INTEGRATED COMBINED HEAT AND POWER AND GAS COOLING

Milton Meckler, P.E.
Design Build Systems

Lucas B. Hyman, P.E.
Goss Engineering, Inc.

ABSTRACT

Fully dedicated on-site combined heat and power (CHP) systems present both challenges and opportunities for large multi-building projects; particularly when employing a combined cycle approach in the 3-20 MW range[1]. While some distributed power generation systems hedge their bets through reliance on both the sale and export of power (e.g., paralleling with a serving utility to achieve favorable economics), disappointing de-regulation benefits and the failure of energy trading to smooth out power supply vs. demand cost uncertainty has been a sobering experience for many California customers.

Recent rethinking by concerned CHP designers has focused on exploring smaller footprint alternatives to use of higher cost heat-recovery-steam-generators (HRSGs). One such approach involves the use of prefabricated and fully integrated steam generators, complete with associated heat exchangers, controls and pumping systems, employing low pressure, non-volatile, recirculating heat transfer fluids (HTF) capable of direct heat extraction of turbine exhaust gas waste heat to generate steam and allow cascading the remaining captured waste heat to drive absorption chiller(s), and space and domestic hot water heating systems enabling greater utilization of available heat reclamation potentials in satisfying highly variable annual building power, heating and cooling load demands. This is achieved through maintaining favorable log-mean-temperature-differentials (LMTDs) at the turbine gas extraction coil also resulting in a lower exhaust gas temperature discharge to ambient. Various examples of such alternative HRSG cycles will be presented for gas tur-

bine driven chiller and/or generator application, as well as gas turbine combined cycle operation to demonstrate the operational versatility and life cycle benefits of this approach for the above referenced range of commercially available gas turbines.

INTRODUCTION

Design Build Systems (DBS) is actively involved in developing cost effective CHP systems that are more user friendly to the highly variable load demands of building occupancy, often requiring simultaneous space heating and cooling.

Currently the conventional wisdom seems to look at employing a downsized version of utility type generation plants for buildings. Does this really make sense? Accordingly, the design engineer is faced with selecting all individual system components and matching engine or turbine driven electric generation prime movers with their respective, interconnected engine muffler, heat exchanger or gas turbine HRSGs, single or two-stage absorption chillers, or combined cycle steam turbines for larger gas turbine applications to meet client requirements.

In the public and private sector, where competitive bidding practice dominates, the designing A/E firm can expect to face time pressures from unpredictable equipment substitution(s) proposed by successful contractors, under separate pressure to also reduce their cost. Often the result is diminished performance and accordingly a recognized greater risk and reluctance for the designing A/E firm to consider use of a CHP design strategy for its building project.

For those A/E firms and clients recognizing the benefits of CHP for their projects, there are alternatives to the use of higher cost HRSGs, particularly for larger building programs with highly variable diurnal thermal loads. One such approach involves the use of smaller footprint, prefabricated steam generators mounted on modular skids functionally integrated with associated controls, heat exchangers, pumps, piping, etc. and arranged to re-circulate non-volatile, low pressure HTF capable of direct extraction of turbine waste heat to either generate high, medium or low pressure steam while enabling the remaining waste heat content of the exiting heat transfer fluid to cascade through absorption chiller(s), and space and domestic hot water heating systems. Use of this available waste heat results in greater utilization of CHP cycle heat reclamation potential through higher LMTDs across turbine extraction coils, while more closely tracking highly variable annual building heating, cooling and power demands.

POWER DEREGULATION UNCERTAIN

The state Legislature is currently considering a variety of new measures to stabilize California's electricity industry; the most prominent of which would also retain some elements of deregulation that proved traumatic in recent years.

Since soaring prices and blackouts shook apart the state's attempt to create a competitive energy market approximately 3 years ago, the Legislature has debated virtually nonstop how best to reconfigure the state's electricity industry – yet this effort has come to no resolution. Last year, for example, lawmakers considered returning to the same electric utilities regulation policies that had dominated it for nearly 90 years, before the disastrous launching of deregulation legislations in 1998.

Currently the two most prominent bills under consideration assume that California will retain certain elements of deregulation. They both also assume a role for the private energy companies that bought or built power plants, gambling that California's one-of-a-kind electricity market may pay off.

