Comparing Economics of Various Methods of Improving Energy Efficiency of Commercial Buildings

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SUMMARY

Various means of improving the energy efficiency of commercial buildings while preserving and/or improving their internal environmental quality have been extensively studied. In the recent past, the Gas Technology Institute (GTI), produced several of such studies oriented exclusively to identifying the benefits of applying various energy efficiency technologies to different types of commercial installations in the U.S.A. and also in Europe. Independently, these involved technologies for desiccant dehumidification and/or systems of combined heating, cooling, and power generation, (CHP). The applications and their performance were simulated by internally developed programs such as the Building Energy Analyzer, using the DOE2.1E computational engine. Studies identified potentials of targeted application of combined technologies in comparison to using the traditional building heating, ventilation, and air conditioning equipment.[1]

The latest study, which is the subject of this paper, expands on the previous ones. Authors compare the economics of investing either in installing the energy saving mechanical equipment, such as CHPs and solar thermal cooling, or applying the modern means of improving the building envelope and reducing internal loads. As in previous studies the results were found to be “case specific”, yet for the assumed installations the preferred ways of improving a building performance were identified and are reported in this paper. This has been accomplished for the specific case of selected buildings on the campus of the University of Hawaii, yet the implications can be valid for other locations with similar climatic conditions.[2]

INTRODUCTION

In a renewed effort of making the American economy less dependent on foreign oil several approaches to improving the efficiency of power conversion systems are getting higher attention again. One of those is the concept of co-generation, a concept that over a half century of its modern evolution went through a series of names and modifications. Currently, most often labeled as combined heat and power systems, they usually incorporate various kinds of natural gas-fired prime movers and electricity generators in a configuration with equipment providing air conditioning and heating services. A solid wheel desiccant dehumidification of the indoor air, powered by heat recovered from a CHP system found to be attractive in many applications.

One of the original objectives of the Gas Technology Institute previous studies was to determine the economical value of CHP systems and their contribution to energy savings in commercial building applications. In a broader spectrum, that study was aimed at finding the benefits of recovering heat for space heating/domestic hot water, desiccant dehumidification, and absorption cooling for five specific building types, considering climatic conditions and local utility rate structures of several U.S. cities.[1]

Subsequently, these studies were expanded to cover other means of improving the energy efficiency of commercial buildings while improving their economics, such as those shown later in this report. While these additional studies were carried out for one location only, (i.e. the University of Hawaii at Manoa), the results can be considered as providing an important guidance in the process of implementing energy conservation measures for all locations with similar climatic conditions, and as such are presented here.

BACKGROUND AND OBJECTIVES

Energy is a key factor in the success of Hawaii's economy. Efficient use of Hawaii's indigenous and sustainable energy resources can reduce the state's high dependence on imported oil, increase local economic development, and reduce the potential negative economic impacts of oil price fluctuations.

As a major research university, the University of Hawaii presented an ideal setting to research energy savings by way of viable technologies and strategies that can be used to reduce energy consumption and cost while increasing energy self-sufficiency.

The Hawaiian Electric Company, (HECO) owns and operates oil-fired power plants that produce electricity for the island of Oahu. Crude oil used in the plants is imported primarily from foreign sources and then locally refined. Naphtha, a byproduct of refining process is converted by the Gas Company, (TGC) to clean-burning synthetic natural gas (SNG). Utilizing the SNG displaces the need to import additional barrels of oil. Consequently, one of the targets of GTI's study was to evaluate ways to maximize the use of this indigenous energy sources.

The following collection of energy-efficient and sustainable technologies and strategies were evaluated in terms of how much energy could be saved annually and the economic feasibility of implementation:

- SNG-fired reciprocating engine for combined heat and power (CHP) - using waste heat for domestic hot water, and absorption cooling.
- SNG-fired reciprocating engine-driven vapor compression chiller with engine heat recovery for domestic hot water production. No power production.
- Solar cooling based on the application of medium-grade heat (approximately 180°F) thermal collectors driving absorption chillers.
- Energy-efficiency strategies recommended in the local Hawaii Model Energy Code (HMEC).

In this paper we concentrate on the issues of recommended Energy-efficiency strategies as the represented the most economical means of improvements.

BUILDING SELECTION

Based on the results of evaluating the existing campus buildings it was decided to develop prototypical models that closely resemble typical existing structures as well as new buildings projected to be built on Manoa campus as well as West Hawaii and Hilo. The prototype models were then used to determine appropriate methods for targeting and applying energy-efficient strategies and technologies.

