane or SNG must be processed to extract the hydrogen prior to use.</p>	

Notes: SNG=synthetic natural gas

Applicability

In Hawaii, BCHP systems are applicable in buildings with significant and relatively constant hot water demand. Good examples include hotels and high-rise residences with swimming pools. In those facilities, the waste heat can produce domestic hot water that is used for washing and showers and can then provide pool heating. Hospitals can also be appropriate applications

because they may have a relatively large and constant hot water load.

Installation of a BCHP system is most likely to be cost effective in a new construction project or as part of a major renovation. Among existing buildings, good candidates include hotels with aging and inefficient chilled water and hot water plants.

BCHP systems are less likely to be cost effective in general commercial buildings such as offices or stores because they have relatively small heating requirements and may not have 24-hour electricity demand. They are also less cost effective in facilities with widely fluctuating heat demands. In those cases, large storage tanks would be required, which would add cost to the system.

**Regulatory
Issues**

BCHP systems face a number of regulatory issues that should be considered as early as possible in the planning phase.

Hawaii State Department of Health — Clean Air Branch

Hawaii clean air regulations are essentially equal to the U.S. Environmental Protection Agency regulations and are administered by the Clean Air Branch of the Hawaii State Department of Health (telephone 808/586-4200). Fuel-burning equipment such as BCHP units require a permit, but there are a number of specific exemptions:

- Equipment with less than 1 MBtu/hr heat input.
- Equipment with emissions of less than one ton per year of regulated pollutants.
- Equipment with emissions of less than 0.1 ton per year of hazardous pollutants
- Other specific exemptions.
- Discretionary exemptions from the Clean Air Branch.

The actual requirements for permitted equipment will be project specific but may include a requirement for best available control technology. The Clean Air Branch may perform a modeling assessment of pollutant impact to determine appropriate measures.

For exempt systems it is not necessary to contact the Clean Air Branch for a determination, but it may be a good idea, especially for a system that is close to the emissions limit. Information submitted with a permit application includes equipment specifications, fuel type and location.

Local City and County

Permits are required from the local Building Division to cover electrical, mechanical, plumbing and structural work.

Zoning regulations set noise limits that vary depending on location. Residential zones have lower allowances.

Utilities

Utilities set interconnection requirements to maintain power quality on the electricity distribution grid. Due to the potentially high cost of connection equipment, it is critical to discuss requirements with the utility early in the planning process. The U.S. Department of Energy is working on a nationwide standard, IEEE 1547, for interconnection of distributed generation, but each utility company still sets its own requirements.

Some electric utilities also impose standby charges for on-site generation equipment. These charges account for the fact that the utility may have to provide power at short notice if the on-site generator fails. These charges can have a significant impact on project feasibility and should be identified at the beginning of project planning.

Fuel suppliers may offer special rates for cogeneration facilities. It is important to identify the appropriate fuel prices when evaluating project feasibility.

Water

A water permit may be required for an existing facility if the new system will increase water consumption. For example, if an absorption chiller is installed to replace an electric chiller, the heat rejection load will increase and cause higher cooling tower water consumption.

Benefits

Under the right conditions, BCHP systems reduce air pollutant emissions and increase energy efficiency. BCHP produces both electric or shaft power and usable thermal energy on site or near site, converting as much as 80% of the fuel into usable energy.

- BCHP systems reduce energy costs if properly applied and operated.
- On-site generation reduces electricity transmission losses.
- Engine-driven generators are relatively efficient, converting up to 40% of the fuel energy into electric energy.

- Utilization of waste heat improves overall energy conversion efficiency to as high as 80% or 90% if the heating requirements are well matched to the availability of waste heat.
- If appropriate redundancy is provided, BCHP systems can improve electrical grid reliability (by reducing the potential for peak-time blackouts).
- BCHP systems can be used as a load management tool to reduce peak demand on the electric utility.
- They are easier to site relative to new central power plants that face greater regulatory hurdles.
- They form an effective foundation for district energy plants.
- BCHP systems may get credits toward Leadership in Energy and Environmental Design (LEED) green building certification from the U.S. Green Building Council.

