Air Source Heat Pump for Preheating of Emergency Diesel Backup Generators

ET08SCE1020 Report


02/09/2009 12:09

Prepared by:

Design & Engineering Services
Customer Service Business Unit
Southern California Edison

December 31, 2009

SOUTHERN CALIFORNIA
EDISON®
An EDISON INTERNATIONAL® Company

Acknowledgements

Southern California Edison's Design & Engineering Services (DES) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technologies Program under internal project number ET08SCE1020. DES project manager Dr. Roger Sung conducted this technology evaluation with overall management guidance from Paul Delaney, ET Technology Assessment Manager. For more information on this project, contact *roger.sung*@sce.com.

Disclaimer

This report was prepared by ASW Engineering Management Consultants located in Tustin, California and funded by California utility customers under the auspices of the California Public Utilities Commission. Reproduction or distribution of the whole or any part of the contents of this document without the express written permission of SCE is prohibited. This work was performed with reasonable care and in accordance with professional standards. However, neither SCE nor any entity performing the work pursuant to SCE's authority make any warranty or representation, expressed or implied, with regard to this report, the merchantability or fitness for a particular purpose of the results of the work, or any analyses, or conclusions contained in this report. The results reflected in the work are generally representative of operating conditions; however, the results in any other situation may vary depending upon particular operating conditions.

ABBREVIATIONS AND ACRONYMS

ASHP	Air Source Heat Pump
BH	Block Heater
BTUH	British Thermal Units per Hour
C	Celsius
CEC	California Energy Commission
COP	Coefficient of Performance
CZ	Climate Zone
F	Fahrenheit
HP	Horsepower
Hz	Hertz
kW	kilowatt
kWh	kilowatt-hours
MW	Megawatt
RH	Relative Humidity
SCAQMD	South Coast Air Quality Management District
W	Watt

FIGURES

TABLES

EQUATIONS

CONTENTS

EXECUTIVE SUMMARY

Emergency backup generators are designed to keep critical systems operating in the event of a power emergency. These units are found in most large commercial and industrial buildings as well as other facilities that have a critical need for electric power such as data centers, hospitals, and communications centers. Emergency generators are generally internal combustion diesel engines and are normally kept hot and ready to run in the event of a loss of utility-provided electric power. The required heating energy is normally provided by electric resistance immersion heaters (generally two heaters per engine, with a total power draw of 5,000 Watt (W) or more). These heaters are used to heat the engine block and coolant that circulates through the engine's water jacket. The warmed coolant then gives up its heat to the engine block proper as it circulates, keeping the engine at temperatures normally found to be between 90°F and 110°F.

Electric resistance heating converts electric energy to heat energy with a coefficient of performance (COP) of unity (1). COP is the ratio of output heat over the input energy or electricity. When it leaves the immersion heater to circulate through the engine the temperature of the water is often above 150°F. The circulation is by convection resulting from the rising of the heated coolant. As a result, the temperatures at the top of the engine block are generally very hot (as much as 120°F). As the liquid cools, it "falls" slowly to the lower reaches of the water jacket. A significant amount of unwanted heat is transferred due to the temperature differential of the hot upper part of the engine to the surrounding environment; that heat is lost. Significantly less heat loss is possible if the engine is uniformly kept at the desired temperature.

A technology is emerging that provides the required heat energy by the use of an air source heat pump (ASHP) and circulates that heat energy through the engine with the use of a small (100W) pump, keeping the engine at a relatively uniform temperature. ASHP can have a COP as high as 4.0, depending on the heat quality of the air source.

Three sites and a total of four emergency generators were monitored to quantify the energy savings potential of this technology. The results indicate that the immersion heaters run a very large percentage of the time; one heater appeared to run almost continuously, only shutting down when the monthly performance test was performed.

The heat pumps consume less power and operate fewer hours when compared to the resistance heaters. These two factors, combined with the reduction in heat loss described above, provide considerable energy savings. One limiting factor is that the immersion heaters still need to operate when the temperature dips below approximately 50°F. When temperatures are below 40°F the heat pump ceases to work and needs to be replaced by immersion heaters in order to provide engine coolant heating.

The results of the data analysis indicate that depending on the climate in the area, a typical 1.75 megawatt (MW) emergency backup generator can save as much as 30,300 kiloWatt hours (kWh) annually by using the new technology instead of the electric resistance immersion heaters. This corresponds to about 75% reduction in electric energy consumption. Our project demonstration shows that the immersion heaters provide a valuable backup to the heat pump equipment. If the heat pump goes offline for any reason, the immersion heaters will energize and begin providing the necessary heat energy to the engine so it remains warm and ready-to-start. This redundancy provides added system reliability that was not available in the original design for the backup generator. Based on the study results, we recommend that the ASHP technology information be disseminated and transferred to the Energy Efficiency Group within Southern California Edison (SCE) for possible development of a work paper and including in a commercial incentive program.

INTRODUCTION

The primary objective of this project is to demonstrate the application of air source heat pumps (ASHP) at a commercial facility under field operating conditions. Secondary objectives include estimating the possible energy savings when installing emerging technology and projecting the energy savings across the eight climate zones (CZ) within Southern California Edison's (SCE's) service territory as well as validating manufacturer performance claims.

BACKGROUND OF EMERGENCY BACKUP GENERATORS

Emergency backup generators use electric resistance heaters to keep the engine warm and ready-to-start. If the technology used to provide this heat is changed and/or improved, there can be significant energy savings.

SCE has a great interest in identifying emerging technologies that can provide energy savings, and their Design and Engineering Services group has field tested and monitored energy usage of the ASHPs to determine energy savings achievable when used to maintain emergency backup generators in ready-to-run condition.

There are a large number of emergency backup generators in SCE's service territory. Although the exact number is not readily available, an estimate and use-trends can be obtained by examining the number of permitted engines of this type. A 2001 *Inventory of Backup Generators in the State of California* report prepared for the California Energy Commission (CEC) indicates that the number of emergency backup generators larger than 500 HP in the South Coast Air Quality Management District (SCAQMD) at that time was 1,935 units.

