A Showcase for Energy Efficient Hotels in Southeast Asia

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ABSTRACT

This paper discusses an innovative project known as the Green Energy Management project, or GEM, to create an energy efficiency showcase in a major hotel located in Singapore. The project involves a major retrofit in a flagship hotel in Southeast Asia for a major international chain. This project is a unique undertaking for a commercial hotel. Innovative and new energy-saving technologies have been specified in order to meet the project goals. Aggressive design and innovative system technologies will be brought in from around the world, including the United States, Japan, and Europe.

An energy audit was performed to assess energy savings and performance improvement opportunities to be addressed during the retrofit. The audit was conducted in five stages: 1) central plant; 2) air handlers; 3) domestic hot water; 4) lighting; and 5) other equipment. The expected reduction in utility costs from the retrofit is about S$1 million (US$600,000) per year, which could pay for the retrofit within three years.

The energy audit was completed in September 1999 and results presented to the hotel management. The retrofit stage of the project commenced early this year and is scheduled for completion in 2001. The focus of this paper is on the methodology and results of the energy audit and the retrofit design. Project background and goals are also discussed.

Project Background

The Green Energy Management (GEM) project was initiated by a major hotel with the objective of accelerating market transformation and improving its own service and financial interests. In late 1998, the innovative company met with the consulting engineers to discuss cost-effective energy-saving solutions and set high goals for implementing new measures that would improve occupant comfort and health and ensure reliable service, while at the same time reducing costs and energy, diesel fuel and water consumption. The hotel has been guaranteed energy savings and performance improvements necessary to maintain its five-star rating.

To date, funding for the project has been provided solely by the hotel, which has received tax incentives from the Singapore government. The project has also received support from the Singapore Productivity and Standards Board, which has praised the GEM project's proactive approach in protecting Singapore's environment. Additional funds are being solicited from agencies in the United States, Europe, and Japan, in particular for market transformation. Manufacturers from the countries listed above will donate new technology, engineering application resources and equipment.

The results of the project will be used to create performance indices and benchmarks and to improve operations in other hotels within the chain around the world. Documented results will also be made available on the Internet to the public and to other hotels. The reduction in energy consumption and concern for the environment has been a driving force in helping to educate a large global market player about energy efficiency. The intention of the hotel management is to provide online access to real-time data to the hotel industry and the general public, and to offer public tours of their physical plants. The local hotel and tourism industries have expressed interest in this project for the money-saving potential as well as the improvements to climate control and guest comfort that would increase tourism and gain publicity for the region.

The hotel solicited an evaluation of energy usage in the hotel, including a technical report assessing economic impacts and providing recommendations for action. The results from this energy evaluation are included in this report. Implementation of the recommendations discussed in this paper has only just begun and is not covered here.

Whole-System Approach

The consulting engineers brought to the project the concept of a *whole-system approach* and least life-cycle costs. In the whole-system approach, the whole system is optimized, not just its components. The main focus of the whole-system approach is to use a retrofit as an opportunity to redesign the system and bring it in line with the current state-of-the-art technology. The whole system approach will yield:

- Higher air-side performance
- Control of air volume with enhanced control on existing variable speed drives
- Control of air ambient conditions to maintain comfort and interior finishings
- Optimization of equipment performance for weather conditions
- Higher water side performance

The key to finding synergies in the redesign is to eliminate parasitic losses wherever possible. Parasitic losses typically decrease component performance. In addition, the extra heat generated by additional operation must be removed. Commissioning the system is also important to ensure the system is operating as efficiently and correctly as intended. **Figure 1** below shows how system components interconnected and how inefficiencies might be missed if the system as a whole is not considered.

