Innovations in Demand Control Ventilation

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ABSTRACT

As energy costs continue to rise across the country and decreasing the environmental footprint becomes more and more of a priority for commercial, industrial, and institutional facilities, many of these facilities are turning to innovative methods to decrease energy consumption. Conditioning spaces for comfort and indoor air quality requires mechanical cooling and heating of the air. In general, ventilation systems are designed for the worst case scenario that rarely occurs. For instance, auditoriums, gymnasiums, and schools with occupancy driving the ventilation are designed for maximum occupancy, offices with large weather dependent loads are designed for the weather conditions that occurs less than 1% of the time, and laboratories are designed to purge the air quickly and safely in the event of a rare spill. Additionally, many laboratories require 100% outside air for safety reasons. With no recycling of the exhaust air, this increases the load and energy use for the chiller and boiler systems. Any safe reduction in ventilation rates without affecting indoor air quality and comfort levels can provide for a significant decrease in energy consumption at the fans, pumps, chillers, and boilers.

Demand Control Ventilation – General Concept

Demand control ventilation (DCV) involves varying the ventilation rates to match the need for air in the space. Sensors are installed that measure carbon dioxide (CO_2) and other pertinent parameters for indoor air quality (See Figure 1) in facilities with large occupancy fluctuations in the air. Standard Indoor Environmental Quality (IEC) levels are mandated by the federal EPA, state authorities, and the US Green Building Council LEED® NC version 2.2 rating system.

Figure 1: Summary of Air Parameters Monitored for DCV Control

Air Parameter	Typical Sources
Carbon Dioxide	Occupants breathing
Total Organic Volatile Compounds (TVOC)	Cleaning compounds, new building materials, furnishings, carpets, paints, and consumable products.
Carbon Monoxide	Leaking vented furnace, combustion, or flue gas exhaust, unvented combustion appliances, and parking garages.
Formaldehyde	Pressed wood products, furniture, and furnishings.
Relative Humidity	Water spills, rain leaks, and leaking of pipes.

There is a direct correlation between the levels of CO_2 and the number of people in a space. Thus, as the levels of CO_2 rise, so do the levels of other contaminants. In this instance, a demand ventilation system would increase the amount of conditioned outdoor air brought into the space. As the CO_2 levels fall, the ventilation rate is reduced which, in turn, reduces the energy consumption.

In laboratories, ventilation systems are designed to ensure the safety of the workers in the event of the spill. Since this is a rare occasion, spaces are typically "over ventilated" the majority of the time. With this type of space, additional particulate sensors may need to be installed to sense a spill and ramp up the ventilation to purge the air in the space quickly.

Traditional DCV System vs. Aircuity System

A traditional DCV system involves several sensors in the space that report back to a central control system. While this system will provide a level of demand ventilation control and will save energy, innovations have been introduced to provide more concise control which, in turn, leads to additional energy savings. Aircuity has developed a system that involves sending packets of air to a central sensor suite and control system for analysis. The air packets are transported to the central sensor in a predetermined rotation. The system is designed such that each area will send a new packet of air every 10-15 minutes. This patented system, illustrated in Figure 2, improves the performance over a traditional system by reducing the number of sensors. This allows for the use of high grade sensors while remaining cost effective, eliminates differential error due to comparison of results from difference sensors, and simplifies the maintenance procedure with the requirement to calibrate one sensor rather than multiple sensors in a traditional DCV system.

Figure 2: Distributed Office Building Multi-Point Sample Network

The first cost can often be a deterrent to the implementation of any energy efficient measure. A typical DCV system will have a minimum of a sensor in each zone. Larger zones will require multiple sensors. A Honeywell CO_2 sensor for DCV applications that is California Title-24 compliant retails for \$370[1]. The single sensor suite utilizes one sensor for up to 15 data points. Even with a more expensive single sensor, the first cost difference is significant.