A recent review of the SCAQMD permitting database in October 2009 indicates that there now are at least 2,922 diesel-fueled emergency backup generators larger than 500 HP in the SCAQMD. It is important to note that although the air quality district includes a few municipal utilities, a significant number of these engines are in SCE service territory, and the number of engines is likely to increase by a large amount because of the rapid growth of commerce and industry in Southern California. This project focuses on engines larger than 500 HP because heat pump technology may not be cost-effective on smaller engines at the present time.

HEATERS FOR BACKUP GENERATOR ENGINES

Emergency backup generators for commercial settings are largely internal combustion diesel engines. These engines operate on the compression ignition principle, which requires that the air in the cylinder be compressed to obtain the minimum temperature necessary to ignite the diesel fuel. These engines do not have "glow plug" assisted starting that is used by transportation sector engines and do not have a "warm up" period after the start. The engine is required to provide full power as soon as it reaches full speed. Due to these operational characteristics, an emergency backup generator must be kept quite warm and ready to run in the event of an electric power outage.

Electric heaters serving the engine's water jacket provide warming heat energy. The warmed coolant gives up its heat to the engine block as it circulates through the water jacket, eventually returning to be re-warmed by the heaters, with the intent of keeping the engine temperature at approximately 100°F.

An operation and maintenance bulletin for a large engine manufacturer indicates the following:

"Jacket water heaters help to improve startability in ambient temperatures that are below 21°C (70°F). All installations that require automatic starting should have jacket water heaters."

"Check the operation of the jacket water heater. For an ambient temperature of 0°C (32°F), the heater should maintain the jacket water coolant temperature at approximately 32°C (90°F)."

CURRENT METHODS OF HEATING ENGINES

Historically, the source of heating energy has been electrical resistance heating. Electric resistance heating converts electric energy to heat energy with a coefficient of performance (COP) of unity (1); a COP is the ratio of output heat to input energy. This implies that one unit of heat is produced for every unit of electricity input. If this number can be improved to higher COP ratios, it will decrease the required input energy.

This method of heating the water jacket has some built-in inefficiency. For instance, the temperature of the water as it leaves the immersion heater and circulates through the engine is often above 140°F, which is much hotter than the recommended temperature for keeping the engine ready-to-run. The circulation in the water jacket is caused by the heated coolant rising, and as a result, the temperatures at the top of the engine block are normally very hot (as much as 120°F). A significant amount of heat is lost because of the temperature differential of the hot upper part of the engine to the surrounding environment. As the liquid gives up this heat and cools, it "falls" slowly to the lower reaches of the water jacket. Much less heat would be lost to the environment if the engine were uniformly kept at the desired temperature.

IMPROVEMENTS IN ENGINE HEATING TECHNOLOGY

A heat pump is a device that moves heat from one location at a lower temperature (the source) to another location at a higher temperature (the sink). An ASHP takes heat out of the ambient air and efficiently transfers it to the engine cooling system by the use of a vapor compression refrigeration system. A typical ASHP has a COP of four or greater, which enables the facility to keep the engine warm and ready-to-run using 1/4 of the energy required by the immersion heater systems.

Heat pumps are efficient at moving energy from one heat "reservoir" to another. In this application, energy is transferred from the surrounding air of the engine room by the heat pump as the heat from the air evaporates refrigerant inside the evaporator coil (with the temperature of the air becoming cooler in the process). The evaporated refrigerant vapor is then compressed by the heat pump compressor which raises both the pressure and temperature of the vapor.

This hot gas (as it is termed) then enters the heat pump condenser, where the refrigerant returns to liquid form. The change of state of the refrigerant vapor to liquid as it condenses gives off a large amount of heat that is absorbed by the engine coolant in the heat pump's condenser section. The coolant then transports and transfers the heat to the engine block. The resulting coolant then completes its path through the engine water jacket and returns to the heat pump condenser to absorb more heat energy. The process repeats itself again. Figure 1 is a schematic diagram that illustrates how the heat pump works in the field.

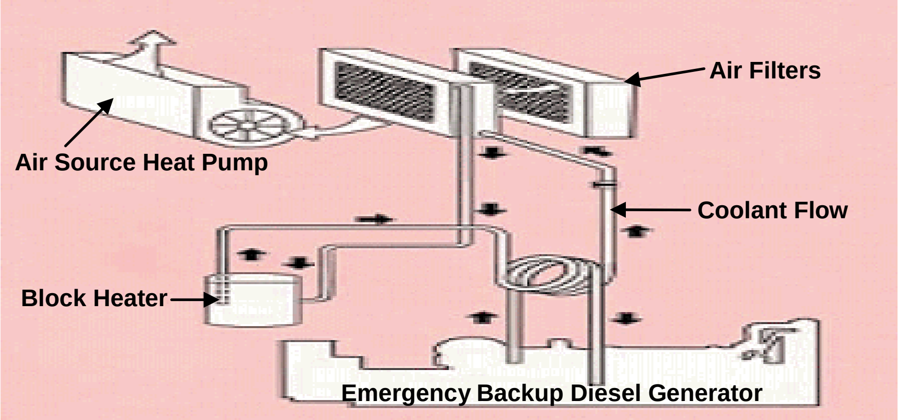

FIGURE 1. SCHEMATIC DIAGRAM OF AN ASHP (TAKEN FROM A GTS INFORMATION PAMPHLET)

The electric resistance immersion heaters that were originally installed on the engines do not normally have a pump to move the heated engine coolant through the engine block. Instead, the temperature gradient of the coolant across the heater induces a convective flow of heat in the water jacket because hot water rises. The convective heat flow is not strong and requires a significant temperature gradient to establish circulation. As a result, the temperature at the outlets of typical electric resistance immersion heaters is fairly high, and quite often exceeds 140°F.