Costs

An engine-driven generator and heat recovery equipment costs roughly \$1,000 to \$1,500 per kilowatt of electric power capacity. Several factors can lead to significant variability in price:

- Interconnection equipment may be costly and is critical to the economics of a BCHP project.
- Wiring from the generator to the point of utility connection costs about \$1,000 per foot. Therefore, location within the site is an important factor.
- In some cases, emission control equipment may be needed and may add extra cost.
- Costs in Hawaii are about 40% higher than on the mainland due to higher labor rates.

Chilled water system costs are additional. Absorption chillers cost roughly \$700 to \$1,000 per ton to install. Electric chiller systems are less expensive, typically in the range of \$500 to \$700 per ton.

Maintenance costs can be significant for BCHP systems and must be considered in a lifecycle cost analysis. Check with manufacturers for recommended service and replacement intervals.

Check to see if tax credits or utility incentives are available.

Design Considerations

Professional Design Assistance

BCHP systems are complex, and it is recommended that mechanical and electrical engineers with extensive BCHP

experience be selected. It is also critical that contractors and operators have experience with BCHP systems.

Grid-connected vs. Stand-alone Systems

A BCHP system may be connected to the electricity grid, or it may remain independent. A grid-connected system offers the advantage of utility backup in case the BCHP system fails or needs to be shut down for maintenance. In some areas it is possible to sell excess electricity back to the utility (net metering). But grid connection also requires relatively expensive interconnect equipment. And grid-connected systems may be subject to standby charges from the utility. Standby charges account for the fact the utility may be required to take on the facility's electrical load if the BCHP system shuts down.

A stand-alone BCHP system avoids the cost and complexity of grid connection, but requires equipment redundancy to provide reliable power. Stand-alone systems are most applicable in locations without existing utility service or where adding utility capacity would be too expensive.

Even in a grid-connected system, redundant generators are likely to be necessary to achieve the full demand reduction (and corresponding utility bill savings). In estimating the cost effectiveness of the system, it is important to realize that even a short system shut down, when utility backup is required, can lead to high peak electric demand charges and offset much of the savings.

Emergency and Standby Generation Issues

Some facilities such as hospitals require emergency generators to keep critical equipment running when the electric grid fails. Other buildings have standby generators that provide tenants with power in the case of an electricity outage. Ideally, a BCHP generator would be able to take the place of these emergency and standby generators in order to offset part of the construction cost. However, there are several issues to consider.

- The emergency generator must be large enough to meet the load of critical systems, while a BCHP generator should be sized based on the facility's thermal load. Therefore, it is possible that the emergency generation requirement is larger than the appropriate BCHP capacity.
- BCHP equipment is typically more expensive than standby equipment because BCHP units are designed for continuous operation.

- On-site fuel storage may be required by code for some emergency generator systems, limiting the fuel options and affecting operating cost.

A thorough review of code requirements is recommended before choosing to use a BCHP system for emergency power.

Engine-driven Systems

The most common BCHP system type in Hawaii includes an internal combustion engine-driven generator, running on either diesel or propane fuel. In a typical engine, heat is dumped through the radiator and out the engine exhaust. In a cogeneration engine, heat exchangers are used to capture this heat. They typically produce water at about 200°F, and are available in a wide range of sizes, from as small as 25 kW up to 5 MW. Issues to consider with engine-driven systems include:

- They are relatively efficient, reaching 40% electric generation efficiency.
- Engine emissions can be controlled through several means including catalytic converters, spark retard ignition, and water injection.
- Propane engines require a special design to account for the variability of the fuel's heating value. Otherwise they may suffer reliability problems.

Microturbine Systems

Microturbines are newer and less common than engine-driven BCHP systems. These work like a jet engine except that the hot combustion exhaust spins a turbine to produce electricity rather than to propel an aircraft. Heat is recovered from the hot exhaust air after it passes through the turbine. Here are some issues to consider with microturbine systems:

- They are available in sizes of 30 kW to 100 kW.
- Efficiency is moderate, typically around 30%.
- Precooling of inlet air to about 59°F improves efficiency and reduces emissions.
- Maintenance requirements should be lower than engines due to air bearings and fewer moving parts.
- Current microturbine systems need to be rebuilt after about 1,500 starts and may not be desirable in applications with intermittent operation.