Inaccuracies in sensor measurements can lead to over ventilation or more outside air than is required. A pilot CO_2 sensor accuracy study by Lawrence Berkeley National Laboratory

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[1] Honeywell Model number C7232A1032. http://www.cleanairsystemsinc.net/product-227.html

(LBNL) revealed that 38% of the CO_2 sensors were off by more than 20%[2]. With the existence of a comparison of results from different sensors, error propagation becomes an issue. The error could exceed 40% or hundreds of PPM. With this additional error and with indoor comfort and safety in mind, a traditional demand control ventilation system will be set for a lower threshold and result in a higher CFM/person. Since in a single sensor suite the packets of air are analyzed by the same sensor, this system does not require this comparison and greatly reduces this error and the associated energy consumption conditioning the outside air.

The required calibration frequency of sensors greatly varies. Although the recommended manufacturer's frequency can be as little as three months, as long as five years, or never required with auto-calibration, ASHRAE 62.1-2004, Section 8.4.1.7 recommends verification of the accuracy a minimum of once every six months. The more frequent the calibration requirement to prevent long-term drift, the greater the impact in maintenance costs. However, if there is a single sensor, the sensor can be replaced more frequently with a reduction in maintenance costs. Although many sensors claim an auto-calibration function, this component leads to three major problems when used in DCV systems. First, the auto-calibration typically occurs at night. During the "recalibration", the nighttime CO_2 levels may not reach the background or outdoor levels if the fans are off or ventilation is significantly reduced during unoccupied periods. Secondly, the outdoor background levels can vary by more than 100 PPM. If the sensor is "recalibrated" during this time and the building did reach the background levels, an error will be created. The third source of error involves a one point or an offset only calibration method. For example, if the sensor's gain has drifted 10%, an offset only calibration will still generate an error in the differential indoor to outdoor value of 10%. Thus, a minimum of a two point recalibration is required in any recalibration procedure to ensure that a gain and offset adjustment are verified and acceptable.

Figure 3: Summary of Benefits of Aircuity and Traditional Demand Control Ventilation Systems

Benefit	Innovative Demand Control Ventilation System	Traditional Demand Control Ventilation System
First Cost	A single sensor is used for up to 15 zones.	A sensor is required for at least each zone.
Sensor Accuracy	Sensor specification ranges from +/- 45 to 75 PPM.[3]	With a typical sensor accuracy of +/- 75 PPM, a differential measurement can have an inaccuracy of as much as 150 PPM. Studies have shown that actual accuracy of sensors drifts dramatically from the rated accuracy.
Maintenance Costs	Even with complete replacement, a single sensor greatly reduces the maintenance costs.	Frequent calibration of hundreds of sensors leads to an extreme annual maintenance cost.

In an office or occupancy driven space, the DCV system reacts to CO_2 levels and increases or decreases the ventilation rates accordingly. However, in a laboratory environment, safety in the event of a spill is a major concern and must be accounted for properly. The standard

