National Accounts Energy Alliance

FIELD TEST AND VERIFICATION OF CHP COMPONENTS AND SYSTEMS

Office Tower:
Microturbine/Absorption
Electric Load Reduction & Cooling & Heating

Supermarket: Microturbine/Absorption
Electric Load Reduction & Liquid Refrigerant Subcooling

Quick Service Restaurant: ICE/Desiccant
Electric Load Reduction & Desiccant Dehumidification

Supermarket: Microturbine/Desiccant
Electric Load Reduction & Desiccant Dehumidification

Theater: ICE/Desiccant
Electric Load Reduction & Desiccant Dehumidification

American Gas Foundation

gti

UT-BATTELLE

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

EXERGY **Partners Corp. Organizational Overview**

EXERGY provides technical and market commercialization support for the U.S. Department of Energy's Distributed Energy Resources Program and also provides program management, technical direction and test and verification services for the American Gas Foundation's National Accounts Energy Alliance.

Founded in 1998, EXERGY is a consulting firm designed to capitalize on opportunities arising out of the nexus of utility deregulation and global climate change in the energy and construction industry. In particular, EXERGY's president, Richard Sweetser, utilizes his 30 years of research, development, demonstration and product commercialization experience to provide fast, flexible and professional services in the field of: technical business and market planning, product development and high impact marketing and technology transfer programs. There are few entities that combine technical knowledge of the energy and building trades with the proven ability to conceptualize, design and produce the products and tools for successful market penetration.

EXERGY Partners has developed a client base working in the field of refrigeration and HVAC system integration and dehumidification technologies, and has taken a leadership role in the emergence of the integration of onsite power generation, energy recovery and thermal energy management. EXERGY Partners is providing strategic direction for the new buildings focused initiative on combined heat and power (CHP).

EXERGY utilizes its strong network of proven producers to augment its own capabilities through a series of contracts providing its clients with "just-in-time" delivered services at the lowest possible cost.

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NAEA Fast Tracks Distributed Energy Resources

The electric power industry is in transition with the intended outcome leading to competition in a formerly restricted and regulated environment. While the events of September 11, 2001 have definitely slowed down our economic growth and stress on our nation's electric grid, in time, the energy issues and events of the past of years will resurface.

Distributed energy resources widely dispersed from a successful NAEA program could provide:

Homeland Security – less dependence on central power generation means fewer major terrorist targets need to be protected like nuclear power plants which are under threat this very day! Furthermore, if the unfortunate should happen to a power plant or a series of transmission lines, then supermarkets, pharmacies, restaurants, hardware stores could function, because for economic operating reasons they added DER systems, which now can provide energy when the grid is down. Healthcare facilities, instead of using their dirty standby generation (perhaps for a very long time in the event of a power plant incident) could save money year round and also operate for significant periods of time without severely polluting our air.

Food Safety – supermarkets, food processing and distribution centers and restaurants, must refrigerant food. DER can economically help protect our food supply and delivery system.

Reliability - electricity disruptions over the past several years are well-documented and future demand of global competition and e-commerce will increase customer need for high reliability.

Power quality - brownouts are becoming commonplace as grid reserve margins sag. Even minor power anomalies can permanently damage digital equipment and appliances.

Energy density - e-commerce is creating a new level of electricity demand with high energy requirements to service digital transactions which creates high power requirements on feeder cables usually in urban centers that do not have capacity.

Grid congestion - limited transmission capacity coupled with siting difficulties in expanding transmission capacity limits electricity availability in certain areas and increases line efficiency losses.

Energy Price – sooner or later the inevitable will occur. Peak electricity prices will rise substantially as the economy expands and the pressure to reduce global warming asses increases. Twenty year buying decision must take this into account and CHP will be an important hedge tool in the hands of energy customers.

National Accounts Energy Alliance Value Proposition

Customer focused energy technologies including distributed generation (DG) and combined heat and power (CHP) are emerging and will play an essential role in moderating energy prices for commercial buildings in the future. National accounts and utilities recognize this potential for and wish to partner with non- profit organizations, industry, state governments and the US Department of Energy (DOE) to rapidly explore the technical merit of these technologies. Recognizing the essential need for synergy, the American Gas Foundation and GTI developed an Alliance program in 2001 where investors learn from the application and verification of Advanced Energy Technologies to enhance their strategic planning efforts to rapidly deploy successfully verified equipment.

Public/private partnerships are emerging to accelerate development of Advanced Energy Technologies. The key missing element is a robust Energy Technology Test and Verification Program (TA&VP). The American Gas Association's (AGA) National Accounts Program working with GTI and DOE, since early 2001, has successfully proven that a customer led Energy TA&VP could successfully and cost-effectively develop, fund, install, test and assess a series of Advanced Energy Technologies.

This offering builds upon the success of AGA's business model and the investor-based technology demonstration model successfully implemented in the past few years under GTI's Mutual Fund Program. DOE has indicated their strong desire to cost share in this endeavor because the Alliance incorporates essential improvements to institutionalize energy technology testing and verification.

- Providing investment opportunities to National Accounts and to Utilities, Gas Marketers and ESCOs.
- Focusing exclusively on supermarket and restaurant chains, hospitals and extended care facilities, hotels/motels and "big box" retail stores to significantly leverage each successful site.
- Consolidating efforts and partners with interested government entities.
- Requiring minimal investment for information, technology transfer and networking access and simply requires investors to reserve funds for their projects.
- Letting the market decide the projects through its National Accounts Advisory Board.
- Enabling strong technology transfer mechanisms through its monthly Technology Reports WEB site, and Annual Technology and Marketplace Conference and Exhibition.

Investors

This principle value of NAEA is rapid, inexpensive and leveraged application and testing of viable DER and energy efficient technologies to reduce operating costs, improves reliability, improve power quality, increase energy efficiency and reduce emissions. It is through collaboration and synergy that NAEA will succeed.

- **Networking**
  - Close working relationship between national account customers, utilities, government agencies interested in energy efficiency and grid reliability and energy technology developers.
  - Key participation in Annual Technology and Marketplace Conference and Exhibition

- **Leverage**
  - Dramatic investment dollar leveraging by bringing together national accounts, utilities, DOE, other government entities and GTI.

- Access to a broad spectrum of NAEA available data[1].
- Access to GTI's DER products and equipment test facilities. GTI has extensive facilities and experience in assessment and development of distributed energy technologies.
- Access to DOE's National Laboratories for technical expertise in all disciplines involved in technology development.
- Use of NAEA Website
- Further research cost savings from leveraging of GTI and government investments in market transformation tools, and knowledge of GTI and government research managers and selected contractors with expertise in DER and energy efficient technologies.

Consumers

A successful NAEA program would create a portfolio of proven technology solutions that can quickly and easily be deployed where national accounts have need of DER solutions. This will provide the general public with:

- Enhanced electric grid reliability through reduced peak electric demand
- Lower cost energy through optimizing the use of natural gas & CHP (energy efficiency)
- Lower cost goods and services keeping energy costs as low as possible
- Improved health & safety reducing food spoilage problems due to power outages
- Increase economic prosperity by keeping businesses operating.