The ASHP does not efficiently provide heat at 120°F or higher because it requires an excessively high discharge pressure which acts to reduce the heat pump efficiency. Lower discharge temperatures are generally associated with higher efficiencies for these devices. As a result of the reduced temperature gradient associated with the heat pump, the convective flow is not sufficient to move the heat through the engine. A small (approximately 100W) circulation pump located in the heat pump enclosure is provided to move the engine coolant through the system, giving a more uniform heating of the engine coolant.

ADDITIONAL BENEFIT OF TECHNOLOGY

The electric resistance immersion heaters remain installed on the engine cooling systems when they are retrofitted with an ASHP. The immersion heaters provide a valuable backup to the heat pump equipment. If the heat pump goes offline for any reason, the immersion heaters will energize and begin providing the necessary heat energy to the engine so that it remains warm and ready to start. The small circulation pump is still necessary for circulation through the system because of the restriction caused by the inclusion of the heat pump in the engine coolant circulation loop.

PROJECT DATABASE

ENGINES

The emergency backup generators monitored during the course of this project were all Caterpillar® 3516 diesel-engine driven generators. It is not surprising that all the engines were Caterpillar since 45.9% of all installed emergency backup generators use Caterpillar engines as prime movers; Detroit Diesel and Cummins engines have 20.9% and 19.6% of the market-share, respectively and the remaining (approximately 10% of installed engines) are made by other manufacturers, and none of those comprise more than 2% of the population.

Table 1 is an excerpt of a list of manufacturers provided by the technology vendors.

TABLE 1. EMERGENCY BACKUP GENERATORS BY MANUFACTURER

ENGINE MAKE	Engine MODEL	Generator Power kW	BLOCK HEATER WATTS
Caterpillar	3306	230-250	3,000
Caterpillar	3406	300-400	3,000
Caterpillar	3412	550-800	6,000
Caterpillar	3508	800-1,200	6,000
Caterpillar	3512	1,200-1,500	6,000
Caterpillar	3516	1,750-2,250	6,000 or 12,000
Caterpillar	D398	600-800	6,000
Caterpillar	D399	800-1,000	6,000
Caterpillar	C32	1,000	6,000
Cummins	NTA855	275-400	2,500 or 4,000
Cummins	VTA28	550-750	5,000
Cummins	VT1710		4,000 or 5,000
Cummins	KTTA150	800-1,200	4,000
Cummins	KTTA19	800-1,200	4,000
Cummins	KTTA38	1,200-1,500	8,000
Cummins	KTTA50	1,100-1,500	8,000
Detroit Diesel	8V92		2,500
Detroit Diesel	12V92		4,000
Detroit Diesel	8V149		4,000
Detroit Diesel	12V149		8,000
Detroit Diesel	16V149	1,000-1,500	8,000

As shown in Table 1, one engine can have more than one generator kilowatt (kW) rating. An engine's power (electrical power), must be drawn from the engine. A smaller generator requires less power than a larger generator to turn it at synchronous speed.

The amount of heat required by an engine to remain at the desired temperature is governed by the engine size, and the temperature of the environment. The larger the engine's physical size, the greater the surface area that radiates heat away. The colder the engine's surrounding environment, the greater the difference in temperature, resulting in increased heat radiation. For a given environment, the amount of immersion heater kW required by an engine to maintain the desired temperature varies with the engine's physical size and not the amount of power produced by that engine.

IMMERSION RESISTANCE HEATERS

The resistance heaters generally available are manufactured by either Watlow®, or Kimhotstart, and range in wattages from 1,500 Watts (W) – 6,000W or higher. The units can be selected for service voltages from 120V through 480V.

The emergency backup generators studied during this project were all equipped with Watlow heaters. The two heaters at Site 1 were 1,500W, and the heaters at Sites 2 and 3 were both 2,500W units.

AIR SOURCE HEAT PUMPS

The heat pumps used in this project were Trane units and were provided and installed by Geothermal Systems, Inc. The specifications for these units are listed in Table 2.

TABLE 2. TRANE HEAT PUMP SPECIFICATIONS

ITEM DESCRIPTION	UNIT SPECIFICATION
Heating Capacity	19,000 BTUH
Cooling Capacity	15,200 BTUH
Voltage	208V/230V single phase
Circuit Ampacity (Amps)	6 Amps
Maximum Power Consumption	1.4 kW
Coefficient of Performance	4.2 (@90°F entering air and 100°F water)
Dimensions	24" x 24" x 39"
Weight	160 lbs.

METHODOLOGY AND INSTRUMENTATION

The focus of this project is to evaluate energy savings by comparing post-installation energy use over an identified time period with pre-installation energy consumed during a similar period. The pre-installation data set is termed the "baseline" data while the post-installation data set is termed "post" data.

The following steps define the energy savings evaluation process:

- Select the test sites and determine the scope of the measurement work required to capture the baseline data.
- Install instrumentation on the equipment and collect the baseline data.
- Install heat pump equipment. (This was not required for the call center site, as the heat pump was already in place at that site.)
- Collect post data.
- Analyze post data.
- Write report documenting post data analyses.

Two sites were originally chosen for the project: a telephone call center building and a medium-sized data center building.

The telephone call center engine (Site 1) located in Climate Zone (CZ) 8, inside a facility building envelope, was already equipped with two resistance heaters and an ASHP at the time this project began. Electric resistance heat energy usage and temperature data were taken for a period of time with the heat pump disabled, then the ASHP was enabled and more data was acquired for evaluation of the technology.

The office building engine (Site 2) is located in CZ 10, in an outdoor ventilated enclosure adjacent to the facility parking lot. This engine was installed with only two original resistance immersion heaters. Energy use and temperature data were taken on this system for a period of time before the ASHP was installed. Data collection continued after the ASHP was installed.