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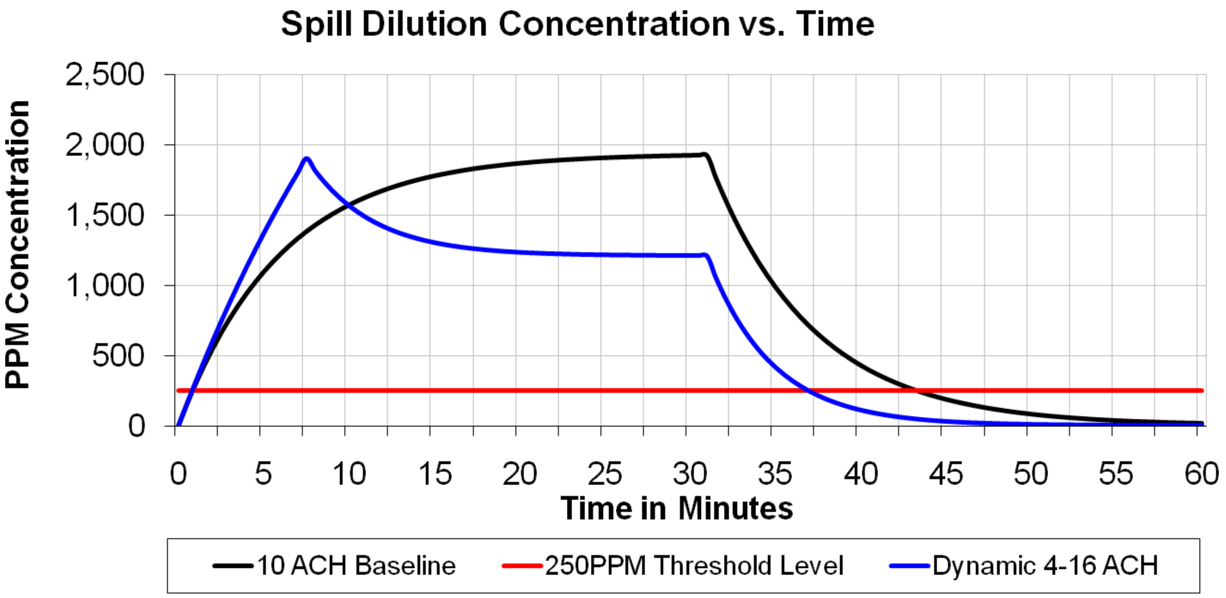
[2] Fisk. A Pilot Study of the Accuracy of CO_2 Sensors in Commercial Buildings. Lawrence Berkeley National Laboratory. LBNL260E. 2008.

[3] OptiNet® Sensor Suite Sensors Specifications. http://aircuity.com/marketing/documents/SSSCO@_12709.pdf

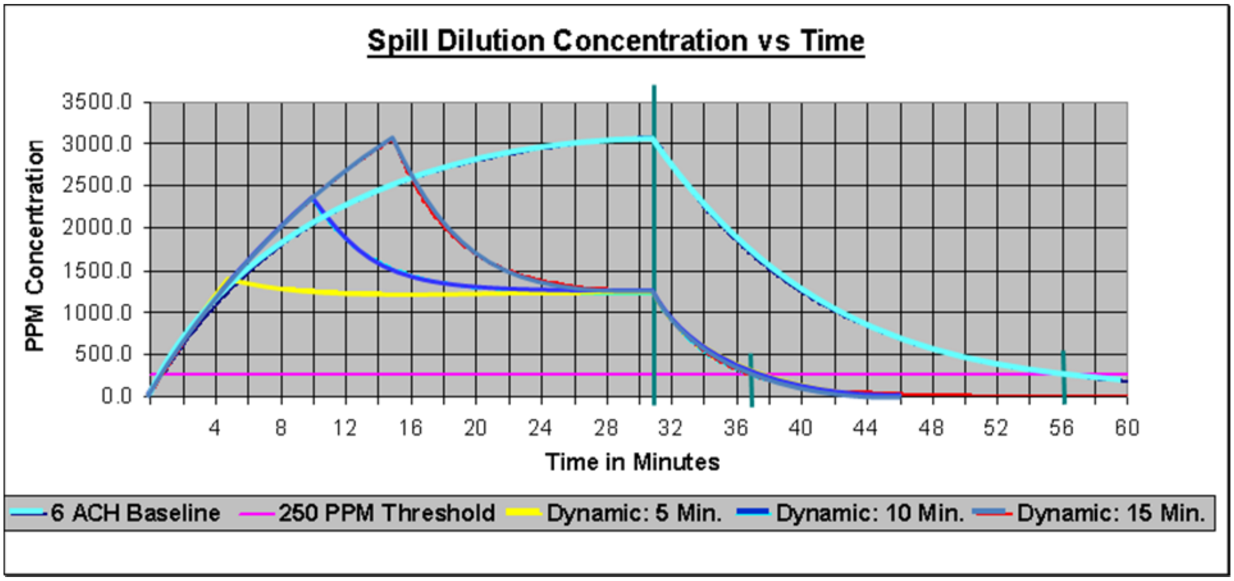
ventilation system will have a constant ventilation rate with high volumes of air intended to dilute and diffuse compounds in normal laboratory use or in the unlikely event of a spill. The air flow rates will be set with safety factors in mind to adequately dissipate the chemical spilled. A DCV will ramp up the air flow rates when a spill is detected. Figure 4 illustrates the difference in concentration for a DCV and constant flow system. The test was conducted in a 200 ft^2 with a 1.5 liter acetone spill. The graph illustrates that the total PPM for the DCV is lower than the constant system. Additionally, after vaporization, the DCV reaches the threshold level faster than the constant system.