NAEA Class of 2003

The NAEA coordinates tests of energy-related equipment in a variety of environments placing emphasis on energy-intensive industries with nationwide operations. In 2002, NAEA's primary focus was on supermarkets and other grocery stores that comprise the third-largest consumer of energy in the commercial building sector (behind foodservice and healthcare). NAEA projects developed in 2002 include:

1. **Russell Development, Portland, Oregon:** base loading a 30 kW Capstone, a Unifin exhaust gas to hot water heat exchanger and a 10 RT Yazaki absorption chiller to provide office tower lighting and supplemental cooling.
2. **A&P-Waldbaums, Hauppauge, NY:** Combines a 60 kW Capstone microturbine, a Unifin exhaust gas to hot water heat exchanger and a Munters dehumidifier make-up air unit. The recovered hot water provides dehumidification energy in the summer and heating in the winter
3. **HEB, Southern, TX:** A Bowman 80 kW microturbine with an exhaust gas fired Broad absorption chiller will provide the store with power plus 20 RT of liquid refrigerant subcooling resulting in substantial year-round energy savings.
4. **Cinemark, Plano, TX:** A 52 kW Stirling Engine will provide demand reducing power, two SEMCO add-no integrated desiccant modules will provide the dehumidification.for seven theaters.
5. **McDonald's, Tampa, FL:** Providing a SEMCO add-on desiccant dehumidification module designed to balance latent and sensible capacity with loads matches with a new 50 kW GENERAC natural gas engine-generator.

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[1] All NAEA Fund members will have access to the Technology Report that provides a general level of information. Specific test and verification sites will receive significantly greater information and certain site based information, necessary for assessment and modeling will remain confidential to the direct participants for competitive reasons.

Russell Development, Portland, Oregon

Site Description:

Design has been completed of a 30-kilowatt Capstone Microturbine to generate electricity for emergency/night lighting circuits for the entire office facility located at 200 SW Market St. Portland, Oregon. The electrical output is being utilized 8,760 hours per year. All available waste heat from the natural gas turbine is being reclaimed through a Unifin Micogen model exhaust-to-water heat exchanger. All the hot water generated from waste heat reclaim is being used either directly for space heating or to generate chilled water through a Yazaki, indirect-direct fired, absorption chiller.

The electric output of the Capstone is estimated to be 27 KW and will be fed through an automatic transfer switch to a new sub-panel for night lighting/egress lighting, PNL-4EL. Night lighting was chosen because it represents a 24/7 100% load factor and a load that is fairly linear. Electronic ballasts may affect the power factor and final load will be adjusted accordingly to maximize the net output of the turbine. Under turbine curtailment of any kind, load will be automatically transferred to the utility. All egress fixtures have battery backup so no interruption to egress function is anticipated.

Exhaust gas from the turbine will be ducted to a Unifin heat exchanger, manufactured by Koch Industries of Canada, designed to produce 190 °F hot water at 40 gpm. A diverting damper in the Unifin will automatically send turbine combustion products to either the heat exchanger (HX) or to the atmosphere depending on operating requirements. Final products of combustion will contain less than 9 ppm NOX.

The hot water will be either used to pre-heat boiler feed water or to produce chilled water through an absorption chiller. The energy management system, has logged runtimes on the boiler system for the past 5 years and averages indicate 25% runtime. This percentage was used in the calculations to show decreased boiler load. It is important to note that the heat reclaimed is significantly lower than the boiler plant capacity at approximately 180 MBH. The remaining 75% of the time, the hot water will be diverted through an automatically controlled 3-way valve to a direct, water-fired absorption chiller. The absorption unit selected is a Yazaki 10 ton-refrigeration chiller.

Figure one present the front of the office building with the new Cooling, Heating and Power (CHP) demonstration building located on the ground floor on the left side facing the front of the building. This new building addition blends into the “green” nature of the building with a three foot deep earth roof. The prominent picture window was constructed to allow the public to view the CHP systems as well as the computer monitoring system.

Figure 1 200 Market Street Building and CHP Demonstration Site

Figure 2 Microturbine, Heat Recovery Heat Exchanger and Absorption Chiller

Figure two presents the nominal 30 kW Capstone microturbine (left), a Unifin heat recovery heat exchanger (center) and finally a Yazaki nominal 10 refrigeration ton (RT) (right). The insulated exhaust duct work delivers the microturbine exhaust to the Unifin heat exchanger (top left foreground) and the flue gas exhaust leaving the Unifin (background right). Figure three presents the opposite view of the CHP facility where the back of the control station is seen on the left.

Microturbine

The microturbine ran intermittently throughout the summer period as summarized in Table 1 and Table 2. Data collection was also intermittent. Some performance data were captured from July 18 through September 11. The data were not collected from September 11 through October 21. Data collection has been occurring consistently since October 21, though we are typically collecting about one 10-minute record per hour (or about 1 out of every 6 possible records). As a result, the total energy use data in Table 2 are not necessarily representative of the month. The cumulative operating hours provide the best indication of turbine activity for the month. The parasitic power is about 10% of the total output as expected. The average net efficiency based on higher heating value is about 20-22%.

System Efficiency

Cooling, heating and power (CHP) system fuel efficiency is the key energy measure for this project. This efficiency measure is determined by the formula:

$$\left[\left(electric \quad output \quad MBtu/h\right) + \left(thermal \quad output \quad MBtu/h\right)\right] \div gas \quad input \quad MBtu/h$$

The microturbine and absorption chiller performance used in the calculation are rated data points as more data will be necessary to plot final performance.

Data collection has been occurring consistently since October 21, though the project has typically been collecting about one 10-minute record per hour (or about 1 out of every 6 possible records). For December the data collection rate increased to about one quarter of the possible records. As a result, the total energy use data in Table 2 are not necessarily representative of the month. The cumulative operating hours provide the best indication of turbine activity for the month. The parasitic power is about 10% of the total output as expected. The average net efficiency based on higher heating value is about 20-22%.

Table 1. Data Periods

July 18, 2002	First Data Collected
Aug 2, 2002	Capstone output changed from 27 kW to 25 kW
Sep 11, 2002	Last Recorded Chiller Activity for Cooling Season
Sep 11 – Oct 21, 2002	Data not collected or lost
Oct 21, 2002	Intermittent Data Collection begins again

Table 2. Monthly Summary of Energy and Runtime Data

Month	Percent Valid Data (%)	Logged Turbine Operating Hours	Total System Power (kWh)	Net Power Output (kWh)	Parasitic Power (kWh)	Gas Use (therms)	Avg Efficiency (% HHV)	Recovered Heat (MMBtu)
Jul-02	11.8	83	955	852	103.3	138.1	21.0%	0.7
Aug-02	52.7	143	2,218	2,048	206.7	336.4	20.8%	16.1
Sep-02	9.1	55	720	663	69.9	102.7	22.0%	4.8
Oct-02	7.9	360	1,605	1,486	146.5	230.8	22.0%	10.6
Nov-02	18.3	700	3,591	3,322	307.1	511.9	22.1%	23.1

Table 3 attempts to estimate monthly energy use using the cumulative logged turbine hours from Table 2. The collected data records also indicated that the turbine was never down for the month. Therefore, we assume that the turbine ran continuously and the electric production and gas use are estimated by proportionally scaling the collected data for the month.