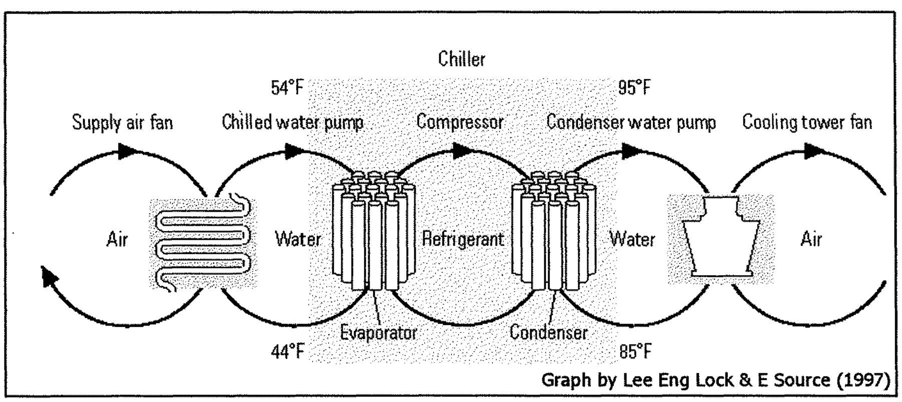


Figure 1. Whole-System Solutions

Implementing the whole-system approach requires collecting accurate measurement data to create a knowledge base that can be reliably used to detect and diagnose problems that might otherwise be overlooked. The front-end of the system is crucial as it must be able display the data in a manner that provides useful information in an efficient manner. Plots can be generated on demand which aid in the interpretation of large amounts of data. For example, viewing three-dimensional plots of power vs. day vs. time of day can help to accurately identify major problem areas. This issue is explored further in Piette, et al. (1999), which describes a multi-institution research project, "Diagnostics for building commissioning and operation."

Information Monitoring and Diagnostic System

As part of the retrofit, a sophisticated monitoring system will be installed which will provide continuous information on system conditions to the operators anytime and anywhere. This is the same type of system, dubbed the Information Monitoring and Diagnostic System (IMDS), as described in Piette, et al. (1999), which was specified and installed by the authors of this paper. Added features will include integration of AutoCAD drawings, videos, and manufacturer equipment cut sheets on the hardware installed. The information is used by the data visualization and control system to optimize operation. In addition, the Java web interface will be upgraded and PC notebooks provided to the hotel engineers so that they may use real-time data to troubleshoot from anywhere inside or outside the hotel using wireless technology. It is anticipated that by project completion the technology will be available in Singapore to allow engineers access to the monitoring system using laptop computers and 300-kilobyte per second (kBps) data access via cellular phone.

Most plant control is currently done manually. It is anticipated that improving automation, sensor and data quality will significantly improve the building operation and efficiency. The IMDS-type system will greatly aid the operators in ensuring that equipment is operating as expected and space conditioning requirements are being met.

Energy Evaluation

The 700-room five-star hotel in which the pilot project is being conducted is located in a hot and humid climate where air-conditioning is used daily throughout the year. Problems the hotel was experiencing which helped spur them to action included equipment breakdowns, condensation problems, humidity control, and hot and cold water riser pressurization. In addition, much of the mechanical equipment is nearing the end of its useful life.

An energy audit was commissioned in order to gain insight on utility costs in the hotel. The energy audit was divided into five phases: 1) central plant; 2) air handlers and ventilation system; 3) domestic hot water; 4) lighting; and 5) other equipment. The energy audit is simply an accounting of all energy uses and their costs using utility data, monitored data, and standard energy consumption and manufacturers data for such items as refrigerators and pumps. At the end of the energy evaluation, the hotel was provided with an overview of current utility costs, specifications and recommendations for reducing consumption and improving comfort, and a cost reduction analysis. The findings from the energy audit indicate that the retrofit may result in a 40 percent decrease in utility costs.

Methods

A secondary data acquisition system was used to collect high-quality data. An initial engineering review was conducted and high-resolution sensors were added to the monitored systems and to the existing energy management and control system (EMCS). Data from the existing sensors were also incorporated into the data analysis. These data showed many savings opportunities and guided the design of the retrofit. The same monitoring systems used in the audit stage will be used to verify savings once the retrofit is complete.