Operationally an ASHP or heat pump is wired in series with the existing block heaters. The heat pump has dual control thermostats and two contacts. The existing block heaters are wired to the second contactor and controlled by second-stage thermostats. The heat pump serves as the primary heater unless temperature drifts down to block heater set-point (approximately 40°F). When the ambient temperature drops below 40°F, the heat pump is automatically shut off to avoid freeze-up and the block heaters turn on. The block heater also becomes operational when the heat pump fails to turn on. Both the block heaters and the alarm are activated when this happens, signaling failure in the heat pump.

DATA ACQUISITION EQUIPMENT

Data acquisition equipment consisted of the following:

- Data Logger System
- Power Transducer
- Temperature Measurement
- Scanned and Data Recording
- Data Collection Methods

DATA LOGGER SYSTEM

The heart of most data acquisition systems is the logger that provides signal conditioning and digitizing of analog inputs. All the sites involved with this project used the same model of equipment, a Campbell Scientific CR1000 logger system. This device provides eight differential inputs (16 single-ended), two pulse counters, three switched excitation voltage outputs, and eight digital input/output channels for frequency measurement, digital control and triggering. This logger is considered to be one of the very best devices of its type.

POWER TRANSDUCER

All of the Campbell Scientific CR1000 systems were configured with two high accuracy Watt transducers from Ohio Semitronics, Inc. (Model GW5-019A). The power transducers are factory calibrated and traceable to the National Institute of Standards Technology (NIST) standards. According to manufacturer literature, the accuracy of the power measurement is within +/- 0.2% of the reading (indicating a probable measurement error of +/- 4W for the approximately 2kW immersion heaters).

TEMPERATURE MEASUREMENTS

Temperature data was taken using type T thermocouples to validate that the engines were kept adequately warm by the technology under investigation. The thermocouples were calibrated by the equipment supplier before delivery to ASW Engineering Management Consultants. The Campbell data logger incorporates a built-in reference junction thermistor with an accuracy of +/- 0.3°C (0.5°F) which is used to compensate for the cold junction offset associated with thermocouple temperature measurement.

SCAN RATE AND DATA RECORDING

The data logger’s scan rate is a result of how many individual measurements and analog-to-digital conversions are made during each scan. The logger integrates each voltage signal for a full 25 milliseconds, and, since there are 10 channels, the tenth is the logger battery voltage. The fastest expected scan rate is one scan every 250 milliseconds (4 Hertz (Hz) per second. The actual scan rate is somewhat slower than this, but the system should easily complete a scan of the inputs once every second. For memory conservation purposes, the system was set up to continually average the data over time and then write a record to the system memory every 15 minutes.

DATA COLLECTION METHODS

The data was collected from the first two sites by modem with the third site collected by directly downloading the loggers. All monitoring equipment was calibrated on-site prior to project initiation and was also verified for accuracy whenever data was retrieved.

RESULTS AND DISCUSSION

DATA DISCUSSION

After the data from these two sites was evaluated, preliminary findings showed a significant energy savings due to the heat pump technology. It also became apparent that the original design of the evaluation project at Site 1 has a minor flaw, in that once the heat pump was installed, it became necessary for the small circulation pump to remain in operation even though only data from the electric immersion heater data was desired. It was also discovered that the performance of the electric immersion heaters changes when a circulation pump is introduced into the system. The immersion heaters use less energy when the circulation pump is operating than they do without the circulation pump. Since the project design was intended to gather performance data on the systems in both summer and winter conditions, it was necessary to operate the electric resistance immersion heater when the circulation pump was operating.

At Site 2, the data from this operational mode was not in complete alignment with the pre-installation data. This being the case, a third site was recruited in an effort to eliminate the effect of the circulation pump on the immersion heater characteristics.

At the data center (Site 3) instrumentation was placed on two identical engines. Each of these engines was originally equipped with resistance heaters only. Energy use and temperature data was taken on both engines in this configuration for a brief period of time in order to validate that the energy use of the engine heaters were comparable. After this relationship was established, a heat pump was installed on one of the two engines. Data collection on both engines continued for approximately one month after the ASHP was installed.

DATA ANALYSIS

One of the goals of this project is to identify the potential energy savings of the technology across SCE's eight CZs. In order to accomplish this goal, the daily energy consumption (kWh) of the immersion heaters and the ASHPs are independently modeled as a function of the daily average temperature at the sites.

The modeling turns out to be quite simple, as a first order equation appears to fit the data reasonably well. The form of this type is shown in Equation 1.

EQUATION 1. LINEAR EQUATION

$y = mx + b$

where y is the daily kWh consumption,

x is the daily average dry bulb temperature of the CZ

and m and b are constants developed by the regression tool.

The model for the immersion heater energy usage must reflect the real-life situation in order to be used with confidence; and hence, must take into account that, when turned on, immersion heaters operate at a fixed power demand. That is to say, the maximum total energy (kWh) that is consumed by the immersion heaters in a 24-hour period is the maximum heater power (kW) times 24 hours. Data taken in the field indicates that immersion heaters will operate continuously when average daily temperatures are below 65°F. The projected calculation of immersion heater energy usage in the eight CZs is the maximum daily kWh for days when the daily average temperature is below 65°F.

This project involved four separate engines with a total of eight immersion heaters. The heaters were two different sizes, with the two Site 1 heaters at 1,500W and the others at 2,500W. Since the heaters at Site 1 were smaller than those at the other sites and there were other complicating factors (as shown in Appendix C) associated with that site, only the larger heaters are used for this projection.

The average of the maximum power demand of the remaining six heaters is the maximum possible immersion heater usage used in the modeling (times two, of course, since there are two heaters per 1.75 MW generator unit). For completeness, Table 3 presents the maximum recorded power for all of the immersion heaters at the sites.