Table 3. Monthly Estimated Energy

Month	Total Monthly Hours	Estimated Total System Power (kWh)	Estimated Net Power Output (kWh)	Estimated Parasitic Power (kWh)	Estimated Gas Use (therms)	Estimated Heat Recovery (MMBtu)
Nov-02	720	19,623	18,151	1,678	2,797	126.4

Table 4. CHP System Performance

	Power + thermal out		
Month	Microturbine Avg Efficiency (% HHV)	Useful Output in HEATING Mode: E+Qh (MMBtu)	Overall "CHP" Efficiency in HEATING Mode
Nov-02	22.1%	188.4	67.3%

A&P-Waldbaums, Hauppauge, NY

Technical System Description

A Capstone 60 kW microturbine is being integrated with a 20,000 cfm Munters air handling unit that is currently part of A&P's standard store design. The Munters unit provides cooling and eating to the main sales areas of the store. The unit also includes a desiccant section to provide dehumidification. A Unifin heat exchanger will be installed to recover heat from the microturbine exhaust that can be used to provide both space heating and desiccant regeneration.

The glycol piping from the Unifin will be directly connected to hot water/glycol coils in the Munters unit (supply heating and desiccant regeneration). The Munters unit is capable of using recovered heat when it is available or reverting back to the conventional natural gas-fired burners otherwise.

The microturbine skid, which includes the Capstone turbine, Unifin heat exchanger, and natural gas compressor module, will be installed on the roof adjacent to the Munters desiccant unit as shown in Figure 1. Glycol piping will connect the heat exchanger and desiccant units.

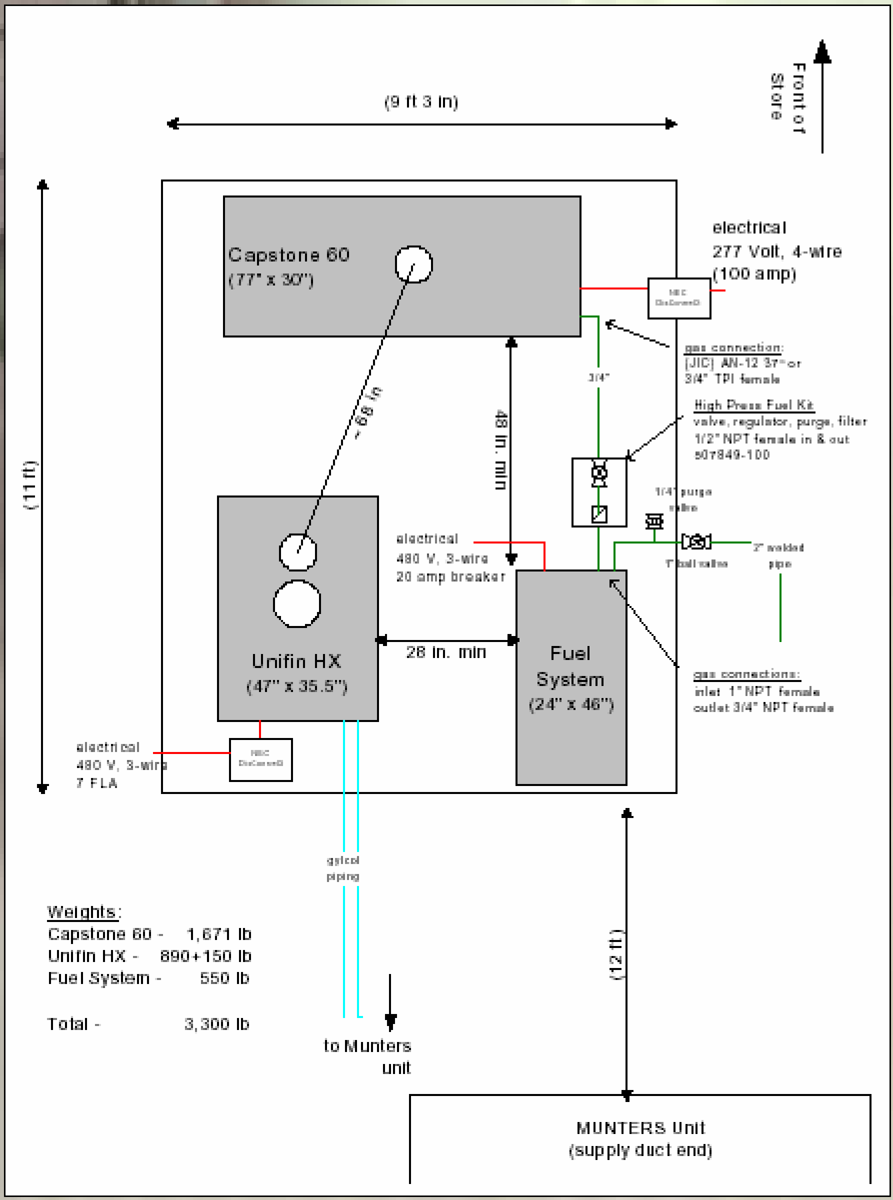


Figure 1 Layout of Microturbine Skid on Rooftop near Munters Unit

Data Collection

Monitoring Objectives

The cooling, heat and power (CHP) system at A&P will be continuously monitored to assess how well it operates across the year. The primary monitoring goals are to:

1. Quantify the variation of turbine output, gas consumption, and efficiency over wide range of operating conditions.
2. Quantify parasitic loads (e.g., gas compressor, Unifin pump, etc.).
3. Determine the thermal and electrical loads imposed on the CHP system by this application; quantify the variation of these loads with ambient conditions so the findings from this site can be extended to other climates.
4. Develop thermal performance maps of the CHP components that can be put into TRNSYS routines, including: microturbine exhaust conditions as function of output and ambient conditions, and turbine

backpressure, thermal performance of the Unifin heat exchanger/heat recovery coil network as function of exhaust conditions, thermal loads, and operating conditions, desiccant wheel performance as a function of operating conditions and loads.

5. Extend the measured results to other equipment configurations, climates, and utility rates.

Interconnection Issue

The onsite power generation equipment (the Capstone microturbine) was commissioned in early September 2002 and has been ready to begin the test and verification phase since that time. The test has not gone forward because the interconnection agreement between the site and the electric utility (Long Island Power Authority "LIPA") has not been executed. The issue delaying the project seems to be one of liability. To seek complete understanding of this issue, the New York State Research and Development Authority "NYSERDA" convened a meeting on January 14, 2003.