One is a bill sponsored by Southern California Edison (SCE), which now supplies power to 11 million Californians. The other is backed by private energy companies that hope to either lure away SCEs customers or sell it power.

Authors of both bills claim their goal is the same: set clear rules for the regulated utilities and private energy companies so they know how many customers they'll be serving for the foreseeable future, which would assist them in seeking the necessary long term funds to build additional power plants. Otherwise, as lawmakers correctly warn, California could suffer power shortages as soon as 2006, as its economy strengthens, because a power plant can take up to five years to permit and construct.

Consumer advocates oppose both bills. They remain suspicious of private generators and seek a return to a system in which most Californians got their power from the original three utilities — Edison, Pacific Gas & Electric and San Diego Gas & Electric -- regulated by the California Public Utilities Commission (CPUC). In fact, a proposed bill aimed at re-regulating the industry passed the state Senate in 2003 but was defeated by the Assembly Utilities Committee.

As lawmakers continue their debate, California continues to rely on a cobbled-together system that includes elements from both the 1996 deregulation plan and the state's prior over-reaction to the emergency, including billions of dollars of long-term power contracts now held by the utilities that will not expire until 2009.

Another key difference between both bills involves "direct access" or the ability of a utility customer to buy electricity from a company other than the local utility. Under California's 1996 deregulation plan, all utility customers were given this choice. However as a practical matter, the direct access option was exercised primarily by large industrial and commercial customers with many of them returning to their respective serving utilities when market prices rose sharply in 2001.

In September 2001, in fact, the CPUC elected to suspend new direct access deals while not canceling existing contracts. Currently approximately 13% of the demand for electricity in areas formerly served by the same three principal regulated utilities is provided by retail electricity companies, including Strategic Energy, Constellation New Energy, Sempra Energy Solutions and Electric America.

The SCE sponsored bill would give certain businesses; namely those that use at least 500 kW of peak power, the freedom to leave their respective regulated utilities after January 2006, while at the same time relieving those utilities of any obligation to serve those customers. If, however, their large business customers chose to remain with the utility, the businesses would have to do so for at least 5 years and accordingly could face higher costs than existing customers.

The other bill favored by private generators would allow customers that also use at least 500 kW of peak power to sign direct access deals after January 2007. Unlike the SCE sponsored bill, their bill would allow smaller utility customers to band together or aggregate to reach the same 500 kW peak power threshold requirement, thereby allowing them to also sign direct access contracts.

All sides agree that debate is far from over and that both bills will probably change many times in the Legislature. In a report released in March 2004, the PUC staff concluded that large customers should not be allowed to leave the utilities until 2009 at the earliest, so as to spread as widely as possible the burden of long-term power contracts signed at the height of the electricity crisis. If there was ever a time for serious consideration of on-site CHP building systems in California and elsewhere in the USA, this is it.

HEAT RECOVERY VIA HIGH-TEMPERATURE HEAT-TRANSFER FLUIDS

The proposed integrated CHP and gas cooling system[2,5] (ICHP/GCS) illustrated in Figure 1 incorporates a hot-oil high-temperature heat-recovery system interconnected with a modified gas-turbine-driver, which is capable of powering either an electric generator, screw or centrifugal chiller (not shown). The proposed new configuration shown utilizes the waste heat from the gas turbine driver exhaust at approximately 950°F passing through the Industrial Heat Transfer, Inc.'s (IHT) coil on its way to ambient at approximately 350°F (or lower, depending upon condensation constraints). This heat is captured by recirculating high-temperature-resistant heat transfer fluid (HTHTF) also passing through the IHT coil located in the ducted turbine exhaust, also shown entering the IHT coil at approximately 250°F (or below) and discharging at approximately 600°F. The HTHTF is then utilized to generate either low-pressure steam (15 psig steam) for direct injection into combustion turbine (CT) gas/air fuel mixture or high-pressure steam if, for example, combined cycle operation, as shown in Figure 4 is desired. The HTHTF is then cascaded to serve building space and domestic hot water loads and where thermal energy storage (TES) is desired, a low-temperature absorption chiller interconnected, as shown in Figures 1 and 2. This cascaded approach for use with programmatic, simultaneous building heating and cooling requirements maximizes the utilization of the gas-fueled energy source required by the CT driver by achieving a high log mean temperature differential (LMTD) across the IHT extraction coil.