TABLE 3. BASELINE ELECTRIC RESISTANCE IMMERSION HEATER KW (MEASURED)

DESCRIPTION	HEATER 1 KW	HEATER 2 KW	TOTAL HEATER KW
Site 1: (kW data not used)	1.4	1.4	2.8
Site 2	2.5	2.3	4.8
Site 3: Gen 4	2.1	2.1	4.2
Site 3: Gen 5	2.3	2.4	4.7

The maximum daily immersion heater kWh consumption used in the model is the average of Site 2 and Site 3 kW or (4.6 kW) * 24 hours = 110.4 kWh. This level of consumption is substituted for the results of Equation 1 describing the baseline immersion heater kWh consumption whenever the model for the immersion heater calculates a usage greater than 110.4 kWh.

Relative humidity (RH) data was taken at the sites, however investigation of the correlation between RH and energy usage by the ASHP did not prove useful. This was likely due to the location of the ASHP in the enclosure where the relatively warm engine(s) are located. The warm engine(s) raise the temperature of the air, which in turn reduces the RH in the space. Thus, the response to RH was not observed to be a meaningful correlation for the sites under study.

ENERGY SAVINGS METHODOLOGY ACROSS CLIMATE ZONES

The CEC has created 16 CZs that cover the state’s varying geographic areas and provides representative annual weather data files for each of the CZs. SCE provides electric service to its customers in eight of the 16 CZs. This weather data can be used to provide temperature-dependent projections of energy usage in the regions of interest.

The following is a brief description of the methodology associated with the creation of the weather data. (This excerpt is from the CEC web site.)

The Energy Commission established 16 climate zones that represent a geographic area for which an energy budget is established. These energy budgets are the basis for the standards…. (An) energy budget is the maximum amount of energy that a building, or portion of a building...can be designed to consume per year.

The Energy Commission originally developed weather data for each climate zone by using unmodified (but error-screened) data for a representative city and weather year (representative months from various years). The Energy Commission analyzed weather data from weather stations selected for (1) reliability of data, (2) currency of data, (3) proximity to population centers, and (4) non-duplication of stations within a climate zone.

Using this information, they created representative temperature data for each zone:

- CZ 8: El Toro
- CZ 9: Pasadena
- CZ 10: Riverside
- CZ 13: Fresno
- CZ 14: China Lake
- CZ 15: El Centro
- CZ 16: Mount Shasta

Daily average dry bulb temperatures (one for each day of the year) were created and used to predict energy savings for each of the eight CZs using the process below:

1. Average daily temperature data from the vicinity of the engine sites is correlated to the current CZ data, then the daily total kWh is projected from the current CZ data and that projection is compared to the actual usage of the systems at the site and inspected for reasonableness.
2. After this process is complete, the standard CZ data is used to project the usage of the two heating systems individually.
3. After the CZ-specific annual energy use profiles for the immersion heaters and the ASHP are created, the expected energy savings from the application of ASHP technology are derived from the profiles by subtracting the projected energy use of the ASHP from the immersion heaters.

ENERGY CONSUMPTION COMPARISON

Immersion heaters are typically resistance heaters. In this application, they are used to provide heat to the engine coolant that circulates by convection through the water jacket. The heaters are positioned as either "On" or "Off" depending on the thermostat setting. As a result, energy consumption is fairly constant irrespective of the ambient air temperature. Unlike the immersion heaters, an ASHP is highly sensitive to the heat energy of the ambient air. The higher the ambient air temperature, the less energy is required to heat the engine coolant. Figure 2 shows the comparison of energy consumptions of a heat pump vs. a resistance block heater as a function of ambient temperature.

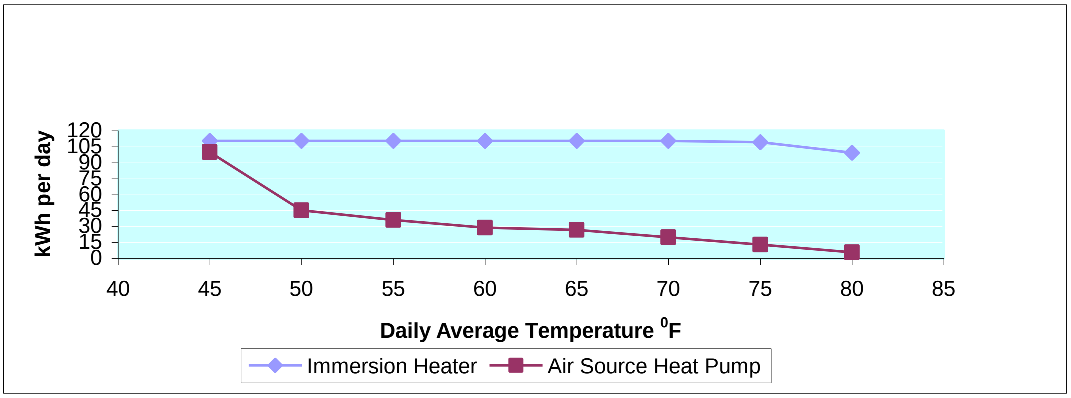

FIGURE 2. EMERGENCY BACKUP GENERATOR ENGINE HEATING ENERGY USAGE

SITE ISSUES DISCUSSIONS

SITE 1

Site 1 is a communication center and has several emergency backup generators installed in the facility's generator room. The equipment selected for study is driven by a Caterpillar 3516 engine, a large V-16 diesel engine with a displacement of 69 liters. The engine is equipped with dual turbochargers and after-coolers to enhance the engine's power output. The generator and engine as equipped are both rated at 2MW, which is equivalent to almost 2700 HP.

The Site 1 backup generator engine was already equipped with an ASHP when project monitoring began. The circulation pump of the heat pump system was in operation during the entire data acquisition period, which began in early July 2008 and continued through August 2009. Initial data was gathered about the operation of the immersion heaters for a period of approximately one month. As previously noted, this data is not indicative of the true baseline (immersion heater by conductive and convective heating) case, since the immersion heaters were not in their original configuration due to the addition of the circulating pump associated with the ASHP.