Dana Levy, Project Manager, Industrial Research – NYSERDA
Andris Garsils, Manager Distributed Resources Management – Keyspan – LIPA
John Ventresca, Senior Engineer, Distributed Resources Management – Keyspan – LIPA
David Tomicki, Corporate Director of Engineering & Utilities, A&P
Alfred Baker, PE, Electrical Consulting, Inc.
John Pifer, Applications Engineer, Capstone Microturbine
Jignesh Patel, Research Engineer, Keyspan Energy
Richard Sweetser, President, Exergy Partners

Technical Issues

The Waldbaums supermarket is located in a strip mall in Hauppauge, Long Island (see Figure 1). An underground single loop distribution circuit was installed by LIPA to feed the strip mall. This was likely a choice of low cost versus any logical discussion on the merits. A loop feeder starts at the utility pole runs through strip mall serving other mall costumers and Waldbaums and returns to the pole.

If the pole fuses tripped, then the other customers in the strip mall (on the 300 kVA transformer) could have their power interrupted and thus have a claim for lack of service.

Note: In order for the microturbine to cause a fault at the pole, the following customer-owned protective devices would have to all fail at the same time:

- Internal protection device inside the (type-tested) Capstone unit,
- Two 100 amp fused disconnects
- 100 amp breaker for the microturbine,
- 1,600 amp main breaker

Figure 1. Strip Mall Electric Distribution System Layout Veteran's Highway Hauppauge, NY

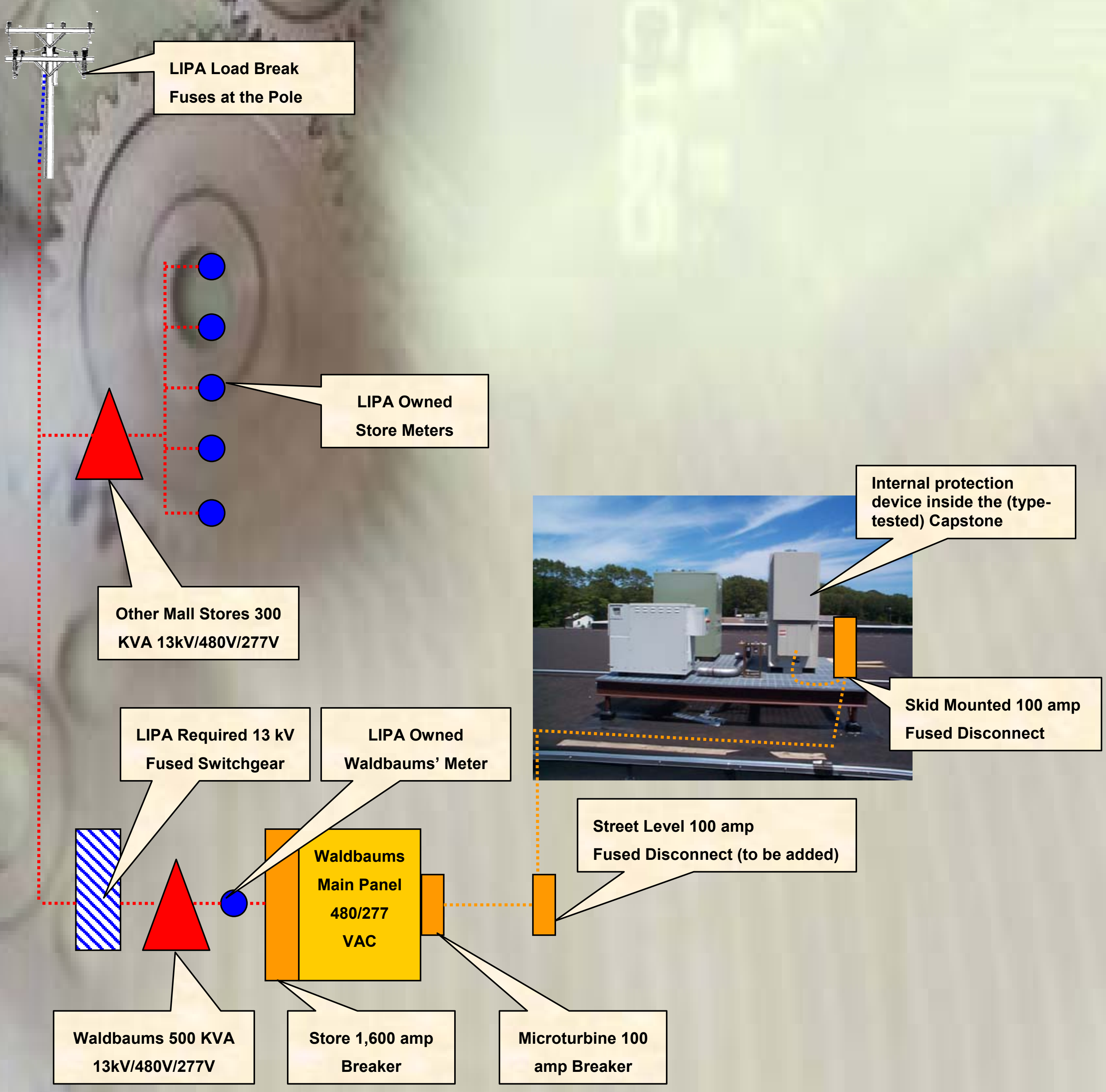


Figure 2. Waldbaums Onsite Power System Electrical Schematic with Safeties and Proposed Utility Requirement

Keyspan is the system operator for LIPA under a management contract which is in force through December of 2008 and thus represented the system operator during this meeting. They explained that the strip mall developer owns the wires from the LIPA pole transformers through to the loads. The developer chose the least cost underground system which LIPA describes as a single loop feeder. This means the developer (landlord) essentially assumes the liability to the tenants for any failure on this loop feeder. In other words, if a fault occurs at one of the stores in the strip mall that shuts down the feeder at the utility pole, then the landlord is liable to Walbaums and the other tenants for this service interruption.

The addition of the microturbine and its interconnection to the loop feeder causes a liability issue to surface. The issue is this: since the point of common coupling (PCC) for the microturbine, in terms of the utility, is the 13 kV loop feeder owned by the landlord, then either the landlord must execute the interconnection agreement (thus offloading LIPA of any fault caused by the microturbine[2]) or LIPA must require a 13 kV Fused Switchgear upstream of the Waldbaums transformer[3] which LIPA would control and thus mitigate the liability to this safety device.

The proffered choices were actually:

1) To run a new underground line directly from the Waldbaums transformer to new LIPA load break fuses at the pole. This would create a radial feeder whereby any fault at Waldbaums would only affect Waldbaums. This would be an expensive proposition to perform as a retrofit. However it poses an interesting question: Does the developer/landlord understand his liability vis-à-vis ownership of the loop feeder? Would it be more prudent for the utility to recommend radial feeders, at least to large power users initially when the costs might be more manageable?
2) The interconnection agreement could be signed between the landlord and LIPA. This action would contractually offload the "feeder fault liability" to the landlord. The question here must be asked: "What is in it for the landlord?" In this particular case, good relationship with the anchor tenant "Waldbaums" may carry the day. Looking forward, an important lesson-learned that must be managed is that multi-tenant properties pose a liability dilemma that needs to be managed. One possible method is through some sort of safety certification process at the federal or state level that demonstrates that devices like the 60 kW Capstone microturbine is no more likely to cause a fault problem than the 40 kW refrigeration compressor drive in the back of the supermarket and thus there is no engineering/safety reason for LIPA to have any such concern. In the meantime, standard liability language could be constructed for onsite generation coupled to loop feeders that utilities could incorporate into their grid interconnection agreements.
3) The third option is to add a 13 kV fused switchgear on the utility side of Waldbaums meter to prevent any line fault in the Waldbaums store from tripping the fuses at the utility pole. The cost for LIPA to install this additional fuse protection is $40,000, about 12 weeks lead-time and 6 to 8 hours of no power to the store. This is exceptionally arduous on supermarket as an outage of less that four hours requires significant action to protect frozen and refrigerated foods.