This technology also enhances the potential for a "plug and play" trigeneration system approach without the necessity of providing a licensed 24/7 operator when operating in the low-pressure steam modality, while avoiding need for a large footprint, costly utility type heat recovery steam generator (HRSG) both of which have become major cost barriers to implementation of gas turbine type CHP building facilities.

What was unique about the ICHP/GCS is being able to employ a commercially available HTHTF operating at high temperature up to

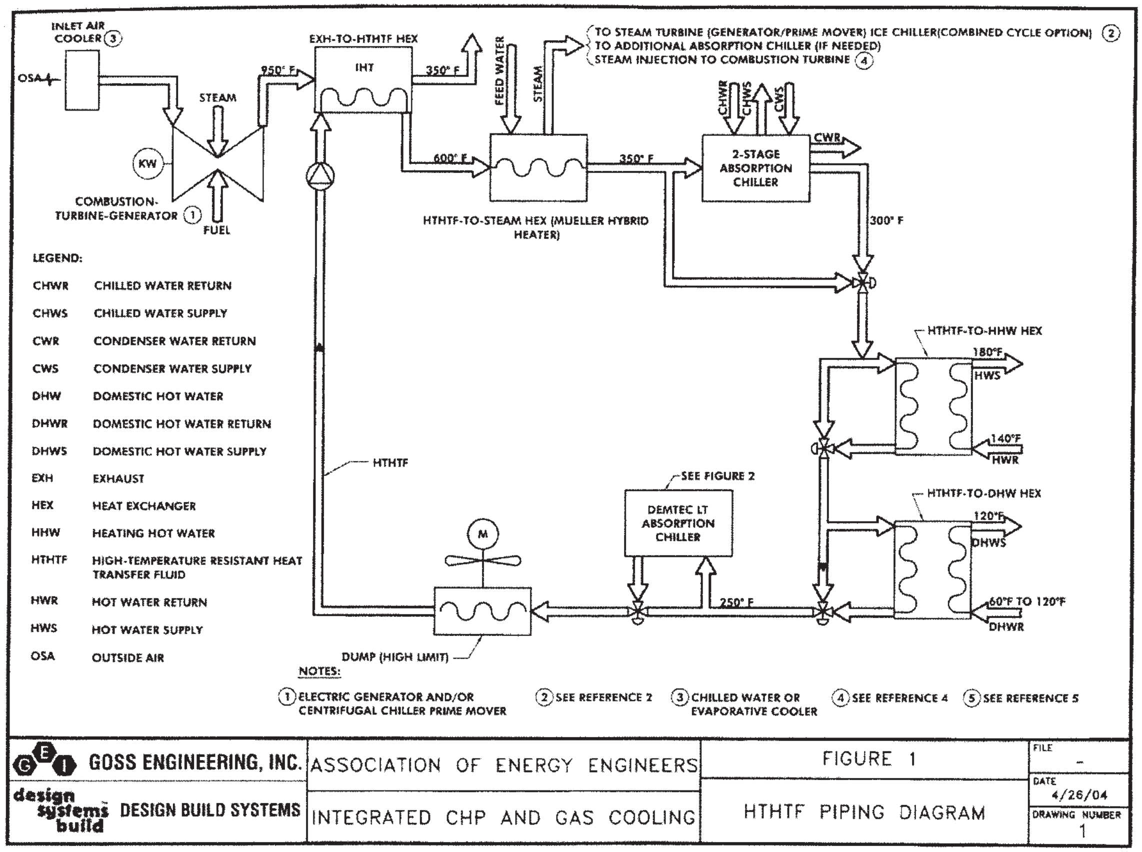


Figure 1. HTHTF Piping Diagram

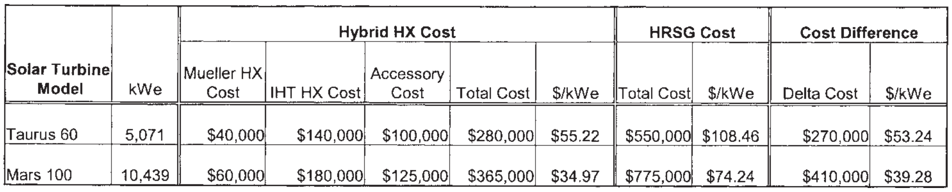
600°F. These HTHTFs offer a number of benefits for gas fired CHP building systems as discussed in this article. The HTHTF itself is a highly efficient, thermally stable, cost effective, nontoxic, safe to use and easy to dispose of fluid with a high heat-transfer coefficient and low pressure drop as a result of friction.