Site 1 heat pump data indicates that the average electric energy used by the heat pump over a one-month period during the summer is 0.58 kWh. During that time the average recorded engine block temperature was 97.4°F. During a similar period of time under similar conditions, the electric resistance immersion heaters used an average of 2.4 kWh, during which time the average engine block temperature was 101.2°F. The hourly energy savings using these numbers is (2.4 – 0.58) = 1.8 kWh, steady state, which projects to an annual savings estimate of 1.8 kW * 8,760 hours/year = 15,768 kWh annually.

It is important to note that the engine block temperatures differ by almost 4°F and as a result, it is acknowledged that directly calculating the savings using these numbers does not provide a completely comparable result. Although these two technologies are difficult to evaluate on an exactly equal basis due to differences in field operating conditions (e.g., coolant circulating pump presence, sensor calibrations, ambient air temperature differences, etc.), the potential savings demonstrated is significant. Due to the circulation pump issue affecting the baseline energy use, the resultant energy savings from Site 1, while quite significant, cannot be considered fully representative of the magnitude of savings that can be realized by the installation of the ASHP system on a standard immersion heater-equipped engine.

SITE 2

Site 2 is an office building that is associated with a nearby data center and is equipped with a single emergency backup generator, driven by a Caterpillar 3516 engine just like at Site 1. This unit is a large V-16 diesel engine with a displacement of 69 liters. The engine is equipped with dual turbochargers and after-coolers to enhance the engine's power output. The generator and engine as equipped are both rated at 1.75 MW, which is equivalent to almost 2350 HP.

The backup generator engine at Site 2 is situated in a stand-alone enclosure located in the parking lot of an office building, and was selected in order to acquire the cool weather operational data as well as additional data gathered through normal temperature operations. At the time when data gathering for this project was initiated, the engine was equipped with two standard immersion heaters and heating was by convection without a circulation pump. Data collection began on July 19, 2008. After more than one month of data collection, the ASHP was installed towards the end of August 2008. During the baseline period it was noted that the immersion heaters ran almost continually, even though it was during the summer season, averaging 4.3 kWh. The maximum possible hourly kWh for those heaters is 4.8 kWh (measured instantaneous kW multiplied by one hour.)

Figure 3 is a graphic depiction of the total daily kWh usage of the immersion heaters, with a usage projection based on average daily ambient temperature at the site. This graph shows that the kWh consumed by immersion heaters can be accurately modeled by a projection based on the average daily dry bulb temperature.

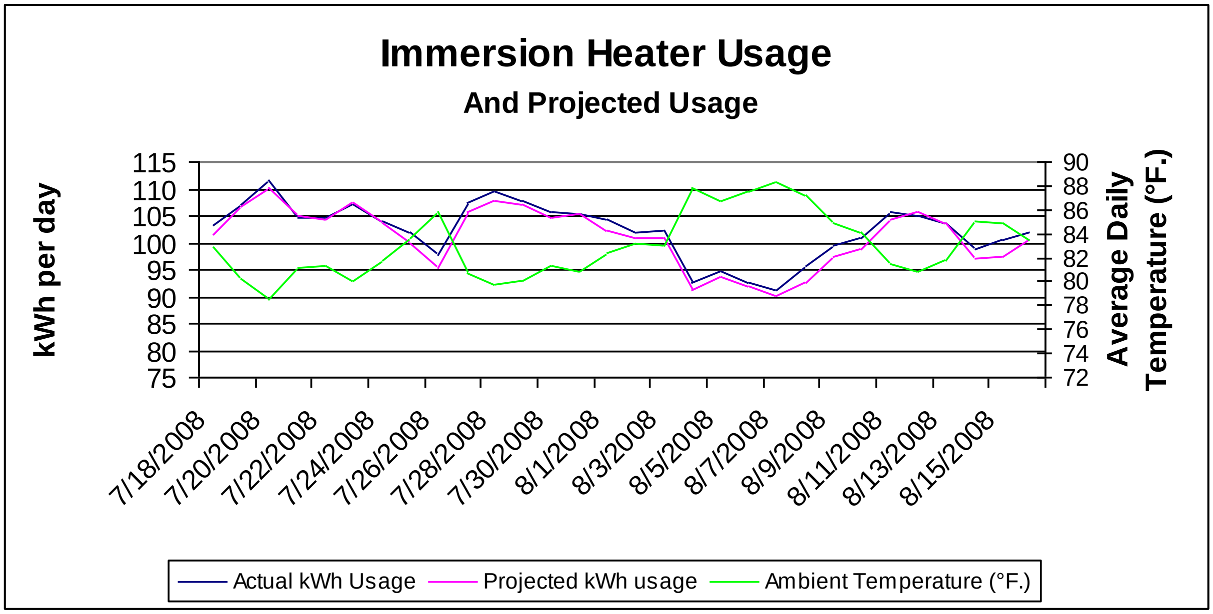

FIGURE 3. IMMERSION HEATER USAGE (ACTUAL AND PROJECTED)

After the heat pump was installed at Site 2, the data collection system was extended to gather information on the operating characteristics of the heat pump system as well as the immersion heaters, and data collection continued. The heat pump system had a number of operating outages during the initial months of data collection. As a result, a solid continuous run of operating data for the ASHP was not acquired until the beginning of November 2008. The reason for these heat pump outages was due primarily to line voltage dipping below 197 volts. The site has subsequently added a buck-boost transformer to resolve this problem.

From late November and into the cooler weather prevalent during the late fall and early winter, the quality of the heat in the air available to the ASHP at this site was slowly reduced as temperatures lowered, consequently reducing the amount of heat energy the heat pump could deliver to the engine. There are times during cold weather periods that the amount of heat loss from the engine is greater than the amount of heat the heat pump can supply at the prevailing ambient air temperature. As a result, the engine block begins to cool to a temperature below the optimum 90°F to 100°F recommended by most engine manufacturers.