Various retrofit options were evaluated using DOE-2 simulations that were calibrated with utility data and component system properties. A sample building simulation model is shown in **Figure 2**. Component operational changes were used with measured data from the facility to determine the most cost-effective solutions and their payback times. Good information about weather and environmental conditions are an important part of these simulations. In this case, weather conditions are relatively constant with the exception of solar gains. **Figure 3** shows a psychrometric plot using TMY data from Singapore, which was used to incorporate air intake and envelope conditions into the energy evaluation and retrofit design. Weather and environmental conditions have a direct impact on utility costs as continuous dehumidification is required.

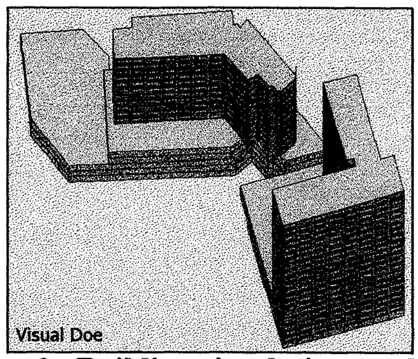
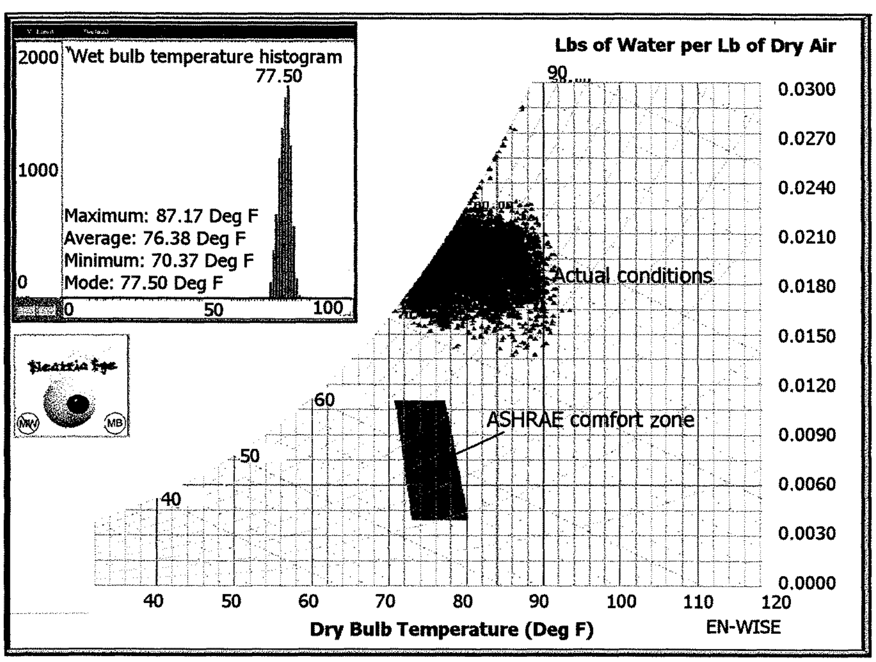


Figure 2. Building simulation model



This graph shows the temperature and humidity conditions that must be overcome to meet ASHRAE comfort guidelines.

Figure 3. Singapore psychrometric chart (1988)

Whole-Building Analysis

The hotel's total building energy profile was analyzed to determine the major factors driving the building's loads. The daily load profile for total energy consumption, shown in **Figure 4**, implies the building is driven by the central plant and internal loads.