Figure 4: Spill Concentration Comparison of Constant and Dynamic Ventilation System



Due to the rotation of the air packets analyzed through the Aircuity system, the spill may not be detected immediately. This contrasts the traditional DCV system that will immediately detect a spill. The maximum time that a spill could be undetected is fifteen minutes if the zone sent a packet of air immediately prior to the spill occurs. The average detection time will be 7.5 minutes. Figure 5 below represents the PPM levels for a variety of detection times with a 1.5 liter acetone spill in a 200 square foot lab. The results show a higher PPM period for the later detection for a maximum of 10 minutes. The DCV reacts and the overall PPM level is lower than a constant air change system and reduces the concentration below the threshold faster than the constant system regardless of the detection time.

Figure 5: Concentration Levels Comparison for Different Detection Rates



Aircuity Case Study

An Aircuity DVC project has been initiated in a six story laboratory building in Emeryville, CA. The building primarily consists of lab spaces but there are also some offices. The ventilation system requires 100% outside air and is operated continuously at a constant rate of eight air changes per hour (ACH). All spaces, regardless of use, received the same ventilation rate. The following provides a description of the existing conditions of the building.

Ventilation

The building has a centralized ventilation system that involves six large air handling units (AHUs). The existing ventilation according to the design documents is 8 ACH for all spaces in the building and at all times during the year. This corresponds to an average ventilation rate of 252,800 CFM. The supply fans currently have VSDs. Each AHU has two 75 HP supply fans with a rated air flow of 29,000 to 33,000 CFM. The fans were observed to be operating at approximately 75% flow. The observed flows per fan were in the range of 21,500 to 26,000 CFM and the observed total flow of 280,100 CFM is actually a little higher than the design flow of 8 ACH.

Within the AHU, the air is cooled or heated to 55°F depending on the outside air conditions. Terminal reheat boxes are used for the remaining increase in temperature, if necessary, to maintain standard occupant 70-72°F room temperature.

Laboratory Spaces and Other Spaces

The laboratory spaces are the primary usage type for most spaces and are moderately sized rooms with several registers. The temperature of the supply air to the rooms is dependent on the internal loads of each space. Typically, there are only a few people working in each lab space. However, plug-in refrigerators and/or freezer units are common. This creates an internal heat load in the space. The supply air temperature was measured with an infrared temperature gun in a statistically valid sample of spaces. A few spaces are “freezer farms” and had supply air temperatures of 55°F. Thus, in this instance, there is no terminal reheat occurring. In larger spaces, more than one register was measured and the results were averaged to obtain a supply air temperature of 65.3°F.