This situation is expected, and at a pre-determined lower setpoint, the heat pump control system energizes the immersion heaters and simultaneously takes the heat pump compressor off-line. This condition continues until the immersion heaters have raised the engine coolant temperature to the upper setpoint, at which time the heat pump control system de-energizes the immersion heaters and brings on the heat pump compressor and the cycle starts over. This situation creates difficulty in analysis as the interaction between the heat pump and immersion heater causes uncertainty in the assignment of energy uses by the system.

The above cold weather scenario was ongoing at the site during the first part of November, 2008. From analysis of the data, this behavior begins when the ambient temperature falls below approximately 53°F. This limit is used in the CZ projections in cold conditions; the heat pump efficiency (and hence available heat output for the same energy input) is <u>reduced</u> by the colder heat source (air) at the same time the engine’s heat energy requirement is <u>increased</u>. This temperature-sensitive characteristic of the ASHP limits the energy savings because, in colder climates, the heat pump using the heat source is affected.

SITE 3

Site 3 is a large data center and is equipped with five identical emergency backup generators, all driven by Caterpillar 3516 engines just like at Sites 1 and 2. These units are large V-16 diesel engines with a displacement of 69 liters. The engines are also equipped with dual turbochargers and after-coolers to enhance the engine’s power output. The generator and engine as equipped are both rated at 1.75 MW, which is equivalent to almost 2350 HP.

The approach to identifying energy savings at Site 3 was different than that used at the previous two sites. At Site 3, two identical engines were monitored to establish that the energy consumption of the immersion heaters was almost equal between the two engines. After this was established, an ASHP was installed on one of the engines.

Some data was collected during a heat wave. During that time it was observed that the immersion heaters shut down only occasionally during the hottest part of the day. The engine block temperatures were kept consistently above 102°F and the immersion heaters were on almost constantly.

Extremely hot conditions (above 100°F) should result in additional reduction of heating energy requirements for the engine, so less work needs to be done by either heat source which results in reduced energy savings during hot weather periods.

Contrary to the logic mentioned above, data gathered during this project shows that immersion heaters provide more heat than necessary during hot weather periods. The ASHP systems are more likely to turn off when engine temperatures are adequate. This is likely because the inclusion of the circulation pump in the heat pump's water jacket heating circuit.

ENERGY SAVINGS PROJECTIONS

The projected energy savings due to ASHPs for similar sized (1.75 MW) engine-driven generators across the eight CZs in SCE's service territory are shown in Table 4.

The energy savings differ a fair amount from one CZ to another since the available heat energy in the surrounding air is the governing factor in the efficiency of the ASHP. And, in extreme cold weather (as in CZ 16), the immersion heaters will need to provide a significant amount of additional heat because the ASHP is not capable of meeting the heat requirement on its own.

TABLE 4. ESTIMATED ANNUAL ENERGY USAGE BY CZ FOR A 1.75 MW GENERATOR

CLIMATE ZONE	CITY	IMMERSION HEATERS	AIR SOURCE HEAT PUMPS	SAVINGS (KWH)
6	Los Angeles	40,296	9,987	30,309
8	El Toro	40,192	9,842	30,351
9	Pasadena	40,083	9,288	30,795
10	Riverside	39,801	11,355	28,446
13	Fresno	38,970	12,851	26,119
14	China Lake	38,993	16,154	22,839
15	El Centro	35,965	6,189	29,776
16	Mount Shasta	40,286	25,696	14,590

The equipment vendor indicates that the typical installed cost of an ASHP for pre-heating of the emergency diesel backup generator of around 1.5 MW (2,000 HP) is $10,000. Based on this study of an average of 30,000 kWh/yr energy savings, this translates to $3,600/yr (assuming energy cost at 0.12/kWh). The simple payback for the ASHP can be calculated using Equation 2.

EQUATION 2. PAYBACK FOR THE ASHP

Simple Payback w/o incentives = (ASHP installed cost) / (annual energy savings) =
$10,000/$3,600/yr = 2.8 yrs.

CONCLUSIONS

The following conclusions were made during this study:

- The monitoring project was successfully completed. The report shows a 75% energy savings was achieved by using an ASHP to heat the diesel backup generator instead of the immersion resistance heater.
- ASHP is the emerging technology recommended to replace the immersion resistance heater as the primary heater for heating the engine coolant of the backup generator.
- ASHP or heat pump provides a more homogeneous heating of the engine coolant than the immersion heater. This is because an ASHP has a built-in internal circulating pump that the immersion heaters don't have; their heating is produced by conduction and convection only.
- Retrofitting backup generators with a heat pump for the eight CZs in Southern California results in energy savings in the range of 30,351 kWh/yr for CZ 8 and 14,490 kWh/yr for CZ 16 depending on the available heat energy in the surrounding air. A typical 1.75 MW emergency backup generator can save as much as 30,300 kWh annually by using an ASHP instead of the electric resistance immersion heaters.
- A distinct advantage of an ASHP is that it has an average COP of 4.2. This means that it can transfer four units of heat with only one unit of electricity.
- A major disadvantage of an ASHP is that it requires supplementary heating from immersion heaters at ambient temperatures below 50°F. The heat pump needs to be shut down in order to prevent freeze-up when the temperature dips below 40°F and immersion heaters become the sole heaters.
- Our test results revealed that the immersion heaters are on almost 100% of the time. Under a similar operating condition, the heat pump runs about 50% to 80% of the time depending on the ambient temperature.
- The immersion heaters can be a valuable backup to the heat pump equipment. If the heat pump goes offline for any reason, the immersion heaters will energize and begin providing the necessary heat energy to the engine so it remains warm and ready-to-start. This redundancy provides added system reliability that was not available in the original design of the backup generator.
- Without any utility incentive or rebates, the simple payback for an ASHP is about 2.8 years.