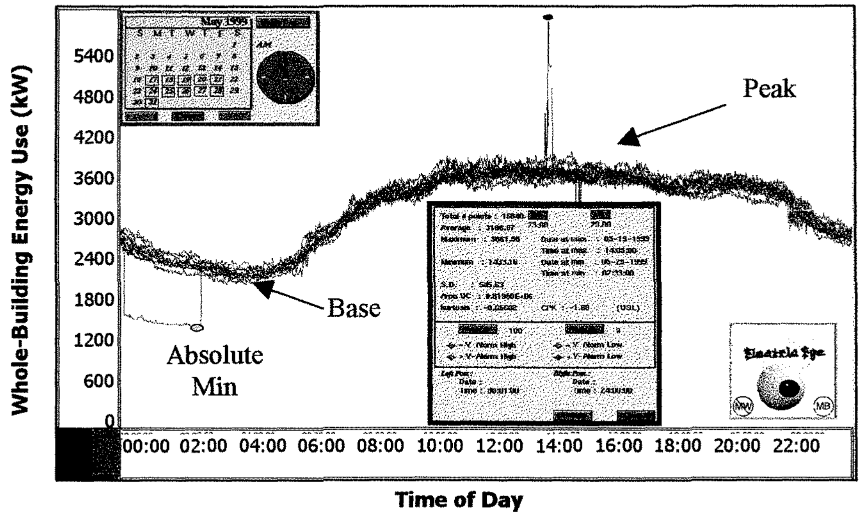


Figure 4. Total Power Profile Over Two-Week Period

Figure 5 gives a breakdown of electric energy end uses in the building. This profile is based on monitored data and is consistent with the energy profiles of other hotels in the region. The central plant and air-side components of mechanical cool represent the largest energy savings opportunities. They represent 39 percent and 24 percent, respectively, of the building's total energy use.

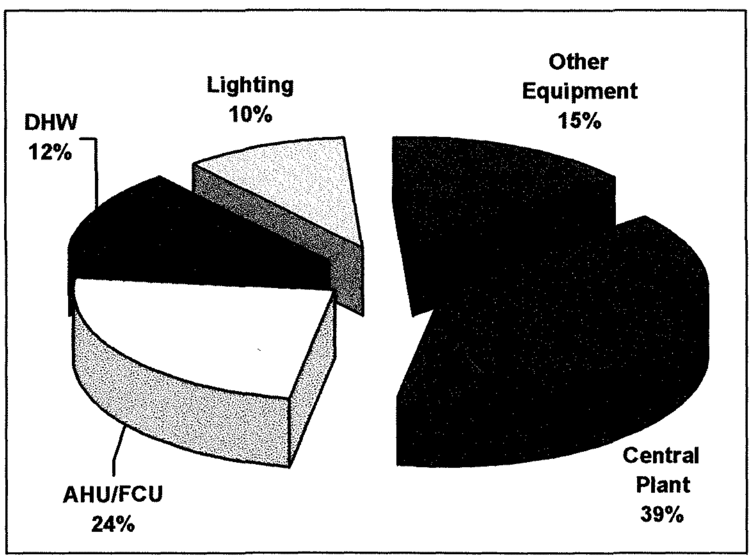


Figure 5. Breakdown of Power Consumption

Central Plant

Chillers. There are four chillers, each with an original rated capacity of 650 tons, for a total capacity of 2600 tons. The chillers were originally R-11 chillers rated at 0.62 kilowatts per ton (kW/ton); however, when they were converted to hcfc r123a they lost capacity and efficiency. Currently each chiller is only able to produce around 525 tons of cooling. Efficiencies range from 0.71 to 0.95 kW/ton with an average of 0.75 kW/ton. The actual cooling load averages 1,300 tons, with a peak cooling load of approximately 1,600 tons. Three of the four chillers are in use during the day and two chillers are operated over evening hours. Supplemental rooftop air-conditioning (refrigeration) units bring the peak capacity to 1,800 tons, with three chillers in operation. The chillers are cleaned and serviced once a year.

As the chillers are nearing the end of their service life of 15 to 20 years, they will need to be replaced. Several options were considered and evaluated using DOE-2 simulations and additional secondary measurement. The most cost-effective chiller option includes the following:

- Use high-efficiency chillers (0.5 kW/ton)
- Replace with three 600-ton and two 300-ton chillers
- Remove non-load-bearing masonry sections from the partition wall between the cooling and boiler plant to utilize exhaust system to relieve high ambient temperature in the plant rooms. (Current temperatures in the plant room exceed 40°C (100 °F)).

The efficiency values of the chillers are stated at design conditions. Lowering the condenser water temperature from 32°C (90°F) to 27°C (80.6°F) for most of the year will achieve an estimated average chiller efficiency of 0.48 kW/ton. The chillers were evaluated with internal data from the chiller micro panels and secondary temperature, pressure and flow sensors.