Central Plant

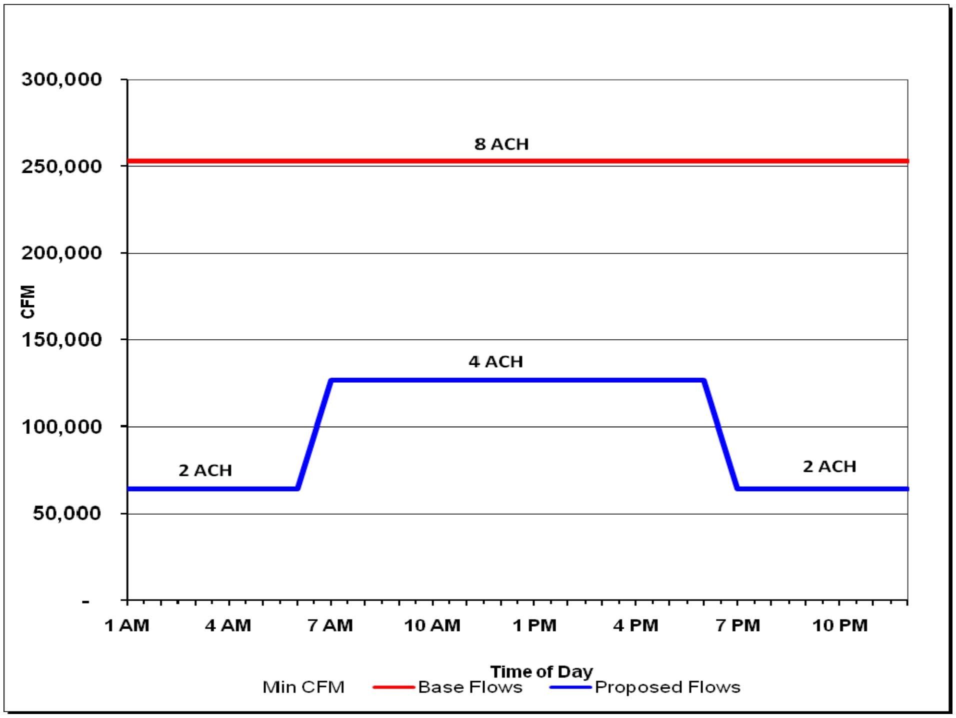
The central plant is located in an adjacent building. There are two 800 ton Trane chillers equipped with VSDs that only serve the laboratory building. The chilled water system is a primary secondary system. The two primary 40 HP pumps are dedicated for each chiller. The two secondary 100 HP chilled water pumps are controlled with VSDs. The two cooling tower fans have two speed motors. The rated capacities are 60 HP at high speed and 15 HP at low speed. There are 100 HP, constant speed condenser water pumps dedicated for each chiller.

Heating System

The two boilers also provide steam to other buildings at the facility. In particular, a significant portion of the heating load seen by these boilers is due to the process in another building. The heating system pumps are 20 HP pumps controlled with a VSD.

As illustrated in Figure 6, the Aircuity DCV system proposes to reduce the ventilation rates to 4 ACH and 2 ACH during occupied and unoccupied times, respectively. Occupied times is defined by 7:00 AM to 7:00 PM, Monday through Friday.

Figure 6: Proposed Weekday DCV Air Flow



Case Study Energy Benefits

The energy savings analysis consisted of a two pronged approach. An eQUEST model and a temperature bin analysis were performed. The results were compared and this examination revealed several interesting differences. Whenever a computer simulation model is used for energy analysis, baseline and retrofit calibration and a complete understanding of the assumed operation in the model is required. The project is currently in the design and installation stage. Thus, the retrofit eQUEST model cannot be calibrated at this time. The demand and energy consumption calibration graphs are shown in Figures 7 and 8. Overall, the model calibrated within 1.2% and -4.2% for the demand and energy, respectively. The steam boilers serve other buildings and process loads. The distribution of this load was not known and this parameter could not be calibrated.