An important side note is the Alfred Baker, PE, Electrical Consulting, Inc. attended the meeting as a technical consultant for Capstone Turbine. Mr. Baker, a former LILCO employee, also happens to be a key onsite power consultant to Keyspan serving LIPA as the system operator. Mr. Baker commented at the meeting: that "the Capstone microturbine was the safest [electrical] piece of equipment on the property".

Current Status

[2] note this is a legal analysis which ignores the fact that with the current safeties installed there is virtually no scenario whereby the microturbine could cause a feeder fault
[3] transformer is actually owned by LIPA

A&P (parent to Waldbaums) will discuss the matter with the landlord and expects they will sign the agreement perhaps with A&P as a cosigner. However their remains one legal issue that needs to be resolved. The LIPA Parallel Generation Agreement (PGA) for Interconnection of New Distributed Generation Units is Accepted and Agreed by Keyspan Electric Services LLC on behalf of LIPA, yet there is no language within the Agreement proving that Keyspan Electric Services LLC has the right to act on LIPA's behalf.

HEB, Southern, TX:

Site Description:

A 71,000 square foot existing supermarket located in southwestern Texas. The store is equipped with one low temperature rack, one split temperature rack, two medium temperature racks and a dual path HVAC system. The four refrigeration systems are packaged rooftop units.

The basic premise for the proposed test at the HEB store will be to supply enough continuous on-site power generation to provide thermal energy for an absorption chiller to supply liquid refrigerant sub-cooling to the low temperature and medium temperature refrigeration racks. This installation will test the viability of providing liquid refrigerant subcooling to four Hussmann refrigeration systems. The four rooftop mounted refrigeration units each have a compressor house with an attached air-cooled condenser. Water-to-refrigerant heat exchangers (HX) need to be installed in the refrigerant liquid line under each air-cooled condenser to provide subcooling.

Figure 1 – HEB Store

The base design is based on the use of a lithium bromide / water absorption chiller suitable for outdoor ground installation. An alternative roof mounted air cooled ammonia/water absorption system is being investigated to eliminate increasing site water consumption (by using a cooling tower). The final outcome of this investigation will not affect the Data Collection Plan.

Calculations, assuming a lithium bromide absorption system, show that subcooling liquid refrigerant to 45°F on each of the four refrigeration condensing units would require a minimum of 15 RT, average of 18 RT and maximum of 31 RT. The essential element is not to take the store grid independent, but to effectively use the thermal energy to provide the liquid refrigerant sub-cooling.

Bowman (80 kW microturbine) providing exhaust gas directly to a nominal 50 RT “exhaust gas” activated Broad absorption chiller. The proposed system consists of a Bowman Power System’s TG80RG Microturbine Generator, a Spectrum Model 2 - Single Stage Li-Br absorption chiller, manufactured by Broad USA Inc., a Bowman VO5G gas boost compressor, and all the necessary ducting, interfaces, and controls. The exhaust of the TG80RG will be used directly to activate the absorption chiller to maximize the total system efficiency and to improve the power/chilling density. The proposed system will have a nominal electrical rating of 80 kW and the capacity to provide 31 RT of chilling at standard conditions. The proposed system will be equipped with an advanced digital control system capable of providing local operator interface as well as communication link for WEB based remote monitoring and data logging.

Figure 2 - Bowman 80 kW Hot Water CHP with Absorption Chiller and Cooling Tower

Figure 3 - 60 kW Microturbine, Broad nominal 50 RT Absorption Chiller with Cooling Tower