Unlike conventional heat-transfer fluids, use of Paratherm HE does not cause hard carbon formation on heated surfaces. Without layers of carbon building up, the common problems of heat transfer and flow impairment are eliminated. In addition, the problems of carbon chunks breaking loose, circulating through the system, impeding flows and fouling components are also avoided. Although the fluid evolves small carbon granules when over-heated, these granules remain in suspension and are generally filtered out.

Additionally, the selected HTHTF for our subject case studies operates at a low vapor pressure, which is less than 1 psia at its planned maximum operating temperature of 600°F. This feature, together with the fluid's characteristic low pressure drop, combine to provide the CHP building plant designer considerable latitude in being able to choose lower overall cost equipment as opposed to employing conventional slow reacting and costly HRSGs.

For example, refer to Table 1 below for a comparative first cost analysis of conventional HRSG and ICHP/GCS alternatives for waste heat extraction of turbine exhaust waste heat for two commercially available Solar gas turbines. Actual vendor quotes were used for each alternative.

Notice that both alternatives are expressed in the basis of $/kWe and reflect a sizable cost savings; namely: approximately $270,000 or $53.24/kWe for an ISO-rated Taurus model and $410,000 or $39.28/kWe for an ISO-rated Mars model, respectively. In short, substitution of the proposed IHT and Mueller heat exchangers for comparably sized HRSGs



		Hybrid HX Cost					HRSG Cost		Cost Difference	
Solar Turbine Model	kWe	Mueller HX Cost	IHT HX Cost	Accessory Cost	Total Cost	$/kWe	Total Cost	$/kWe	Delta Cost	$/kWe
Taurus 60	5,071	$40,000	$140,000	$100,000	$280,000	$55.22	$550,000	$108.46	$270,000	$53.24
Mars 100	10,439	$60,000	$180,000	$125,000	$365,000	$34.97	$775,000	$74.24	$410,000	$39.28

Table 1. Hybrid Heat Exchanger Cost versus Heat Recovery Steam Generator

amounted to approximately a 49% to 53% cost savings. Furthermore, when one considers the additional advantages resulting from greater operating efficiency through increased overall annual waste heat utilization, use of the ICHP/GCS in lieu of a HRSG can represent a major cost breakthrough and gain toward achieving building sustainability.

When used for steam generation, the hot oil approach may also incorporate the use of other commercially available heat transfer oils, such as: Santotherm –60, –66, –75, –VP1 or Bayer –KT 10, for example. When using heat transfer oils depending upon operating conditions, their use may result in reduced total heat recovery because of pinch point issues. However, all of the above referenced hot oils can also be used directly for equipment in which its temperature glide can be matched better, such as a heating system or an absorption chiller. Direct use of such hot oil HTHTFs can provide a better approach than use of steam, hot water, or direct firing of absorption chillers in CHP systems. Each of the latter more conventional approaches, when compared with direct use of above referenced HTHTFs, has their drawbacks. For example, use of steam reduces total potential recovered heat because of to the pinch points, and direct exhaust firing involves very large ducts to transport the exhaust gases and generally involves greater backpressure on gas-fired turbines, which can also reduce available electric output.

HEAT RECOVERY OIL SYSTEM

The proprietary ICHP/GCS turbine exhaust heat extraction system, developed by Design Build Systems (DBS) circulates a HTHTF, as shown in Figure 1. Heat is extracted from the turbine exhaust via a heat exchanger similar to Industrial Heat Transfer, Inc.'s (IHT) fin/tube exhaust heat exchanger extraction coils. The heat is transferred to the HTHTF and can be used first to generate steam, which can be used for steam injection, independently determined to improve thermal dynamic efficiencies by 10 to 15%[4]. After steam production, cooling is produced via an absorption chiller, then heating hot water, domestic hot water and finally, if additional cooling is warranted to a low-temperature absorption chiller (see Figure 2). If additional waste heat is still available, TES can be used prior to rejecting to ambient via a dump heat exchanger, as shown. The actual temperatures and flows will depend, of course, on the size and nature of the loads.