Figure 7: Comparison of Monthly Utility Bill Demand and eQUEST Output

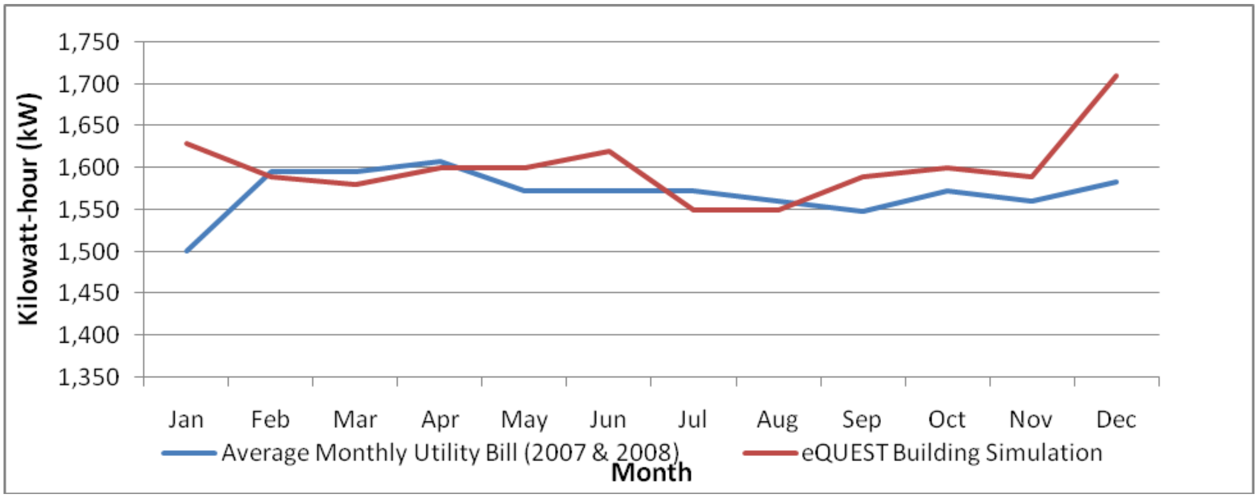


Figure 8: Comparison of Monthly Utility Bill Energy Consumption and eQUEST Output

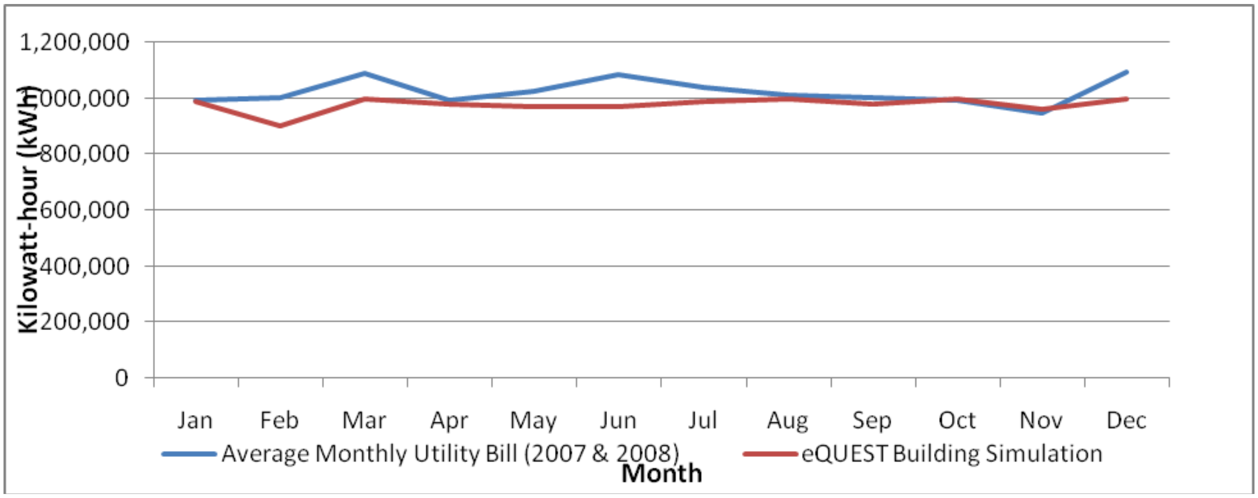


Figure 9 illustrates the comparison of the demand and energy consumption of the end-uses affected by the project. The baseline results in general are close. The retrofit differences are due to eQUEST assuming that the reduced air flow will not be able to meet the cooling load during the hotter periods. This results in additional fan consumption and conditioning from the central plant and boilers.