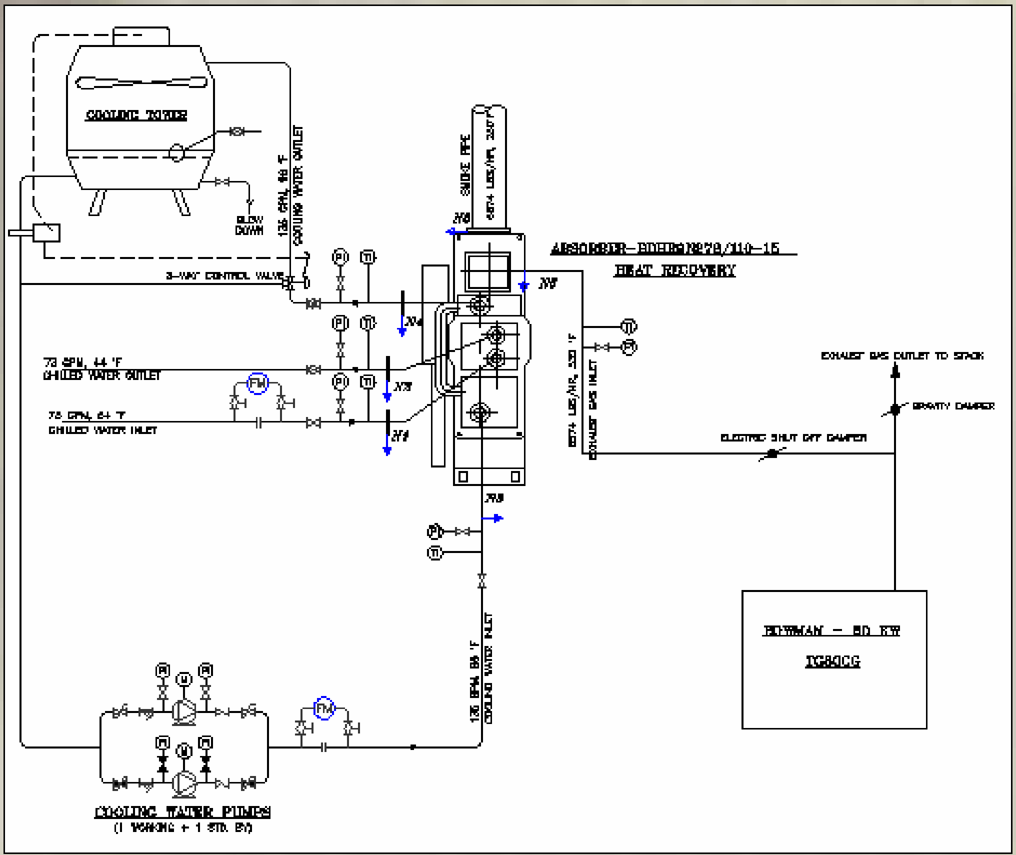


Figure 4 - Bowman/Broad Schematic for HEB

Cinemark, Plano, TX:
Theaters technically are ideal locations for desiccant dehumidification as they largely operate at night (low dry bulb and can have elevated wet bulb), have no windows and have high people density. However, theaters are generally owned by large chains and are reluctant to pioneer. Cinemark USA, Inc. is one of the largest motion picture exhibitors in North America, with 3,014 screens in 33 States and internationally in Argentina, Brazil, Canada, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Honduras, Nicaragua, Mexico and Peru. This will be the first of its kind DG and desiccant dehumidification system applied to a theater. Theaters also have the opportunity to investigate CHP systems for reliability and peak shaving. Retrofitting desiccant systems traditionally has been cost prohibitive. ORNL and SEMCO have created an add-on desiccant dehumidification module (ADM) designed as a retrofit device for rooftop applications. Two ADMs will be retrofitted on a total of seven auditorium systems. Onsite generators have traditionally not been employed at theaters. A Stirling engine generator set will be installed and run to determine the feasibility to match with a number of add-on desiccant modules for future CHP applications.

Figure 1 - Typical Cinemark Tinseltown Theater

Figure 2 – 10 RT Rooftop with prototype ADM (foreground)

Figure 3 – DTE Energy 52 kW Stirling Engine Generator

Space Conditioning Add-on Desiccant Module Test & Verification
Oak Ridge National Laboratory and SEMCO have been working on a novel natural gas / or recovered heat (CHP) regenerated Desiccant Add-on Module (ADM) solution for theaters. The module is designed to augment rooftop units to better manage the outside air load (latent and sensible). In essence, the ADM is situated downstream of the rooftop unit with only a portion of the "supply air" being deeply dehumidified and mixed into the remaining supply air and delivered to the space.

Desiccant Test Configuration
Two SEMCO integrated ADM systems, sized to provide approximately 4,000 cfm of moderately cooled and dehumidified outdoor air will be installed as dedicated outdoor air systems, delivering air to the return air section of the existing Trane rooftop units. In this approach, the integrated ADM systems will handle all of the latent load associated with the outdoor air as well as that associated with the space occupants (internal latent load). For future facilities, this would drop the current 20 ton rooftop and associated ductwork sized for 8,000 cfm down to an 8.5 ton unit with ductwork sized for only 3,500 cfm.

All the installation work, with the possible exception of some indoor sensors and the main power feeds to each ADM can be done on the roof. SEMCO double wall, insulated, flanged and gasketed ductwork will be utilized to assure minimal impact of ambient conditioned upon the treated air. This approach is being taken to provide an optimal retrofit solution for similar Cinemark theaters.

The theater arrangement is ideal for demonstration since the facility is symmetrical. Seven theaters that are located on the right hand side of the facility appear to be identical to the seven on the left. One wing of this facility (seven theaters) will be retrofitted with 2 SEMCO integrated ADM units and instrumented and the other wing served by the conventional systems will also be instrumented as a control. One ADM would serve the four smaller theaters (13, 14, 15 and 16) while the second ADM of the same size would be required for the other three larger theaters (17, 18 and 19). Both groups of theaters require approximately 4,000 cfm of outdoor air.

- Significant improvements can be made in space humidity control without increasing, and for new construction, decreasing the total installed cooling capacity.
- By maintaining lower, more stable space humidity levels, the space temperature can be increased while still reaching occupant comfort, which should significantly decrease the energy utilized for space cooling.
- The ADM will utilize low cost natural gas to handle a large percentage of the latent (moisture) capacity, while allowing for the delivery of much drier air than possible with the current cooling systems. On cool humid days, the active desiccant wheel will provide most of the dehumidification.

Figures 4 through 9 model a 293 seat theater full and half-full and at two ambient conditions It is evident from the model that conventional rooftop equipment will never meat a desired condition of 75ºF and 50% RH. The DOE2 modeling also suggests that the cost of operation is reduced 30-40% by controlling the humidity and allowing the space to be controlled at 75-76 degrees instead 68 -70 degrees required by conventional equipment.

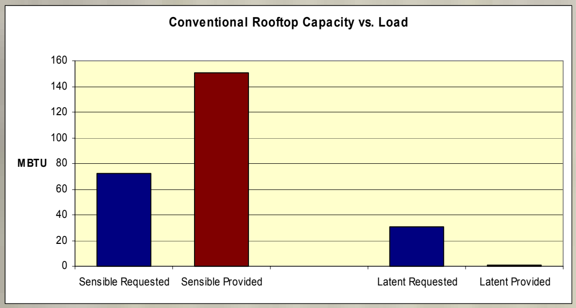
Packaged AC Unit and ADM Solution Space Relative Humidity Model: Peak Sensible OA/Full Occupancy

Air Flow Requirements	
Outdoor air volume	2,198
Supply air volume	8,000
Outdoor Air Dry Bulb	92
Outdoor Air Grains	115
Outdoor Air Enthalpy	40.2
Return Air Dry Bulb	75
Return air RH%	52%
Return air grains	68
Return air enthalpy	29
Coil entering air dry bulb	78.7
Coil entering air grains	77.8
Coil entering air enthalpy	31.1
AHU Tonnage	20
Condenser Ambient Dry Bulb	92
Coil Leaving enthalpy	24.3
RH leaving the coil	95%
Coil leaving temperature	57.6
Coil leaving grains	67.4
Total Sensible capacity provided	182,306
Total Latent capacity provided	56,460

Building Load and Conditions	
Auditorium People Requirements	
CFM/person of outdoor air utilized	7.5
Number of People	293
Sensible load per person (btu/hr)	245
Latent load per person (btu/hr)	105
Desired Conditions (Goal):	
Space Dry Bulb	75
Space RH%	52%
Space grains	68
Space enthalpy	28.6
Calculated Space Loads	
Internal sensible load	71,801
Internal latent load	30,772

Conventional Rooftop Approach	
Supply Conditions to maintain 75 degrees and 50% RH	
Required supply air temperature	66.7
Required supply air humidity	61.9
Required supply air dewpoint	53.8
Comparison of Delivered Loads vs. Desired Loads	
Capacity Available for Space Sensible	150,648
Capacity Available for Space Latent	832
Sensible capacity shown as a percentage of that desired	210%
Latent capacity shown as a percentage of that desired	3%
If controlled off of space temperature setpoint of:	75
Run time required	65%
Outdoor air latent load to space during compressor off cycle	24,748
Total space latent load (including compressor cycling)	55,520
Space latent capacity (including compressor cycling)	542
Percentage of latent capacity required	1%
Space Dry Bulb	75
Space grains	83
Space enthalpy	31
Resultant space relative humidity at setpoint temperature	**64%**