Figure 6 shows a plant efficiency curve for an equipment rotation with three-chiller operation. Three days of data, collected at one-minute intervals, are shown in the graph. Under correct operation, the efficiency curve should appear as a uniform grouping of points along a distinct curve. The circled groups of data on the graph are due to differences in chiller operation. Although the chillers are identical and were all manually set to operate at 90-percent load, the chillers did not produce the same chilled water temperature and operated at different efficiencies. Chiller A, which has the highest kW/ton at 0.97 kW/ton, had lower refrigerant pressure and worn condenser surfaces which affected the condenser operation and required the evaporator to work harder to maintain the setpoint. Chiller B, the most efficient chiller at 0.71 kW/ton, was receiving sufficient flow and operating near manufacturer specifications. Chiller C was only slightly less efficient at 0.76 kW/ton; however, it should have been able to produce a higher load. The piping arrangement created when a secondary loop was added prevented the evaporator from receiving sufficient chilled water flow.

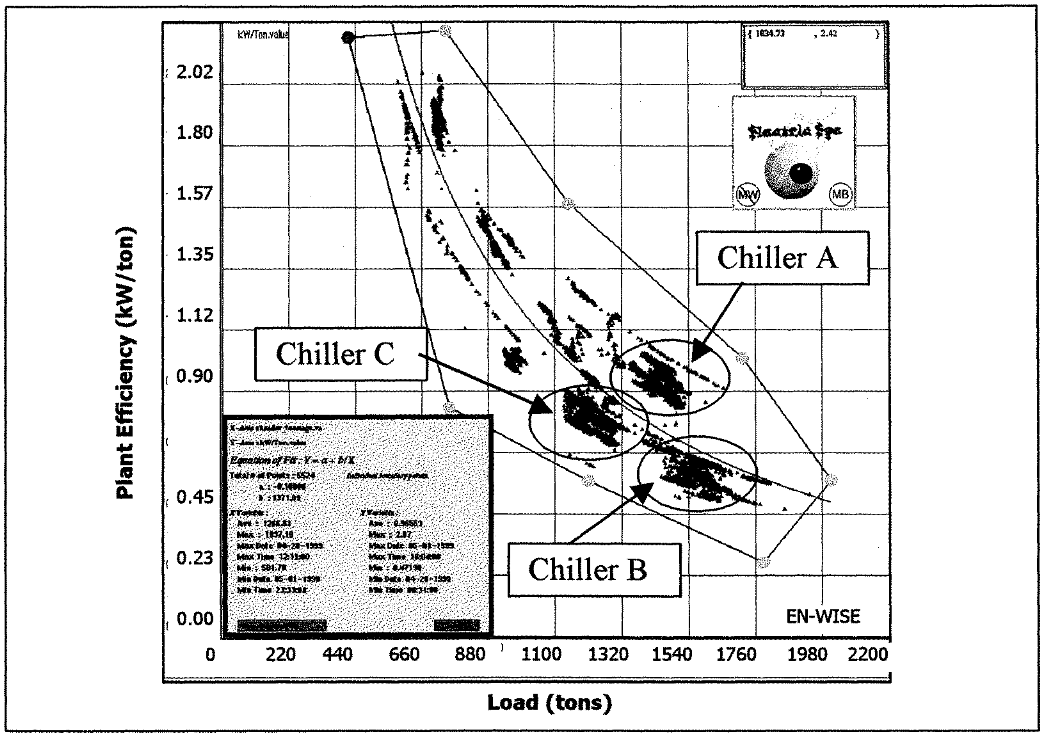


Figure 6. Chilled Water Plant Efficiency Curve

Cooling Towers. Measurement of the cooling tower performance yielded an average efficiency of 0.03 kW/ton. While this is not a particularly poor efficiency, the cooling towers are unable to achieve design condenser water supply temperature on hot days and have suffered from previous breakdowns. The four replacement towers should be sized to meet a full load of 2,400 tons with only three of the towers operating.

The existing cooling towers present a difficult compromise between space fit and the normal cooling tower function of heat rejection. The towers are situated close together and are surrounded by a high wall, preventing air from circulating properly and limiting the supply of fresh air. In addition, a gap between the top of the tower and the deck covering the unit is causing the discharge from the top of the unit to re-circulate back into the supply air intake.