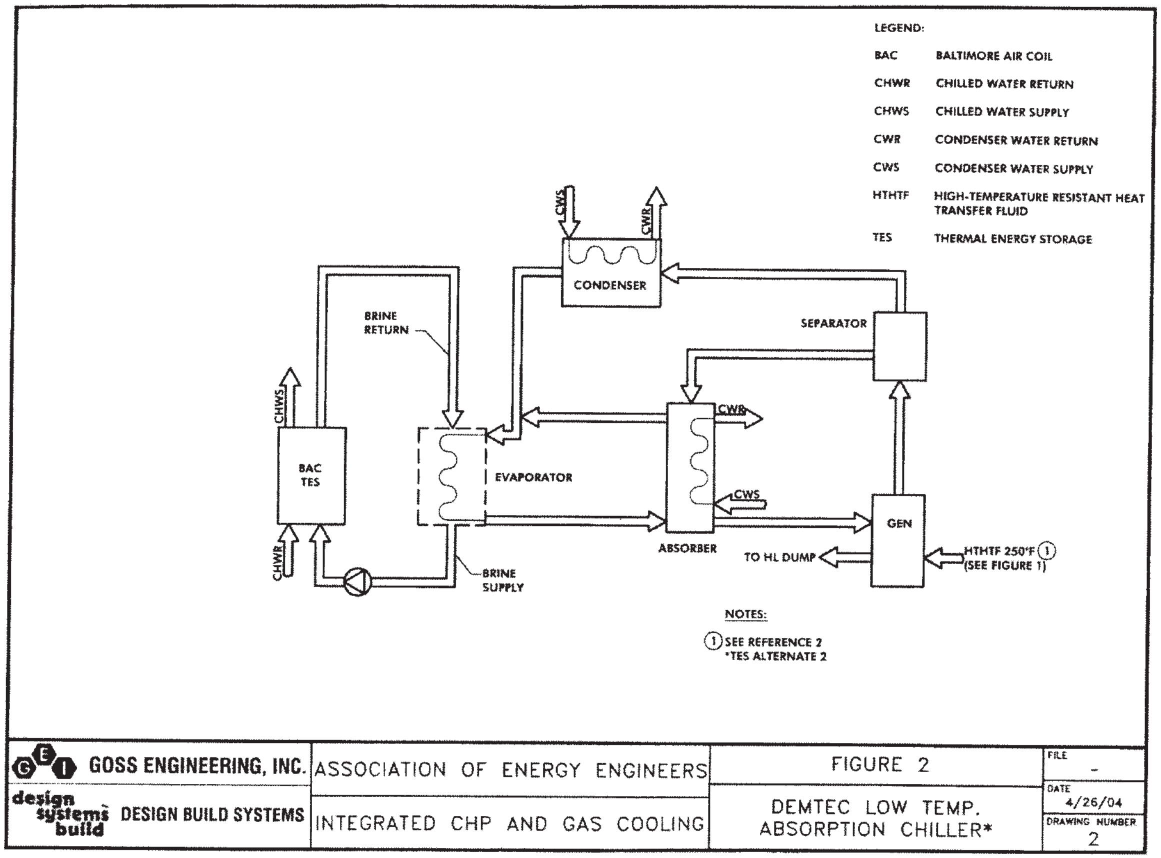


Figure 2. DEMTEC Low Temperature Absorption Chiller

The HTHTF-to-steam heat exchanger currently planned for use is a commercially available hybrid heat exchanger incorporating both shell/tube and plate heat exchanger characteristics, and capacity can be scaled up or down fairly readily. It is manufactured by Paul Mueller Heat Transfer Products and its use offers improvement versus use of conventional HRSGs when utilizing Paratherm HE or any of the above referenced HTHTFs.