Add-on Desiccant Module Approach	
Conditions Possible with ADM Approach	
ADM supply air temperature	62
ADM supply air humidity	61.9
ADM supply air dewpoint	53.8
Comparison of Delivered Loads vs. Desired Loads	
Capacity Available for Space Sensible	112,306
Capacity Available for Space Latent	30,981
Capacity Available for Space Sensible	156%
Capacity Available for Space Latent	101%
If controlled off of space temperature setpoint of:	75
Run time required	100%
Outdoor air latent load to space during compressor off cycle	147
Total space latent load (including compressor cycling)	30,919
Space latent capacity (including compressor cycling)	30,916
Percentage of latent capacity required	100%
Space Dry Bulb	75
Space grains	68
Space enthalpy	28.6
Resultant space relative humidity at setpoint temperature	**52%**



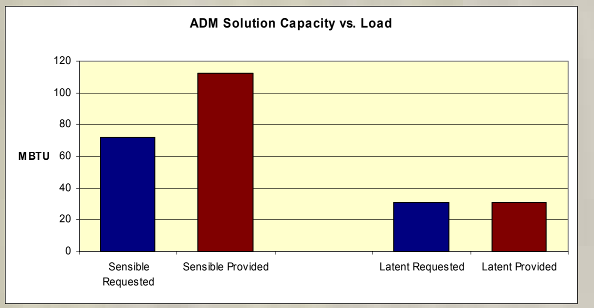


Figure 4 – Theater Full (293 people) and 7.5 cfm per Person @ 92F DB and 115 Grains of Moisture

The general Integrated ADM Equipment will consist of:

1) Two integrated ADM systems including the necessary active desiccant wheel, cooling coil, supply fan, filtration, regeneration section (gas fired), all controls, roof curb if needed (note no roof penetration will be required) and all other components necessary for the system to function.
2) Remote condensing section required for each ADM system. (Note that SEMCO can build the condensing section into the system, but Cinemark may want to have Trane condensing sections so that the same service group can look after them, either way, the cost is the same).

3) Modem for data collection. We assume Cinemark will provide access to a phone line to be accessed for data acquisition during the test period.
4) 20 combination temperature and humidity sensors for instrumentation as well as control.
5) Air balance, install and check out the sensors.
6) SEMCO will provide the insulated ductwork and flanges necessary to connect from the ADM systems to the rooftops.

Stirling Engine Generator Test and Verification
In contrast to traditional Otto and Diesel internal combustion engines that take in fuel and air inside the cylinder, the Stirling engine works differently. Instead, the Stirling engine contains a sealed-in amount of working gas that is used over and over. Rather than burning fuel inside the cylinder, the Stirling engine uses external heat to expand the gas contained inside the cylinder and push against its pistons. The Stirling engine then recycles the same captive working gas by cooling and compressing it, then reheating it again to expand and drive the pistons, which in turn drives a generator. As a result, the Stirling engine provides benefits that are advantageous to many power applications. These benefits include smooth, clean, quiet engine performance without the need for a compressor, muffler or emissions equipment (easily able to operate at emissions levels within the East Texas limit of 0.47 lb/MWh for NOx). In addition, the Stirling engine is highly efficient and durable.

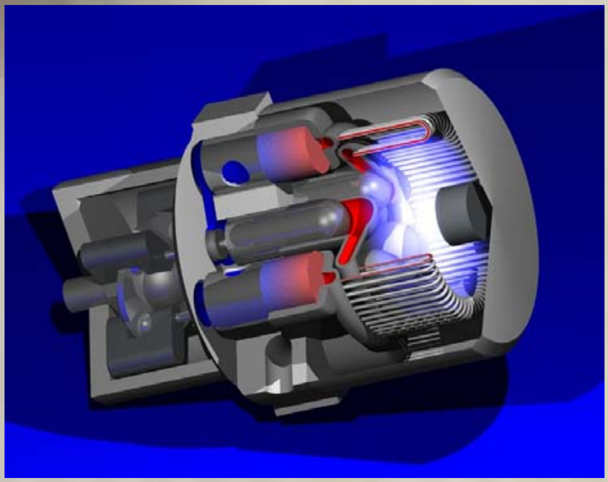


Figure 10 –Stirling Engine cutaway view

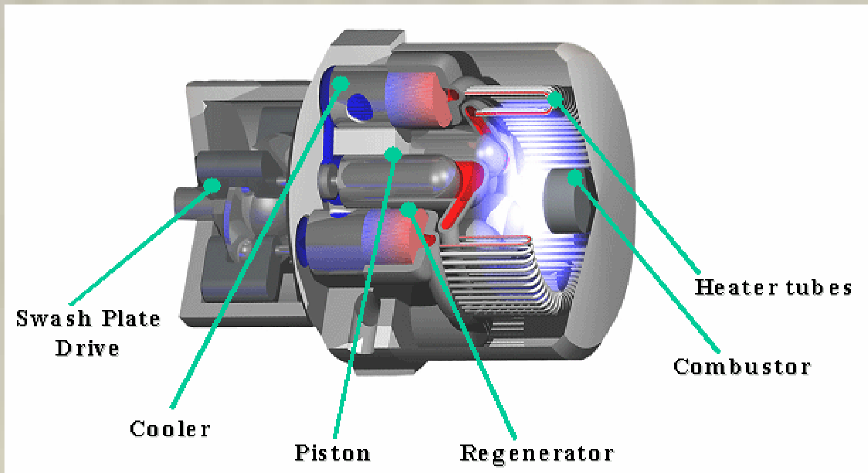


Figure 11 – Stirling Engine component view

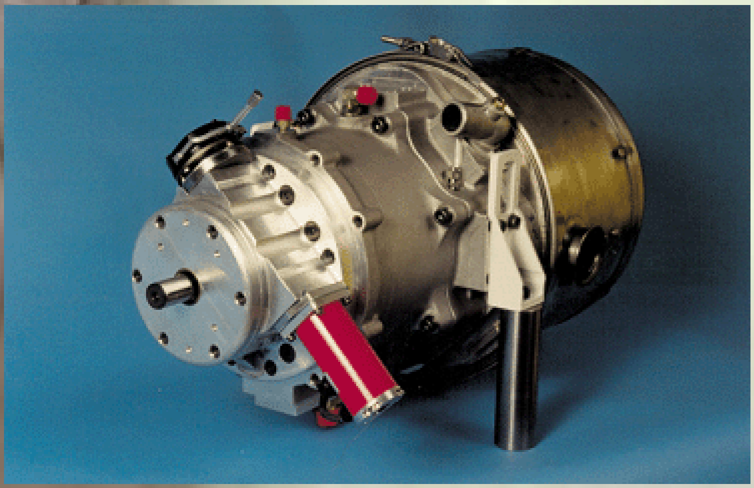


Figure 12 –Stirling Engine view

The engine is a four-cylinder, double-acting Stirling engine with a swash plate drive. At the heart of the engine are four independent gas enclosures each comprised of the volume under a piston (compression volume), the volume above the adjacent piston (expansion volume), a series of three heat exchangers connecting these two volumes, a cooler adjacent to the compression volume, a heater adjacent to the expansion volume and a regenerator between the heater and the cooler.

The four pistons are arranged symmetrically around a swash plate that forces the reciprocating motion of any two neighboring pistons to be 90º out of phase. The gas enclosures are charged with high-pressure hydrogen that serves as a working fluid. The reciprocating motion of the pistons causes the volume of hydrogen to increase and decrease alternately. The expansion spaces are maintained at a high temperature by continuous combustion of fuel or some other source of heat (waste heat) outside the tubes of the heaters.