Below is a summary of the characteristics for the three models:

1. Dormitory - Twelve-story, 65,300 square-foot facility with three independently characterized zones (dormitory wings, common area, and kitchen and laundry). The zones are cooled by a central plant consisting of an electric water-cooled centrifugal inlet-vane controlled chiller. The dormitory wings make up 60% of the occupied space and the common area 35%. The kitchen and laundry area makes up the remaining 5% of the space. Building glazing is 25%.
2. Lab/Class/Office - Four-story, 93,100 square-foot facility with three independently characterized zones (classroom/office, lab/shop, and mechanical). The zones are cooled by a central plant consisting of two electric water-cooled centrifugal inlet-vane controlled chillers. The classrooms and offices make up 60% of the occupied space and the labs and shops 35%. The mechanical area makes up the remaining 5% of the space. Building glazing is 25%.
3. Library – Four-story, 135,000 square-foot single-zone facility. The facility is cooled by a central plant consisting of two electric water-cooled centrifugal inlet-vane controlled chillers. The HVAC system is configured to maintain an appropriate humidity level for library material. Building glazing is 50%.

BUILDING ENERGY MODELING

Building Energy Analyzer (BEA) computer energy modeling tool was used to generate energy and economic models for each of the building case-studies. BEA consists of hour-by-hour computer simulation models for various building types, heat and power generation equipment, and HVAC equipment. Within the BEA models, equipment (e.g. lighting, HVAC, etc.) and building parameters (e.g. wall material, window designs, roofing, etc.), energy rates, and geographical weather data can be defined for specific applications.

BEA forecasts and reports annual hour-by-hour heat and power loads along with hour-by-hour fuel requirements. GTI enhanced the software for this study with solar thermal analyses module.

BEA uses weather data from the typical meteorological year (TMY2) data sets derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The building model data streams are typical for weather during the TMY2 time span.

Alternative Energy-Efficient Technologies

As an alternative to CHP, a collection of energy-efficient technologies and strategies, based on the Hawaii Model Energy Code (HMEC), was applied to the prototypical building models to determine energy reductions and associated cost benefits. Technologies and strategies that were considered in the analysis are as follows:

<u>HVAC</u>

- Application of an economizer cycle (although typically not used in Hawaii) that takes advantage of free cooling using outside air. The system selects outside air to condition building if its enthalpy is lower than that of the building comfort set point.

- Reduced cold-deck temperature from 55°F to 50°F (the lower limit on supply air temperature) for greater humidity reduction and lower air flows and fan power. This does not apply to the Library as the building was already designed for 50°F.
- Minimal HVAC system oversizing – Oversizing was reduced from 20% (often a rule-of-thumb) to 5%.
- Addition of a desiccant wheel dehumidifier with enthalpy relief air heat exchanger. The base system is a standard gas-fired reheat system. The alternative implements an enthalpy wheel system that provides both sensible and latent heat exchange between the relief air and outdoor air. A desiccant wheel with gas-fired regeneration is also used to remove excess latent heat from outdoor air entering building.
- Addition of variable frequency drives (VFDs) on fans and pumps to control flows at partial loads – The air handling and cooling tower fans and the chilled water pump are configured with VFDs.
- Substituting standard electric centrifugal or screw chillers with an engine-driven centrifugal or screw chiller and engine heat recovery to hot water supply of the traditional heating system.

Lighting

- Increase lighting efficiency from ASHRAE standards to HMEC standards (roughly 30% to 50% reduction in watts per square foot).

Shading

- Reduced glazing percentage by 25% to account for overhang wall and window shading and radiant barriers that may be implemented on the buildings.

DISCUSSION OF RESULTS

Figure 1 and 2 show energy and cost savings respectively for the different energy-efficient technologies and strategies that were modeled for the dormitory building. Each of the technologies and strategies is represented by a multi-color bar that shows the contributions from gas and electricity. The individual bars are laid over one bar that is the width of the chart and represents the baseline model without any of the energy-efficient technologies applied. The "T" symbols indicate the change in gas levels relative to the baseline model.

In addition, all of the energy-efficiency strategies were collectively applied and the resulting scenario was titled "Collective EE" as shown in the figures.

Tables 1 through 3 show annual utility cost savings for the dormitory and the other two buildings; lab/class/office building and library, respectively.