A custom tower may be necessary to better utilize the available space. During final design, the cost/benefit of each configuration will be evaluated and the best economic choice made. In general, a standard cooling tower would be more cost effective as long as air flow problems are addressed. Thus the new design will include the following

- Four new cooling towers, each with 800 tons capacity
- Skirting the discharge out to eliminate recirculation
- Silencers to reduce/eliminate acoustic problems
- Evaluating a side draft as opposed to a round tower
- Using condenser water reset to lower average condenser temperature

Pumps. The measured efficiency of the current pumping system is 0.27 kW/ton. This is very energy intensive and provides a dramatic reduction opportunity. The piping design in one wing, installed fifteen years after the rest of the building, leaves much to be improved. The secondary chilled water flow in the new tower was found to be far below the design flow. A rather expensive fix of brute force was used by adding five additional secondary pumps. The cost of the piping changes, pumps and valves is exceeded greatly by the operating cost increases in the plant.

These pumps are theoretically excessive. Measurement of the chilled water flow to the one hotel wing showed that the system is only providing 990 GPM at 15 pounds per square inch (psi). Theoretically that equates to only 9 horsepower (hp). A typical pump efficiency of 80 percent yields a motor output requirement of 11 hp. They are running 60-hp pumps at 50 percent when only 11 hp are needed to overcome pressure drop and head in the secondary loop. Proper redesign of the valves and bypass systems should solve the problem.

The new system will have a lower pressure drop in the chiller evaporator. The calculated theoretical pump power required for the primary chilled water loop is 55 hp or 41 kW. Assuming an 80-percent efficient pump, a motor output of 69 hp or 52 kW is needed. After drive and motor losses the chilled water pumps should consume approximately 58 kW. This would equate to a savings of 73 kW or 56 percent. Varying chilled water supply pressure with outside conditions can achieve further reductions. This would entail reducing chilled water pressure when the outside temperature is lower and cooling demand is down.

Condenser water pumping power can similarly be reduced. Calculations indicate that 40 kW should be achievable, a savings of 113 kW or 74 percent. The methods for achieving the savings include selecting a chiller with a lower condenser pressure drop, cooling towers with a lower pressure drop, and use of variable speed drives for the condenser water pumps.

Air Handlers and Ventilation.

The evaluation of air handling and ventilation systems included monitoring of chilled water use, sensor operation, sensor output, and pressurization, as well as analysis of equipment performance and space conditions. In addition, a number of comfort issues were investigated. The hotel has over 120 fans; of those, 25 are located on the roof and the others are located throughout the building.

The majority of the hotel uses a dual-stage air system to provide comfort to tenant spaces. Rooftop makeup air handling units provide cool dry air to multiple risers. Fan coil units take air from the risers and maintain internal setpoints. The makeup air handlers, cooling coils, and fans are operated for 12 hours per day from 6:00am to 6:00pm. The fan coil units operate 24 hours per day. Both chilled water coils (rooftop and fan coil) receive chilled water from the secondary chilled water loop. Rooftop fans have VSD drive control that has been locked at a set frequency in order to resolve balancing and sensor issues. The air volume supplied to tenant spaces at night is cooler than necessary because the fan coils have a high off-coil relative humidity at a low temperature. This keeps the tenant spaces cooler than required even at low fan settings.

The current coils do not operate with adequate chilled water and do not achieve design delta-T. The added pressure drop of closed-loop coils required to dry the air will increase the fan energy. Another recommendation is to recycle the condensate from the fan coil units and rooftop coils which go to a common drain in the basement. The condensate can be used to precool the outside air delivered to the mechanical rooms. As a water-saving measure, any reclaimable water from systems such as the swimming pool, fountains, and laundry can be sent to the cooling towers to be used as makeup water.