RECOMMENDATIONS

The following recommendations are proposed as a result of this study:

- This emerging technology should be recommended and publicized to the Energy Efficiency Group as a candidate technology for mass deployment.
- In view of the significant energy savings obtained, backup diesel generator manufacturers or suppliers should consider packaging ASHP as an integral part of their new installations.
- Additional monitoring may be needed to fully explore the capabilities and limitations of this emerging technology, in particular in CZ 13 and CZ14 where the ambient air temperature may have extreme variations that may create unforeseen challenges for the heat pump.

APPENDIX A - TYPICAL EMERGENCY GENERATORS

Table 5 shows a complete list of typical emergency generators found in the field, including typical immersion heater (block heater) kW requirements.

TABLE 5. EMERGENCY DIESEL GENERATORS

EMERGENCY DIESEL GENERATORS

Make	Model	Generator kW	Block Heater Watts
Current and older Caterpillar engines which comprise most of the Caterpillar Engines found in the marketplace.			
Caterpillar	3306	230-250	3,000
Caterpillar	3406	300-400	3,000
Caterpillar	3412	550-800	6,000
Caterpillar	3508	800-1,200	6,000
Caterpillar	3512	1,200-1,500	6,000
Caterpillar	3516	1,750-2,250	6,000 or 12,000
Caterpillar	D398	600-800	6,000
Caterpillar	D399	800-1,000	6,000
Newer Caterpillar engines just starting to appear in the marketplace.			
Caterpillar	C15	450-550	We have not seen any of these engines in the market.
Caterpillar	C18	550-600	
Caterpillar	C27	650-800	
Caterpillar	C32	1,000	6,000
Current and older Cummins engines which comprise most of the Cummins engines found in the marketplace.			
Cummins	NTA855	275-400	2,500 or 4,000
Cummins	VTA28	550-750	5,000
Cummins	VT1710		4,000 or 5,000
Cummins	KTTA150	800-1,200	4,000
Cummins	KTTA19	800-1,200	4,000
Cummins	KTTA38	1,200-1,500	8,000
Cummins	KTTA50	1,100-1,500	8,000
Newer Cummins engines just starting to appear in the marketplace.			
Cummins	QSL9	200-300	1,500
Cummins	QSX15	350-500	4,500
Cummins	QST30	680-1000	4,500
Cummins	QSK50	1,100-1,500	8,000
Cummins	QSK60	1,750-2,250	8,000
Cummins	QSK78	2,500	8,000

Current and older Detroit Diesel engines which comprise most of the Detroit Diesel engines found in the marketplace.			
Detroit Diesel	8V92		2,500
Detroit Diesel	12V92		4,000
Detroit Diesel	8V149		4,000
Detroit Diesel	12V149		8,000
Detroit Diesel	16V149	1,00-1,500	8,000
Newer MTU (Detroit Diesel) engines just starting to appear in the marketplace.			
MTU (DD)	Series 60	275-500	2,500
MTU (DD)	12V2000	650-750	4,000
MTU (DD)	16V2000	900-1,125	8,000
MTU (DD)	12V4000	1,500-1,750	8,000
MTU (DD)	16V4000	2,000-2,250	9,000
MTU (DD)	20V4000	2,500-3000	9,000

This data was provided by GalexC Energy Conservation, Inc. and has not been verified.

APPENDIX B - OTHER SIMILAR PROJECTS

Table 6 shows a sample of projected savings provided by GTS (the technology vendor). It is important to note that these projected savings were provided to SCE by GTS based on field data taken for another utility within California by GTS. According to GTS, tested sites have since received utility-incentive money based on the savings noted in Table 6. However, the data has not been verified by SCE. The CZ for these estimates was not provided. The backup generators range in size from 300 - 1,880 kW. In this table, BH represents block heater, which has been referred to as an immersion heater throughout this report, and the GTS annual kWh is the heat pump energy usage.

TABLE 6. GTS PROJECT SAMPLE SAVINGS

Gen kW	BH Watts	BH annual kWh	GTS annual kWh	Savings (kWh)
1,000	5,660	48,959	6,917	42,042
900	7,904	65,155	11,728	53,427
600	4,150	28,205	7,937	20,268
500	4,449	31,644	6,005	25,639
400	2,736	19,964	2,573	17,391
350	1,452	12,133	2,573	9,560
1,250	4,713	39,793	8,440	31,353
400	4,651	33,759	6,005	27,754
800	4,778	41,628	5,853	35,775
1,500	5,858	37,941	8,423	29,518
600	4,326	36,004	5,354	30,650
500	2,180	18,845	5,447	13,398
1,200	7,980	62,315	9,649	52,666
350	1,558	13,648	4,274	9,374
300	2,304	19,174	6,321	12,853
300	2,246	19,676	5,651	14,025
1,000	5,736	48,260	5,134	43,126
350	2,174	15,461	4,144	11,317
1,000	5,813	42,664	11,827	30,837
500	3,492	21,374	2,765	18,609
1,000	4,041	33,094	3,889	29,205
1,880	9,561	47,002	10,300	36,702
1,500	8,998	59,108	6,613	52,495

APPENDIX C - HEAT PUMP MONITORING PROBLEMS AT SITE 1

There were several rounds of e-mail exchanges regarding the observed challenges at Site 1. The discussions were centered on the wiring problem and improper installation of the original heat pump that was installed approximately five or six years ago at the call center by an electrician not affiliated with the equipment vendor. Because of this, there was no warranty for this installation. At the end of the discussions, including many phone exchanges between the customer, SCE, and the equipment vendor, the customer decided not to do anything claiming the retrofit cost was too high for the correction. The customer believed that he was already getting the energy savings of over 70% for the past five or more years without making any changes and that implementing changes to correct the problem may only increase his savings by a limited amount and the implementation cost could be at least several thousand dollars. For that reason, we were not able to gather accurate data at Site 1 and a decision was made to exclude this data source for our final data analysis.