Figure 9: Summary of Temperature Bin and eQUEST Analysis

Parameter	Temperature Bin Analysis	eQUEST Analysis	Difference (%)	Comments
Baseline Supply Fan Demand (kW)	217	267	23%	The temperature bin analysis only accounts for the supply fans. The eQUEST simplified model auto sizes the system. Thus, the model includes a relief fan to account for the effect of air flow from the exhaust fans. This results in the 23% difference.
Retrofit Supply Fan Demand (kW)	61	157	157%	The baseline demand comment applies to this parameter as well. Additionally, eQUEST has a minimum flow parameter of 40%. Aircuity has confirmed that the initial design allows for a flow well below this level even during the peak periods.
Supply Fan Demand Savings (kW)	156	110	-29%	
Baseline Central Plant Demand (kW)	721	1,028	43%	The temperature bin analysis uses actual chiller efficiency curves provided by Trane. The default eQUEST chiller efficiency curves account for this difference.
Retrofit Central Plant Demand (kW)	356	893	151%	The minimum flow required greatly affects the retrofit demand in eQUEST. Since eQUEST predicts a necessary higher flow during the peak period, the additional air must be conditioned to 55°F.
Central Plant Demand Savings (kW)	365	135	-63%	
Baseline Supply Fan Energy (kWh)	2,101,061	1,940,000	-8%	An overall difference of less than 10% should be considered a very good indicator of overall accuracy.
Retrofit Supply Fan Energy (kWh)	538,179	760,000	41%	The minimum flow requirement in the eQUEST model for the hotter temperature periods account for this discrepancy.
Supply Fan Energy Savings (kWh)	1,562,882	1,180,000	-24%	
Baseline Central Plant Energy (kWh)	2,433,269	2,600,000	7%	An overall difference of less than 10% should be considered a very good indicator of overall accuracy.
Retrofit Central Plant Energy (kWh)	1,244,492	2,120,000	70%	The minimum flow required greatly affects the retrofit demand in eQUEST during the hotter periods. Since eQUEST predicts a necessary higher flow during the peak period, the additional air must be conditioned to 55°F. Additionally, the chiller efficiency profile differences result in the discrepancy.
Central Plant Energy Savings (kWh)	1,188,777	480,000	-60%	

Parameter	Temperature Bin Analysis	eQUEST Analysis	Difference (%)	Comments
Baseline Steam Boiler Consumption (therms)	315,286	288,300	-9%	An overall difference of less than 10% should be considered a very good indicator of overall accuracy.
Retrofit Steam Boiler Consumption (therms)	66,385	93,300	41%	The additional flow the eQUEST assumes will be necessary during the hot periods of the year result in additional reheat gas consumption
Steam Boiler Savings (therms)	248,901	195,000	-22%	

Case Study - Benefits

At this point in the project, it is assumed that the temperature bin analysis provides a better estimate of the expected energy savings. Overall, the estimated energy savings through this method are 521 kW, 2,751,659 kWh, and 248,901 therms. This corresponds to an estimated annual utility savings of $475,322.

The total measure cost of $1,100,000 is based on a proposal provided by Aircuity with some additional costs included for internal time and overages.

Lockheed Martin has a contractual relationship with PG&E as a third party to provide incentives for energy efficiency projects in industrial facilities. The incentive money is funded through statewide Public Purpose Programs surcharge under the auspices of the California Public Utilities Commission (CPUC). The current incentive rates for this measure are $0.09/kWh, $100/peak kW, and $1.00/therm saved. The project is eligible for an incentive amount of $534,342 through this incentive program. The net project cost is $565,658. This results in a simple payback of 1.2 years.