The rooftop air handlers can change outdoor air properties more efficiently than the FCUs. Sensors that control the VSD are not in the proper location or are not operational. The fan coils do not remove humidity from the air efficiently, and thus are required to work harder to provide a comfortable environment. A runaround coil upgrade to the rooftop fresh air units will add a closed loop coil, incorporating energy recovery in the air handling units. The face area will be increased to compensate for increased delta-T across the secondary chilled water loop, without increasing fan energy.

Domestic Hot Water

The hotel uses a diesel boiler to produce low-pressure steam and hot water using calorifiers. The current diesel configuration for hot water production is expensive to use. The efficiency of this system could be improved by 40 percent. Proper controls and automation of the system are also important as most of the existing sensors have failed and equipment is run manually. There is no connection to the operation or pressure of the cold water distribution system. The use and control of a gravity-fed cold water system and a pressurized hot water system require that the riser pressure differences be closely maintained.

The use of a diesel boiler is undesirable for several reasons:

- The burned fuel produces various greenhouse gases that add to the warming of the atmosphere
- Exhaust must be properly released so that it does not re-circulate into the building.
- Fuel is stored locally and requires an underground tank that may leak into the surrounding water table.
- It is more expensive to use than electricity.

This audit focused on areas where diesel components can be transferred to existing electrical services to maintain and improve the production of hot water and steam. The use of heat pumps is being considered to improve operation and reclaim rentable space.

Domestic Cold Water Equalization. The cold water distribution system is split into three systems. One system pumps water to the rooftop and is not properly sized for the volume and amount of water that is required. A gravity-fed system and a pressurized system also supply water from the rooftop. The risers are split into two pressure systems such that the riser range is difficult to maintain. The newer wing operates under unified pressure, as both hot and cold water are delivered to the rooftop from the base of the older wing risers. Additional problems include:

1. There is no direct control of the main rooftop tank fill water pumps (located in basement) or the distribution pumps (located on roof).
2. The rooftop tank water level is not fully utilized for pump operation.
3. The rooftop distribution pumps are not operating correctly. The pump type and output do not meet the head and volume requirements.
4. There is no means of reclaiming water pressure on the rooftop.
5. The sensors that supply information to the pumps are not functioning properly, out of calibration, mounted in non-optimal locations or non-operational.
6. Pressure control on the rooftop is not operational. The pressure vessels are by-passed due to equipment malfunction.

Lighting Equipment

The hotel has tested compact fluorescent lamps (CFL) on two floors to reduce energy and maintenance costs. Using non-flickering quick-lighting CFLs, the hotel was able to achieve the desired internal ambient and aesthetic conditions. The aesthetics and longevity of the CFLs made them easier to accept. Spot measurements were taken as part of the audit to estimate the potential for savings; however, the lighting retrofit will be carried out by the hotel independent of this project. The data from the audit indicate a potential savings of S$60,000 per year on a S$180,000 investment.

Other Equipment

Refrigeration Equipment. The hotel makes use of multiple small air-cooled refrigeration units. for food lockers, cold rooms and refrigerators. The units are mounted in spaces where the discharged heat must either be ventilated or conditioned by the existing air handling system. The contrast between the mounting area and the required temperature on the opposite end was significant. Air-cooled equipment is working to maintain freezing temperatures in 100-degree F ambient conditions.

Refrigeration equipment for walk in refrigerators and freezers are operated on independent small air-cooled refrigerator units. These units are very sensitive to ambient conditions. The remote location and noise of the units generally places them in confined warm spaces. There are many ways to use existing systems to remove the heat from a refrigerated space and efficiently dump the heat in a system that has the capacity to remove it more efficiently. The consolidated unit heat load will be added to the condenser loop. The maintenance of older refrigerant devices, storage of smaller individual units and added maintenance and release of freon can then be eliminated.

Miscellaneous Pump Equipment. Waterfall, swimming pool, and distribution pump loads can be trimmed without decreasing performance. For example, waterfalls can be operated with much less horsepower and improved visual and auditory effects. There are several other opportunities:

- Reclaim the water that is drained from the waterfall for cooling tower use.
- Reduce the output and water spray. This will reduce splashing and reduce the amount of water released into the air that otherwise would increase humidity.
- Water from waterfall ponds and swimming pools can be reused for makeup water to other site systems and reduce first and disposal costs.
- Systems can also be shut down or timed to operate at reduced speed or not at all when peak power demands are met by the facility.