The compression spaces are maintained at a low temperature by liquid cooling of the coolers. Therefore, the temperature and the pressure of the hydrogen during expansion is higher than during compression. The hydrogen absorbs heat from the combustion process, converts a portion of it to mechanical power, which it delivers to the pistons, and rejects the balance to the liquid coolant. The mechanical power delivered by the hydrogen to the pistons is aggregated and converted to rotating shaft power by means of the swash plate drive. The regenerator, which is the third heat exchanger, does not exchange heat with the outside. It alternately absorbs heat from and releases heat back to the hydrogen in order to improve the engine efficiency. The engine's output shaft can be connected to a load such as a generator, compressor or pump.

McDonald's, Tampa, FL:
Average McDonald's build cycle is 120 days from project approval. Currently a site is being sought by McDonald's headquarters in cooperation with AGF, GTI and various utilities. McDonalds wishes to test the 50 kW DG system and Desiccant dehumidification Add-on-Module (ADM) in a new stores so that the four rooftop units can be properly designed so that the dining room unit number two can be designated the primary make-up air unit and be properly fitted with the ADM. This will also require some internal ductwork modification to be sure some outside air is ducted to the plenum of dining room unit number one.

Figure 1 - Typical Freestanding McDonalds


Figure 2 – 10 RT Rooftop with prototype ADM (foreground) on Test

Figure 3 - Generac Power System's DG50

Current Design Calculations

The Elite Software runs provide for the subject SE-4474/98 w/2001 Update HVAC presents a difficult dilemma for the designer utilizing conventional rooftop equipment. Table 1 clearly demonstrates the problem whereby conventional rooftops provide 144% of the sensible capacity required and only 70% of the latent capacity required by the building. This is not unexpected in this type of application in humid climates.

Table 1 McDonald's Conventional Design for Humid Climates

1/23/2002

	Specified Equipment							
Current Design	**AHU-1**		**AHU-2**		**AHU-3**		**AHU-4**	
Total Airflow	5000 CFM		5000 CFM		3000 CFM		2000 CFM	
Outdoor Airflow	1250 CFM		900 CFM		900 CFM		400 CFM	
Total Cooling Capacity (tons)	**12.5**		**12.5**		**7.5**		**5**	
Total cooling capacity delivered	158,000		155,000		94,000		64,000	
Sensible capacity delivered	130,000		113,000		59,000		44,800	
Latent capacity delivered	28,000		42,000		35,000		19,200	
Equipment Sensible Heat Ratio	**0.82**		**0.73**		**0.63**		**0.70**	
Equipment Latent Heat Ratio	**0.18**		**0.27**		**0.37**		**0.30**	
	Space Load Requirements							
Space sensible	60,131	72%	79,854	81%	20,566	52%	10,416	55%
Outdoor sensible	23,353	28%	18,792	19%	18,792	48%	8,352	45%
Total sensible	83,484	7.0 Tons	98,646	8.2 Tons	39,358	3.3 Tons	18,768	1.6 Tons
Space latent	17,360	26%	7,400	17%	9,920	21%	2,780	14%
Outdoor latent	49,104	74%	37,410	83%	37,410	79%	16,626	86%
Total latent	66,464	5.5 Tons	44,810	3.7 Tons	47,330	3.9 Tons	19,406	1.6 Tons
Space Sensible Heat Ratio	**0.56**		**0.69**		**0.45**		**0.49**	
Space Latent Heat Ratio	**0.44**		**0.31**		**0.55**		**0.51**	

	Equipment Capacity	Space Load	Equipment Capacity / Space Load
Total Tons	**39.25**	**34.86**	**113%**
Total Sensible Tons	**28.9**	**20.02**	**144%**
Total Latent Tons	**10.35**	**14.83**	**70%**

The dilemma occurs because of the high requirement for ventilation air and conventional rooftop equipment simply do not have a low enough sensible heat ratio to manage the moisture. Heretofore, there have been little viable choices available to the designer. The choices either required too much capital cost, too much maintenance, too high operating cost or any combination these problematic situations.

Oak Ridge National Laboratory and SEMCO have been working on a novel natural gas / or recovered heat (CHP) regenerated Desiccant Add-on Module (ADM) solution for QSRs. The module is designed to augment one of the rooftop units to manage the outside air load (latent and sensible). In essence, the ADM is situated downstream of the rooftop unit with only a portion of the "supply air" being deeply dehumidified and mixed into the remaining supply air and delivered to the space.

The results of this approach are depicted in Table 2. Table 2 clearly demonstrates the impact of redistributing the outside air load to AHU 1 and , equipping it with an ADM providing 99% of the sensible capacity required and only 100% of the latent capacity required by the building. This would provide design conditions within the space 100 percent of the time. Furthermore, an unoccupied mode could be designed permitting the ADM to operate in recirculation mode during unoccupied hours and keep moisture out of the building, thus eliminating the harmful and degrading effects moisture can bring.

Table 2 McDonald's ADM Design for Humid Climates

1/23/2002

	Specified Equipment							
Alternate Approach 1	**AHU-1+ADM**		**AHU-2**		**AHU-3**		**AHU-4**	
Total Airflow	4375 CFM		3000 CFM		3000 CFM		1080 CFM	
Outdoor Airflow	2800 CFM		0 CFM		450 CFM		200 CFM	
Total Cooling Capacity (tons)	**12.5**		**7.5**		**7.5**		**3**	
Total cooling capacity delivered	208,690		82,000		92,000		36,800	
Sensible capacity delivered	70,875		75,500		65,900		24,900	
Latent capacity delivered	137,815		6,500		26,100		11,900	
Equipment Sensible Heat Ratio	**0.34**		**0.92**		**0.72**		**0.68**	
Equipment Latent Heat Ratio	**0.66**		**0.08**		**0.28**		**0.32**	
	Space Load Requirements							
Space sensible	60,131	52%	79,854	100%	20,566	69%	10,416	71%
Outdoor sensible	55,717	48%	0	0%	9,396	31%	4,176	29%
Total sensible	115,848	9.7 Tons	79,854	6.7 Tons	29,962	2.5 Tons	14,592	1.2 Tons
Space latent	17,360	13%	7,400	100%	9,920	35%	2,780	25%
Outdoor latent	113,532	87%	0	0%	18,700	65%	8,313	75%
Total latent	130,892	10.9 Tons	7,400	0.6 Tons	28,620	2.4 Tons	11,093	0.9 Tons
Space Sensible Heat Ratio	**0.47**		**0.92**		**0.51**		**0.57**	
Space Latent Heat Ratio	**0.53**		**0.08**		**0.49**		**0.43**	

	Equipment Capacity	Space Load	Equipment Capacity / Space Load
Total Tons	**34.96**	**34.86**	**100%**
Total Sensible Tons	**19.76**	**20.02**	**99%**
Total Latent Tons	**15.19**	**14.83**	**102%**