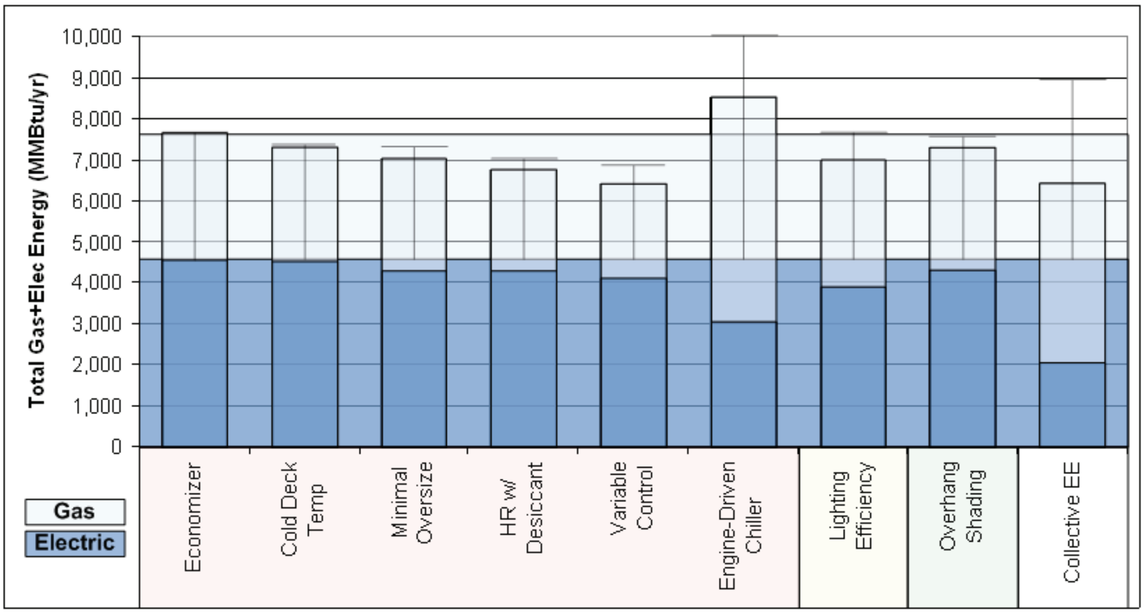

Figure 1 – Annual Energy Savings from Energy Efficient Technologies at the University of Hawaii (Dormitory).

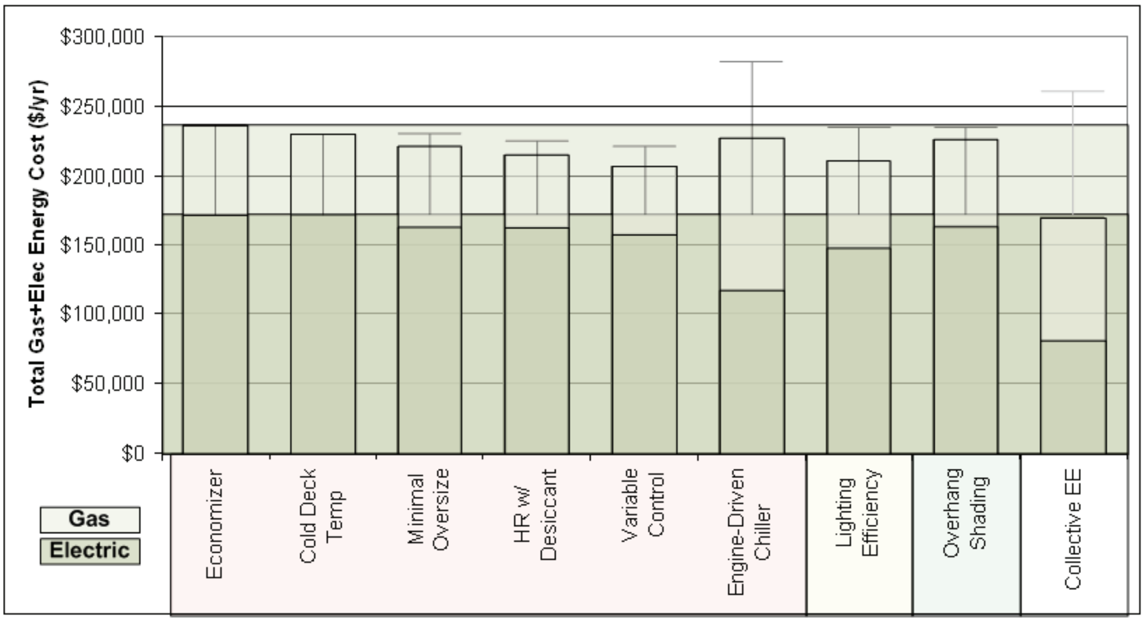

Figure 2 - Annual Cost Savings from Energy Efficient Technologies at the University of Hawaii (Dormitory).

Table 1 – Energy-Efficient Technology Savings (Dormitory).