Fuel Cell Systems

Fuel cells use an entirely different means, similar to a battery, to produce electricity. They consist of two electrodes sandwiched around a catalyst and electrolyte. Hydrogen and oxygen are fed to either side of the “sandwich” and the catalyst causes the hydrogen to split into an electron and a proton. The proton passes through the electrolyte and the electron travels through an external wire (providing the fuel cell output). The proton and electron join with the oxygen on the other side to produce water. Hydrogen is typically created from natural gas in a fuel reformer. When a fuel cell is used as part of a BCHP system, waste heat is recovered to meet heating loads.

System Sizing

BCHP system capacity is usually selected based on the facility’s heating requirements. Otherwise, if the heat output is larger than necessary the system must either be throttled back to reduce output or excess heat must be dumped (via a radiator or cooling tower). And when the system is not operating at full capacity, more time is required to recover the installation cost.

In an existing facility, accurate measurements of actual electrical load, heating load and cooling load are necessary. The BCHP system should then be designed to satisfy most or all of the heating load, as long as the resulting generation capacity does not exceed the building’s electric demand. Typically, if a BCHP system also provides cooling, it will only satisfy a portion of the total load and additional cooling equipment will be required.

For new buildings, simulation programs can be used to estimate the expected loads and choose an appropriate system size.

Heat Recovery Applications

Waste heat from BCHP systems may be used for a wide variety of applications. The most common application in Hawaii is domestic water heating for uses such as showers, kitchens and laundries.

To achieve the greatest overall system efficiency, a BCHP system will supply a cascading set of heating loads where each load can be satisfied with a lower water temperature. A swimming pool is a good example of a low-temperature load that can help utilize the maximum amount of waste heat.

Dehumidification is also a potential use for waste heat in facilities where there are special humidity control requirements, such as

hospitals and some laboratories. The waste heat from the power generation process can be used to reheat overcooled air in conventional mechanical cooling systems, or to dry desiccants for desiccant-based dehumidification systems. For more information, see the Dehumidification Guidelines.

Integration with Chilled Water Systems

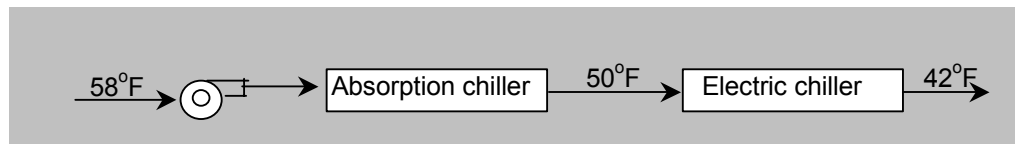
As mentioned at the beginning of this chapter, cooling is an optional element of a BCHP system. Most commonly, BCHP systems provide only electricity and heat. However, BCHP systems can and do provide chilled water through several different configurations:

- Electricity produced by the generator powers a standard electric chiller.
- Waste heat drives an absorption chiller.
- An engine drives the chiller directly.
- A combination of two of the above (for example, the generator powers an electric chiller and also drives an absorption chiller with waste heat).

Electric and absorption or engine-driven chillers can be configured in several different ways to take advantage of the best characteristics of each machine.

Chillers connected in series (Figure 9-1) can be used in high delta-T chiller plants. This arrangement takes advantage of the high temperature preferences of absorption chillers and the low temperature capabilities of vapor compression chillers. The disadvantage of this arrangement is the potential for high pressure loss in the chilled water loop, resulting in higher pumping energy requirements.

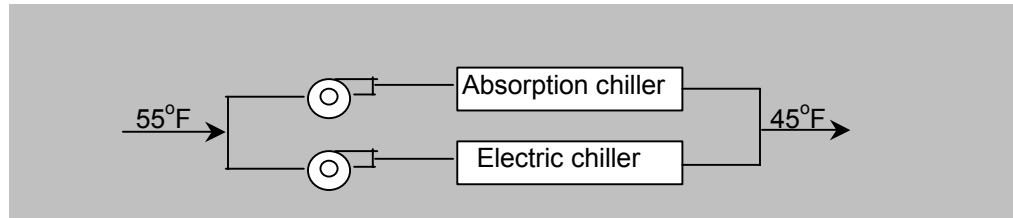
Figure 9-1.
Chillers connected
in series.



A more common arrangement for plants with two or more chillers is to have chillers connected in parallel (Figure 9-2). This arrangement is simple and reduces chilled water loop pressure drop and pumping power, but does not always have the flexibility to preferentially load a specific chiller to manage utility costs.