Key advantages of the ICHP/GCS include:

- Lower heat-recovery heat-exchanger first costs (49-53% savings),
- Greater thermodynamic cycle efficiency as a result of higher LMTDs,
- Greater power production as a result of less turbine back pressure,
- Better load tracking (full modulation),
- Quicker start up,
- Greater ability to handle typical building transients, and
- Improved life expectancy.

Because the HTHTFs are not under high pressure, HTHTF to steam HX construction requirements are not as stringent as with a typical HRSG. Using the HTHTF in series heat exchanger configuration shown in Figure 1 increases the overall LMTD, which allows for smaller heat exchangers, lower first cost, and less turbine operating back pressure. Lower turbine back pressure reduces gas turbine power loss; e.g., as shown in Figure 3, a 2-inch water column reduction on Solar Saturn 20 reduces power loss by approximately 0.5%. Relatively colder return oil temperature also allows for lower exhaust temperatures and overall cycle efficiency improvements.

Some disadvantages of HRSGs when compared with the ICHP/GCS include:

- Cold start time delays reduce HRSG's ability to track cyclic rapid system load variations
- HRSG performance subject to balance of plant equipment, e.g., steam turbine operations
- Base of plant logic is critical to HRSG temperature and steam turbine pressure control at start up
- Accurate balance of plant equipment operational temperature es-

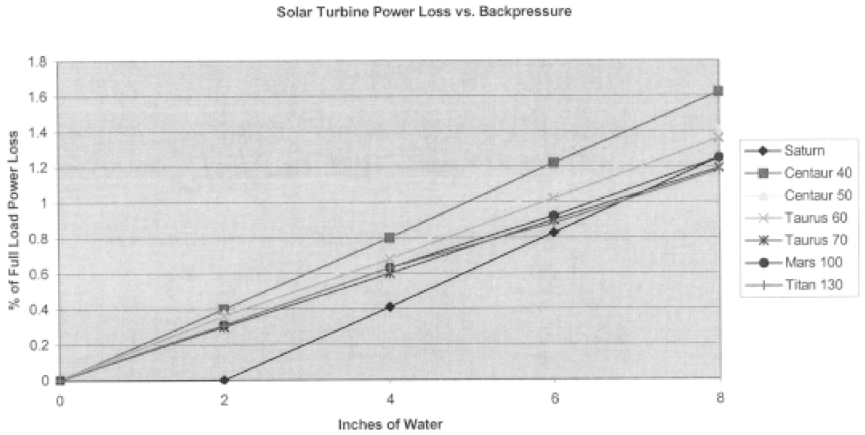


Figure 3. Solar Turbine Power Loss versus Backpressure

sential to HRSG fabrication

- Use of exotic materials to withstand thermal cycling is cost prohibitive
- Materials able to endure plant cycling are limited by current codes/standards
- HRSG design for rapid temperature changes encountered during cold start up are difficult[3].
- Need for costly "soak period" apparatus to reduce HRSG start-up time is eliminated

ADDITIONAL ICHP/GCS ALTERNATIVES

HTHTF-Fired Indirect Absorption Chillers

Should steam production not be required, the hot oil can be used directly at 350°F to produce cooling via an absorption chiller and then heating needs (space heating, domestic hot water production, etc.) via a heat exchanger. By eliminating high-pressure steam production, this could potentially reduce the need for a full-time operator.

Recent discussions with a USA Broad Chiller factory representative on a recent GEI office project study indicated that their current manufactured indirect two-stage absorption chillers can accommodate Paratherm HE fluid flowing at approximately 1.5 GPM/TR as a heating source. However, their standard machine is 85% capacity rated as a result of a required carbon steel (CO) vs. standard copper coil replacement in the generator requiring an estimated chiller first cost premium of approximately 30%. For example, assuming 210 GPM of Paratherm HE fluid entering and leaving the CO coil generator section of a Broad model BH chiller at 356°F and 329°F respectively, its actual capacity would be only slightly lower (165 × 0.85) or 140 TR at rated design conditions. This is because of to the need to utilize a cast iron coil in lieu their standard copper coil, resulting in an estimated first cost premium of 30%. For example, assuming 210 GPM of Paratherm HE fluid entering and leaving the cast iron coil generator section of a Broad Model BH Chiller at 356 and 329°F respectively, its actual capacity would be only slightly lower (165 × 0.85) or 140 TR at rated design conditions. That represents a major breakthrough. Therefore, DBS plans to incorporate Broad chillers initially into its product line until additional manufacturers can demonstrate the same equivalency.