Technology/Strategy	% Cost Savings	Annual Savings on $236,000/yr*
Economizer	0%	$0
Cold Deck Temp	3%	$6,000
Minimal Oversize	6%	$15,000
HR w/ Desiccant	9%	$21,000
Variable Control	12%	$29,000
Engine-Driven Chiller	4%	$9,000
Lighting Efficiency	10%	$24,000
Overhang Shading	4%	$10,000
Collective EE	28%	$66,000

Table 2 - Energy-Efficient Technology Savings (Lab/Class/Office).

Technology/Strategy	% Cost Savings	Annual Savings on $450,000/yr*
Economizer	0%	$0
Cold Deck Temp	4%	$18,000
Minimal Oversize	6%	$27,000
HR w/ Desiccant	16%	$74,000
Variable Control	18%	$82,000
Engine-Driven Chiller	8%	$36,000
Lighting Efficiency	5%	$22,000
Overhang Shading	2%	$9,000
Collective EE	31%	$138,000

Table 3 - Energy-Efficient Technology Savings (Library).

Technology/Strategy	% Cost Savings	Annual Savings on $460,000/yr*
Economizer	0%	-$1,000
Minimal Oversize	10%	$46,000
HR w/ Desiccant	1%	$2,000
Variable Control	23%	$107,000
Engine-Driven Chiller	3%	$13,000
Lighting Efficiency	12%	$52,000
Overhang Shading	7%	$32,000
Collective EE	29%	$133,000

To put these results into the perspective of the other two evaluated energy saving measures, it's suffice to say that none of the considered systems (i.e. particularly those of CHPs and solar thermal cooling technologies considered as retrofits to existing buildings) could match the savings of the most of the above discussed energy efficiency measures. Consequently, also their return on investment would not warrant their deployment.

Summary of the important results for the alternative energy-saving strategies is as follows:

- An economizer cycle has almost no effect on energy consumption, thus no effect on energy cost for all the three modeled buildings.

*These are the assumed operating costs for prototype buildings with the base equipment as originally designed.

- In some cases, HVAC equipment may be oversized to account for extreme weather conditions that may seldom occur, or just due to the rule-of-thumb engineering. The model indicates that over-sizing the equipment by 20% as opposed to only 5% could cost about $15,000/year. This is caused by inefficiencies of partial loading of the equipment and unnecessary pumping and fan power consumption during non-extreme weather conditions. However, variable speed fans and pumps can more than compensate for the additional cost of oversizing by reducing the excessive flows. In fact, the model indicates that equipping the HVAC system with VFDs could save $29,000/year even if the HVAC system is 20% oversized.
- An engine-driven chiller consumes more energy than an electric centrifugal chiller as shown in Figure 1. However, an engine-driven chiller with heat recovery to domestic hot water can reduce the annual cost as shown in Figure 2.
- Collectively, energy-efficient technologies and strategies could reduce annual energy cost for a prototypical dormitory by almost 30% while increasing the consumption of clean-burning gas by over 40% and reducing the consumption of electricity by 55%. Similar values are shown in Tables 2 and 3 for the two other buildings.
- As with the dormitory, the best cost savings for the Lab/Class/Office ($82,000/yr) comes from installing VFDs on the fans and pumps. The savings from VFDs are still based on a 20% oversized system. However, a 5% oversized system with VFDs also reflects significant savings ($68,000/yr).

CONCLUSIONS

The following are the most important conclusions of this study:

- Collective implementation of energy-efficient technologies, such as engine-driven chillers, fluorescent lighting and HVAC strategies could reduce annual energy cost for prototypical UH facilities by as much as 30% while increasing the consumption of clean-burning gas by over 50% and reducing the consumption of electricity by up to 50% at some UH facilities. As such they could be very effective.
- At least 70% to 90% of recoverable heat from power generation must be recovered in a manner that directly displaces heat from the heating source, for CHP systems serving individual UH prototypical facilities to fall within a 5-year payback range. CHP host facilities must present the proper criteria in terms of persistent heat loads, operating hours, and sufficient size to optimize the return offered by CHP. At the University of Hawaii Manoa campus, such facilities are a challenge to identify.
- Solar thermal cooling is not as yet feasible, given the current electric rates, cost of solar panels, and cost of absorption chillers. A significant subsidizing would be needed for implementation.

ACKNOWLEDGEMENT

This program was carried out as a collaborative effort including the Gas Technology Institute (GTI), The Gas Company (TGC), the University of Hawaii (UH), the City and County of Honolulu, and the State of Hawaii’s Department of Business, Economic Development & Tourism (DBEDT). It was developed under the auspices of GTI’s Sustainable Energy Planning Program. The project report outlines the feasibility of sustainable energy applications utilizing energy-efficient technologies and strategies at the University of Hawaii

Manoa Campus. The authors would like to thank GTI for allowing using the results of this project for this paper.

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