Figure 9-2.
Chillers connected
in parallel.

Thermal Energy Storage



Thermal energy storage usually adds to system cost, but it increases utilization of electricity production or recovered heat. The demand for heating or cooling is seldom perfectly constant; loads usually vary over the course of a day. A thermal energy storage system allows excess production of heat or cooling during part of the day to be used later when demand exceeds capacity.

Heat storage simply consists of a large storage tank in a typical system. Cooling can be stored in several forms, either as chilled water, ice, chilled brine or a phase-change material.

Other Design Considerations

- Induction generators need some power from the grid to get started.
- Space requirements are an important consideration.
- Noise and potential odors should be taken into account.
- Factory-integrated BCHP systems may be available that can be delivered as a package to simplify installation.
- Landfill and sewer gas can be used as a fuel source.
- Solar heat can drive an absorption chiller and provide heating needs as well.
- Space for fuel storage is necessary for diesel systems and for propane systems in many locations.
- Existing electrical systems should be carefully inspected rather than relying on “as-built” plans to be accurate.

Design and Analysis Tools

There are no specific tools for design and analysis of BCHP systems. The building energy simulation tools DOE-2.1E and EnergyPlus, and the transient systems simulation program TRNSYS may be used in an energy analysis of BCHP systems. Details of DOE-2.1E and EnergyPlus are available at Lawrence Berkeley National Laboratory’s Web site, <http://gundog.lbl.gov>. Information about TRNSYS is available at <http://sel.me.wisc.edu/trnsys>.

Operation and Maintenance

BCHP systems should be operated as continuously as possible to improve energy efficiency and reduce maintenance costs. Here are some operation and maintenance considerations:

- Experienced or trained operators are needed to operate BCHP systems.
- BCHP systems typically operate about 90% of the time. Downtime occurs as a result of planned maintenance and unscheduled outages.
- Frequent starting and stopping of BCHP system operations increase costs of operation and maintenance significantly.
- Maintenance costs for gas engine generators are in the range of \$0.0075 to \$0.0100 per kWh. Costs for microturbine maintenance are potentially lower, ranging from \$0.002 to \$0.010 per kWh.¹

Case Studies

Wilcox Hospital on Kauai installed five, 400-ton diesel engine-driven chillers (made by Caterpillar) for a total of 2000 tons of cooling capacity. The waste heat is used for domestic water heating. In this case, the BCHP system does not generate electricity, but provides both heating and cooling and offsets the need for electricity.

The Orchid at Mauna Lani Hotel installed four 220-kW synchronous generators (propane engines) and one 240-ton absorption chiller. The waste heat is used for hot water for most guest rooms.

¹ Source: *Combined Heat and Power: A Federal Manager's Resource Guide*, U.S. Department of Energy, March 2000.

*Figure 9-3.
Propane-fueled
generators at The
Orchid at Mauna
Lani Hotel.*



The Pohai Nani assisted living facility in Kaneohe uses one 100-kW propane engine generator (made by Hess Microgen) that provides heat for two 10-ton absorption chillers, domestic hot water and a swimming pool.

The Hale Poahi Towers in Honolulu provides hot water for 500 apartments with a 140-kW generator. Hot water is heated to 190°F and stored in two 2600-gallon tanks.

Products

BCHP products are available from a variety of manufacturers including Honeywell, Trane, York, Carrier, Caterpillar and Hess Microgen. In Hawaii, Hess Microgen provides propane engine units in sizes ranging from 85kW to 220kW. Caterpillar produces propane units from 200 kW and up and diesel units from 265 kW.

Resources

The following Web sites provide useful information on BCHP systems:

- ACEEE Combined Heat and Power, www.aceee.org/chp
- Building Energy Solution Center, www.agcc.org/bchp.cfm
- Cooling, Heating and Power for Buildings, www.bchp.org
- U.S. Department of Energy CHP Program, www.eren.doe.gov/der/chp



HAWAII COMMERCIAL BUILDING GUIDELINES FOR ENERGY EFFICIENCY
BUILDING COOLING, HEATING AND POWER GENERATION SYSTEMS

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- University of Maryland, Center for Environmental Energy Engineering, www.enme.umd.edu/ceee/bchp