Miscellaneous Motor Equipment. Escalators can use sensors and variable frequency drives to reduce energy. Drives allow automated operation and transparent operation for on-peak and off-peak operation.

Miscellaneous Fan Equipment. A savings opportunity exists in improved control of a number of small exhaust fans, such as for carpark exhaust. Many of these fans are set to operate at specific times regardless of the load or internal conditions. New CO2 sensors will be used to gauge carpark conditions and control the exhaust fans accordingly.

Summary of Findings

The energy evaluation of the central plant and air handlers found significant room for improvement. The largest opportunity for savings is in the chilled water plant, which represents half of the energy savings. Significant savings opportunities were also identified in other major building systems as summarized in **Table 1**. Even greater savings may be achieved if optional measures outside the current scope are selected. Water conservation is also of special interest in Singapore as water is very expensive. Rainwater collection is being considered as a water-saving option as is the use of tower bleedoff water for toilets.

If all recommendations are implemented, the target return on investment (ROI) of 30 percent will be achieved if not exceeded. **Table 1** below summarizes the estimated ROI based on the findings in each phase and **Table 2** summarizes the expected increase in plant efficiency.

Table 1. Annual Savings and ROI

	Phase	Annual savings*	Investment*	ROI
I	Central plant	$608,000	$1,800,000	34%
II	Air handler/fan coils	$246,000	$1,000,000	25%
III	Domestic hot water	$133,000	$490,000	27%
IV	Lighting	$60,000	$180,000	33%
V	Other equipment	$23,000	$70,000	33%
	Total (including audit)	1,070,000	$3,600,000	30%
	** All amounts are in Singapore dollars (S$). US$1 is approximately S$1.6*			

Table 2. Proposed Efficiency Upgrades

Component	Efficiency (kW/ton)	
	Existing	Proposed
Plant efficiency	1.05	0.56
Chillers	0.75	0.48
Pumps	0.27	0.06
Cooling Towers	0.03	0.02
Air handler/fan coil efficiency	0.70	0.45
Total system efficiency	1.75	1.01

A simple energy savings calculation may be performed using the equation:

Savings (kW) = Cooling Load (tons) x (Base Case Efficiency – Retrofit Efficiency).

This calculation can be used to evaluate the energy savings over any period of time. It does not, however, address the savings from cooling load reductions or changes in electrical demand reduction.

Electrical demand reductions are more difficult as the rules imposed by the utility to determine maximum demand are rather complex. The time of maximum demand may vary from month to month and there are several end uses that affect demand. Luckily the electrical demand billed by the utility for the facility has varied little over the past two years. The facility demand over 1997 and 1998 averaged 4,264 kW and has not varied by more than 200 kW on a month to month basis. Utility data for 1997 and 1998 shows that the average electrical demand for the two years differ by only 31 kW. Thus we may simply take the average kW billed by the utility as the baseline electrical demand. In the event that significant changes to the space usage or occupancy of the facility were to occur, this number may need to be adjusted to reflect any changes. The demand average baseline will be updated before the construction phase of the project to reflect any recent changes.

Conclusions

The GEM project provides a significant opportunity for the participant hotel to lead the hotel industry towards a more efficient standard of operation. During the audit stage of the pilot project, numerous opportunities to achieve savings were identified which will be addressed during the retrofit stage, which is currently underway. The S$3.6 million investment for the retrofit is expected to pay for itself within three years, and thereafter provide a return on the investment.

While the project certainly has a direct benefit to the hotel, the hotel is providing the majority of the capital for the project and is willing to allow the public, including its competitors, to share in the results from the project, creating a potential for widespread adoption of energy-efficient practices which will have far-reaching benefits throughout the world. The management is interested in an accelerated market transformation of their industry. The hotel chain is large enough, that if they can transfer the technology just to the hotels within the same organization, as they intend to, not only will the energy savings continue to compound, but the rest of the hotel industry, and other commercial property managers are likely to take notice.

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