Combined Cycle Options

Should building CHP loads and utility costs dictate the need for additional electric power versus cooling production or heating needs, high pressure steam can be used to drive a steam-turbine generator operating in a combined cycle configuration similar to that shown in Figure 4. Referring to Figure 4, notice that the gas turbine driver is interconnected by tandem shafts to both an induction motor/generator and a refrigerant compressor that is part of a mechanical chiller system. The operative steam turbine driver, by gearing and clutches shown in Figure 4, can drive either an electrical generator or the chiller compressor. With steam not available, the induction motor/generator can be used as a motor to drive the chiller only. The balance of the system remains the same, as discussed above. With the proposed 2005 California Title 24 currently not allowing credit for the use of waste heat from fossil burning sources (such as with an absorption chiller), both gas and steam turbine prime-mover-driven chillers[2] can provide a cost effective path towards compliance.

EXAMPLE SYSTEM

Actual CHP study results for the above referenced GEI office project involved a 1.5-MW Kawasaki GPB15X gas turbine with an approximate heat recovery of 11 million Btu/hr, coupled with a nominal

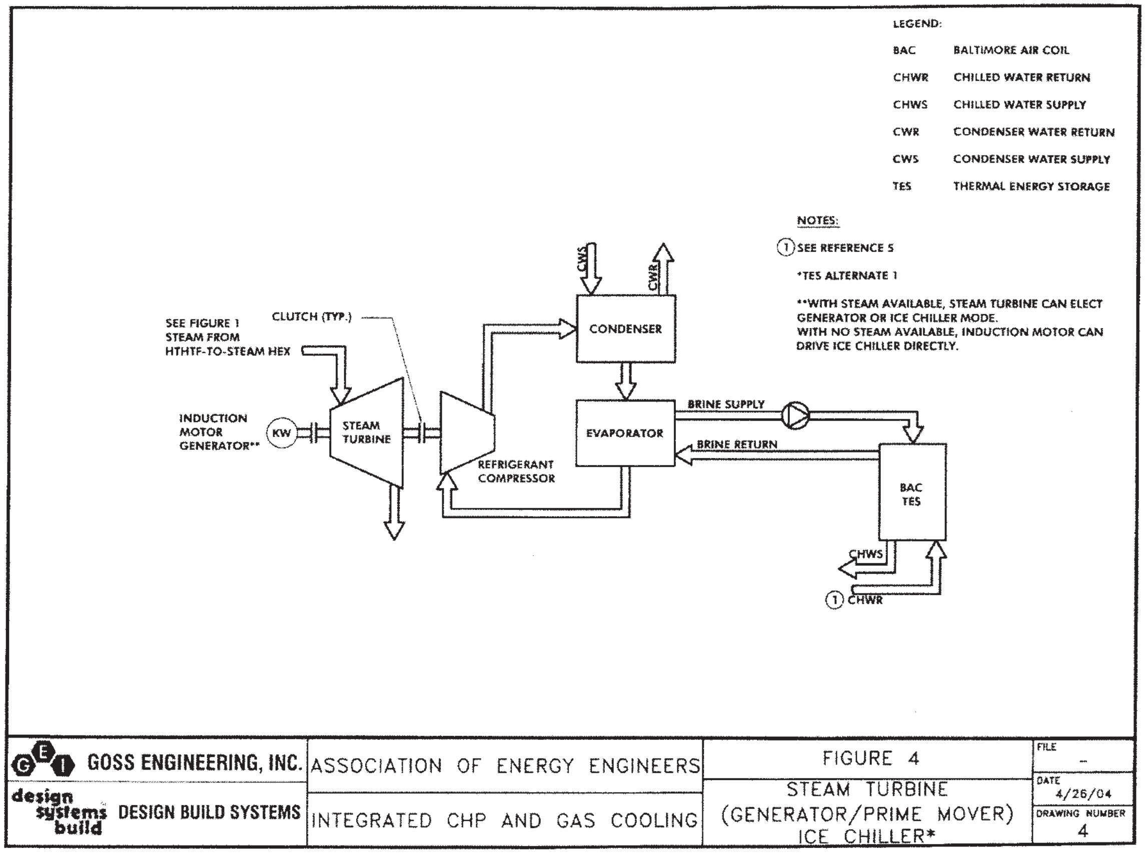


Table 4. Steam Turbine (Generator/Prime Mover) Ice Chiller

1200-ton two-stage indirect Paratherm HE fired absorption chiller. In this example, 130 gpm of the HTHTF in the steam generator can produce up to 11,000 lbs/hr, depending upon the steam pressure and condensate return temperature. The 300°F HTHTF leaving the absorption chiller still has sufficient heat to generate several hundred gpm of hot water depending upon the entering and leaving oil temperatures (e.g., if the absorption chiller is not being utilized, the HTHTF inlet temperature could rise to 350°F, and lower HTHTF temperatures below 250°F increases the LMTD of the turbine exhaust heat extraction coil.

SUMMARY

DBS is now in the process of developing a user-friendly design optimization program to facilitate rapid analysis of user requirements to pre-select appropriate ICHP/GCS components and operating modalities. This will allow CHP designers to proceed to a computer enabled design of one or more integrated skid-mounted systems for off-site fabrication and subsequent shipment for integration with gas (and steam) turbine driver(s), cooling tower(s), and/or absorption/centrifugal chiller(s), with associated interconnecting piping, controls, etc. installation performed at the project site.

Claimed advantages of the above described ICHP/GCS are as follows:

- Much smaller thermal mass of oil and water in the system compared to a HRSG, thus allowing much quicker response to varying thermal input.

- Low-pressure operation of the HTHTF loop. This reduces the mechanical requirements of the exhaust heat exchanger, making it more robust to thermal cycling.

- The relaxed mechanical requirements for the exhaust (IHT) heat exchanger and removing the steam generation from exhaust stream allows for more compact heat exchanger design.

- Reduced exhaust (IHT) heat exchanger pressure drop, which results in slight improvement in power generation.

- Lower overall installation cost.

Finally rising energy prices, environmental and power reliability concerns have a growing number of building managers and owners now considering “going it alone” with more user-friendly on-site CHP systems. On-site CHP systems give facility managers and operators generally unlimited options to manage their energy supplies as they see fit in their effort to reduce what they must pay to operate their buildings. For all of the above reasons and advantages over conventionally designed HRSG-based CHP systems, ICHP/GCS offer increased flexibility in determining how much facilities managers will pay for both power, heating and cooling, as well as how to configure systems for maximum performance and minimum energy costs.

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ABOUT THE AUTHOR

Mr. Milton Meckler, CPC, serves as the President and CEO of Design Build Systems, located in Los Angeles, CA. He is engaged in advanced HVAC studies for buildings, cogeneration, manufacturing, product design, construction safety and management, telecommunications and a variety of related engineering and construction specialty areas. Mr. Meckler has published over 300 feature and technical articles, books, handbooks, videos, design and policy manuals including 7 professional engineering books on energy conservation, indoor air quality, cogeneration and BCHP. He is a graduate of the Worcester Polytechnic Institute and the University of Michigan and is listed in the 1982 edition of American Association of Engineering Society's "Who's Who in Engineering." Mr. Meckler is also a Certified Professional Constructor (CPC) by the American Institute of Constructors. He may be reached at mmeckler@pacbell.net.

Lucas B. Hyman, P.E., is the President of Goss Engineering, Inc. He is a registered mechanical engineer with more than 20 years of experience. His professional career has included projects for major universities, government agencies, schools, hospitals, industrial, military, and private firms. Mr. Hyman has won numerous regional and chapter ASHRAE awards and is the author of several published articles. He has planned and designed central heating and cooling plants, TES systems, cogeneration plants, steam power plants, utility distribution systems, laboratory systems, HVAC improvements, industrial plants, energy conservation measures, landfill gas collection systems, underground storage tanks, fuel storage and distribution systems, hazardous waste remediation systems, and mechanical portions of wastewater treatment plants, as well as other mechanical systems.

He may be reached at lbh@gossengineering.com.